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| Research Article

Application of the Microbiology Concept Inventory to improve programmatic curriculum

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ABSTRACT The Microbiology Concept Inventory is an assessment tool derived from the fundamental statements created by the American Society for Microbiology. This two-tier, multiple-choice question inventory requires students to choose the most correct answer for each question and provide a brief justification of their reasoning. Educators can utilize this tool to identify common misconceptions held by students and adjust curriculum to address and prevent the persistence of student misconceptions. Over the course of 5 years, the Microbiology Concept Inventory was annually administered to undergraduate students enrolled in entry-level, mid-level, and senior capstone microbiology courses at a mid-western rural university. Analysis was completed to compare course, year, majors and minors, gender, ethnicity, and cumulative GPA. Results of this study showed a significant difference in Microbiology Concept Inventory scores between students with high cumulative GPAs (3.5–4.0) and students with comparatively lower cumulative GPAs (2.5–2.99, 3.0–3.49). Results between the other demographic categories revealed statistically different scores in favor of white students, but no differences in scores between genders. The results suggest evidence of ethnic bias, but no gender bias as measured by the Microbiology Concept Inventory. Additionally, significant differences in scores across cohorts are indicative of improvements in the curricula due to prior targeted changes. Analysis of concept inventory results can guide curriculum changes for course instructors. Implementation of curriculum changes can enrich students' academic success.

KEYWORDS concept inventories, bias detection, programmatic curricular reform, microbiology

Concept inventories are a standardized, statistically validated (against a group of users) means of assessment for concepts within many different content areas (1, 2). The Microbiology Concept Inventory (MCI) is formatted as a two-tier test consisting of multiple-choice questions, each followed by a prompt asking the respondent to justify their answer and demographic questions (3). Concept inventories provide researchers and instructors with both quantitative and qualitative data regarding the content knowledge of their students (4). Additionally, this assessment tool allows instructors to analyze student learning gains regarding specific topics covered in a course or program when the MCI is utilized as pre- and post-course assessment (3). Data generated from the administration of concept inventories allows educators to evaluate the effectiveness of their teaching practices to reach targeted learning outcomes (4–6).

Another application of the concept inventory is the identification of content areas where students do not perform well and may indicate a lack of understanding. The analysis of these areas allows educators to identify common misconceptions held by students that could go unnoticed in traditional summative assessments (7, 8). The development of student misconceptions, otherwise referred to as alternative

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conceptions (6, 7), can be attributed to many factors. These include preconceived notions of the world, gaps in content coverage, and misinformation. If not corrected, students can maintain misconceptions into upper-level courses or into their professional careers. Notably, this research study uses a misconception framework rather than a framing and resources framework utilized by other concept inventory research. Building on these misconceptions while learning new material can cause students to develop subsequent misconceptions, creating a disruptive cycle that impedes learning (3, 8). The application of a concept inventory to an entire undergraduate program has the potential to identify specific courses where misconceptions are improperly addressed (4). Professors can then revise the curriculum in their courses to promote and reinforce student comprehension of core concepts (7).

Force Concept Inventory

Physics education research pioneered the practice of applying concept inventories to a classroom environment (8, 9). Researchers identified that students' preconceived beliefs of the physical world did not align with Newtonian physics concepts (10). The Force Concept Inventory (FCI) was published in 1992 to assess student understanding of introductory Newtonian physics and allow educators to identify misconceptions held by their students (8). The FCI was the first of its kind and was eye opening to many other areas of science education (3). Upon successful implementation of the FCI, many other science disciplines followed suit in their own academic areas establishing fundamental concepts and associated concept inventories: biology (9), microbiology (1), astronomy (11), molecular biology, genetics (12), host-pathogen interactions (3), calculus (13), statistics (14), chemistry (15), microbiology health sciences (16), relativity, and discrete mathematics (1, 17). For example, biology education in the Vision and Change in *Undergraduate Biology Education: A Call to Action* formulated core concepts of life science to guide educators along a similar path of baseline instruction (18). The core concepts of life science are evolution, metabolic pathways, information flow and genetics, cell structure and function, and microbial systems (18). The guidelines published by the American Society for Microbiology (ASM) were created in alignment with the biology education core concepts of life science (19, 20).

Bias validation of the MCI

The process of creating concept inventories inherently incorporates biases that may skew results leading to inaccurate assessment of student understanding. Gender, cultural, ethnic, socioeconomic, and geographic biases must be considered during the creation, administration, and revision processes of concept inventories. This validation is ever more important today with the increasing collaboration occurring across international lines between researchers and educators who utilize concept inventories to evaluate student learning (21). The FCI has been repeatedly analyzed to look for evidence of gender bias within its questions. Studies have demonstrated that up to six items on the FCI are unfair against women. To account for this bias, modified versions of the FCI have become available on which biased questions have been removed (22, 23). This evidence of bias in the FCI has caused concern that the same could be true with the MCI. To our knowledge, there are currently no published studies regarding biases within the MCI.

Study goals

Our study aimed to determine whether any gender or ethnic bias was present in the MCI using a sample of students from a midwestern rural university. We believe this research is imperative in the field of education research to promote student equity and inclusion. Our second goal was to analyze learning gains made by students over the course of their undergraduate education to suggest programmatic changes to faculty. Changes to course curricula would better align our program with the national ASM standards and improve student learning outcomes.

METHODS

Demographics of participants

The university demographics are as follows: 86.9% white, 1.2% race unknown, 3.9% two or more races, 2.9% Hispanic, 2.8% Black or African American, 2% Asian, 0.6% American Indian or Alaska Native (24). Gender: 48.5% female; 51.5% male (24).

The study participants demographics specifically were 75.76% white, 4.04% race unknown, 2.02% Hispanic, 8.08% Black or African American, 8.08% Asian, 2.02% American Indian or Alaska Native. Gender: 59.4% female 39.6% male, 0.1% other.

Study context

In the fall of 2018, the Microbiological Sciences Curriculum Committee reviewed and mapped the ASM fundamental statements and objectives to courses offered by the Department of Microbiological Sciences. In the following spring of 2019, the committee initiated the use of the MCI as developed by Paustian et al. (1) to assess students' conceptual understanding of microbiology. This study was initiated after receiving human subject IRB approval from Research Compliance: Exempt Status Protocol #SM20243.

In the spring of 2019, 2020, 2021, 2022, and 2023 semesters, the MCI was administered to undergraduate students enrolled in a General Microbiology II course (mid-program or MP) and Senior Capstone course (final program or FP). Students enrolled in the MP course were primarily sophomore microbiology majors with one microbiology class complete and microbiology minors at various points in their degree completion. Students in the FP course were microbiology majors in their final year of college. Starting in the spring semester of 2021, the MCI was moved online due to the pandemic. In the fall semester of 2021, the MCI was expanded to students enrolled in an entry-level freshman course, Skills for Academic Success (early program or EP). Our timeline of administration of the MCI can be seen in Fig. 1. The number of students in each course by year can be seen in Table 1. Students were not graded based on performance, but their participation was mandatory. The MCI results were analyzed by identifying notable trends and utilizing a thematic coding scheme (25).

Concept inventory data processing

Upon completion of data gathering, score determination (quantitative) and thematic coding was performed to categorize and analyze data for each open-ended justification for multiple-choice answer (qualitative) on the MCI (Fig. 1). Only quantitative data were utilized in this study to elucidate trends by year, course, majors and minors, cumulative GPA, gender, and ethnicity. Recognition of these trends was adequate to begin enacting changes in the programmatic curriculum. Qualitative analyses will be utilized in future studies.

Categories of analysis

We compared MCI results of students across all courses (EP, MP, and FP), microbiology majors and minors, cumulative GPA: below 2.0, 2.0–2.49, 2.5–2.99, 3.0–3.49, and 3.5–4.0, females and males, and nonwhite and white students. It should be noted that ethnicity was split into only two categories intentionally. When students were administered the MCI, they could denote their ethnicity as American Indian/Alaskan Native, Black or African American, Asian or Pacific Islander, Hispanic/Latino, white, or other. However, small sample sizes within some of the categories created statistical analyses, which were distorted and not accurate. Due to this factor, the decision was made to categorize students as being either nonwhite or white. We acknowledge that this categorization does not adequately reflect the diversity of our students; however, the limitations of our sample size required an adjustment.

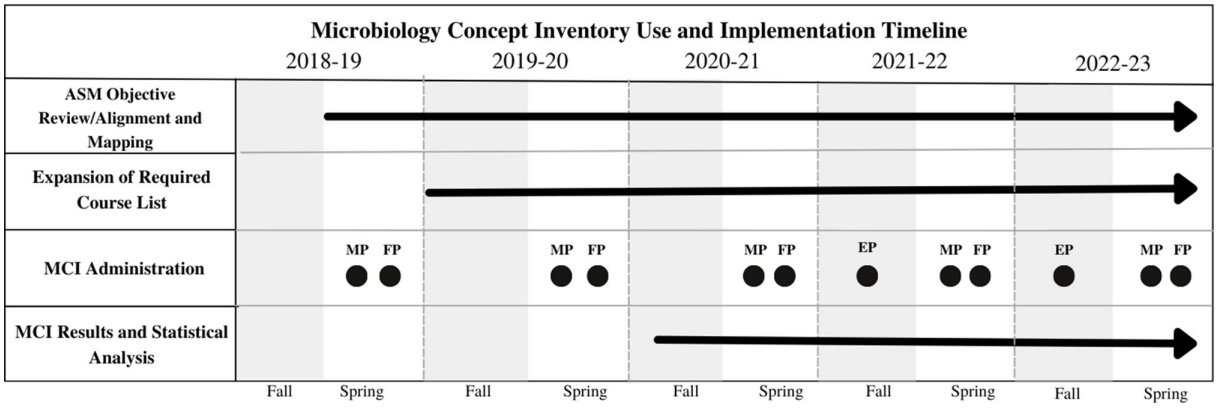

FIG 1 Microbiology Concept Inventory implementation and curriculum changes timeline. Survey administration, analysis, and curriculum changes were tracked over the course of this study.

Statistical analysis

Statistical analyses were completed on quantitative data. We compared scores between years the MCI was administered, EP, MP, and FP courses, and student self-identified cumulative GPAs. We also compared MCI scores to demographic data collected on the MCI such as majors and non-majors, gender, and ethnicity.

We used an analysis of variance (ANOVA) with Tukey post hoc analyses and *t*-tests to determine statistical significance of our data as these analyses are also used in many other studies in education research (24). We used Cohen's *d* to measure the effect size of the varying test scores. Cohen's *d* was the most applicable statistical analysis because it measures the effect size of test score variance. The pooled standard deviation of pre- and post-tests is used as the standardizing coefficient. Thus, the two tests are treated independently. This element eliminates potential bias that could be present if there are abnormal pretest scores, particularly exceptionally high scores (26). Limitations to Cohen's *d* do exist and were considered. The most considerable concern was that Cohen's *d* assumes the presence of homoscedasticity and normality in the survey from which the data has been collected. These elements are typically not found within a concept inventory, as student survey scores can lie far outside the mean and create outliers (26).

RESULTS

Preliminary curricula modifications

After examining student MCI scores from the spring of 2019, the Microbiological Sciences Curriculum Committee discovered that the ASM guidelines and objectives were not being covered in the current, required, content-specific courses. In fact, the FP students showed such poor performance on the MCI that the committee decided to expand the required course list from just two courses, Microbial Physiology and Microbial

TABLE 1 Student responses dependent on program and year[a]

Year	MCI student responses program		
	EP	MP	FP
2019	-	30	21
2020	-	30	20
2021	13	23	13
2022	7	26	9
2023	-	19	9
Total	20	128	72

[a]Each year there was variation as to how many students were enrolled in each course, therefore there was variation in MCI responses.

Genetics, to five courses, Microbial Physiology, Microbial Genetics, Microbial Ecology, Virology, and Immunology. Beginning in the fall of 2019 semester, students entering the program were required to enroll in a new list of courses (Fig. 1). However, students already in the program may or may not have taken all the courses in the expanded list as electives. The consequences of this change may be evident for the coming years in MCI scores and outcomes, as students will have a mixed number of the required courses.

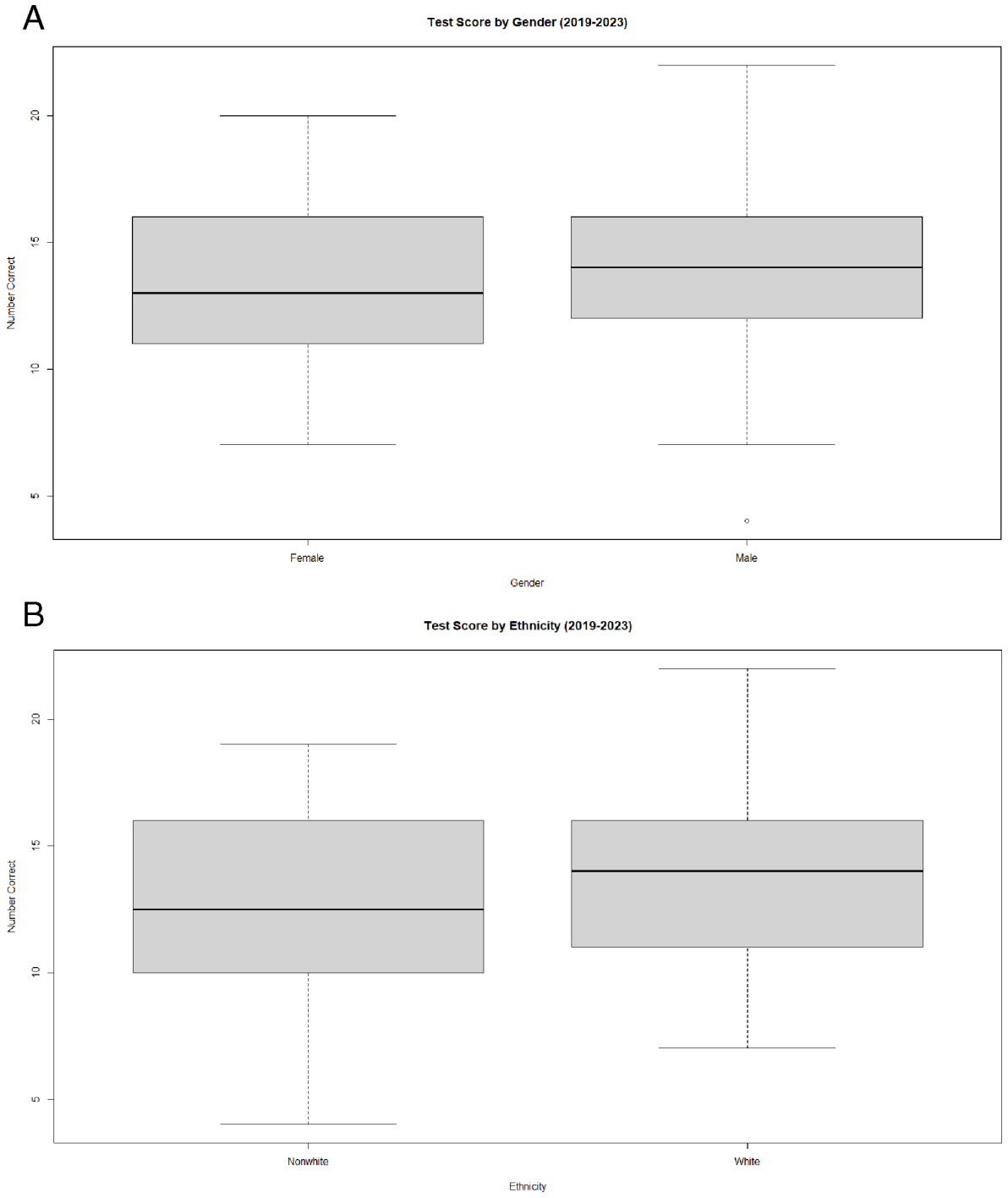

FIG 2 (A) Test results comparing gender data. A *t*-test was completed to determine any statistically significant results between the female (n = 133) and male (n = 83) students (P = 0.4575, d = −0.2262). (B) Test results comparing ethnicity data. A *t*-test was completed to determine any statistically significant results between the nonwhite (n = 42) and white (n = 173) students (P = 0.0485, d = −0.2982).

TABLE 2 ANOVA and *t*-test statistical analyses to compare demographic MCI results[e]

Additional ANOVA & *t*-test results			
Analysis	**Categorical comparison**	***d* estimate**	***P*-value**
GPA	(3.0–3.49) – (2.5–2.99)	0.4317[b]	0.8399
ANOVA	(3.5–4.0) – (2.5–2.99)	1.1819[c]	0.0006[d]
	(3.5–4.0) – (3.0–3.49)	1.1467[c]	0.0023[d]
Course	MP–FP	1.1038[c]	0.0000[d]
t-test & ANOVA	EP–MP	1.2209[c]	0.0002[d]
	EP–FP	1.2997[c]	0.0000[d]
Ethnicity	Nonwhite–white	−0.2982[a]	0.0485[d]
t-test			
Major/Minor	Major–minor	0.0929	0.6995
t-test			
Gender	Female–male	−0.2262[a]	0.4575
t-test			

[a]Indicate a small effect size, *d* estimates of 0.5–0.8.
[b]Indicate a medium effect size, and *d* estimates greater than 0.8.
[c]Indicate a large effect size. Any *d* estimates below 0.2 are considered negligible.
[d]Significant *P*-values are <0.05.
[e]Data of all students (n = 220) was statistically analyzed via *t*-test, ANOVA, or both to determine statistically significant results when comparing varying groups of MCI data. Cohen's *d* estimates of 0.2–0.5.

Additional course-specific changes were made in the fall of 2019 by a new faculty member who took over the instruction of General Microbiology and attempted to further align the course with introductory-level ASM objectives. The previous course instructor approached the course more narrowly, which had led to less coverage of the ASM objectives. We believe that these changes will be evident in the MP MCI scores and outcomes. Beginning in the fall of 2019 semester, all faculty in the Microbiology department were encouraged to align their courses to the ASM outcomes (Fig. 1). These two changes to our content-specific courses and requirements create confounding factors to determine which factor induced change in student MCI scores and outcomes.

Major, gender, and ethnicity

Statistical analyses of microbiology majors and minors, females and males, and nonwhite and white students were conducted utilizing Cohen's *d* and *t*-test statistical analyses, as each independent variable had two categories. We found no difference in the MCI scores of microbiology majors compared to scores from microbiology minors (P = 0.1178, d = 0.1178, Table 2). Additionally, no statistically significant differences were found between MCI scores of females and males (P = 0.3712, d = 0.0891; Fig. 2A; Table 2). However, there was a significant difference found between the scores of nonwhite and white students (P = 0.0485, d = −0.2982; Fig. 2B; Table 2).

Early program, mid-program, and final program course performance on MCI by year

MCI results were then divided into smaller categories based on the course and year. Mean results for each course by year were compared in Fig. 3A. Further analysis was done by comparing each course and year to each other. A total of 12 categories: 2019 MP, 2019 FP, 2020 MP, 2020 FP, 2021 EP, 2021 MP, 2021 FP, 2022 EP, 2022 MP, 2022 FP, 2023 MP, 2023 EP lead to 66 total analyses (Table S2; Fig. S2). Sixty of the 66 analyses had significant *d*-estimates calculated (Table S2). Of these 60 analyses, 13 had small effect sizes (*d*-estimates greater than the 0.2 threshold), 15 had medium effect sizes (*d*-estimates greater than the 0.5 threshold), and 32 had large effect sizes (*d*-estimates greater than the 0.8 threshold). Of the 66 significant *d*-estimates, 14 had significant *P*-values (Table 3).

TABLE 3 ANOVA and *t*-test statistical analyses to compare course and year MCI results[a,b,e]

Significant ANOVA results			
Analysis	**Categorical comparison**	***d* estimate**	***P*-value**
ANOVA	FP 2020–EP 2021	1.1082[c]	0.0026[d]
Course and year	FP 2021–EP 2021	1.2020[c]	0.0000[d]
	FP 2022–EP 2021	1.1476[c]	0.0005[d]
	FP 2023–EP 2021	1.1051[c]	0.0029[d]
	MP 2019–EP 2021	1.1078[c]	0.0026[d]
	MP 2020–EP 2021	1.0526[c]	0.0151[d]
	FP 2021–EP 2022	1.1014[c]	0.0033[d]
	FP 2022–EP 2022	1.0387[c]	0.0215[d]
	MP 2021–FP 2020	1.0638[c]	0.0111[d]
	MP 2021–FP 2021	1.1874[c]	0.0000[d]
	MP 2022–FP 2021	1.0939[c]	0.0043[d]
	MP 2021–FP 2022	1.1113[c]	0.0023[d]
	MP 2021–FP 2023	1.0528[c]	0.0150[d]
	MP 2021–MP 2019	1.0686[c]	0.0096[d]

[a]Indicate a small effect size, *d* estimates of 0.5–0.8.
[b]Indicate a medium effect size, and *d* estimates >0.8.
[c]Indicate a large effect size. Any *d* estimates below 0.2 are considered negligible.
[d]Significant *P*-values are <0.05.
[e]Data of all students (n = 220) was statistically analyzed via *t*-test, ANOVA, or both to determine statistically significant results when comparing varying groups of MCI data. Cohen's *d* estimates of 0.2–0.5. Only statistically significant comparisons included in this table, full results in Table S2.

MCI performance comparison by course

In the fall of 2021, the MCI was administered to students in the EP course for the first time. This was done to better understand the microbiology content knowledge students possess as they first begin their collegiate studies. The additional data from this course meant that three categories of data were being analyzed instead of two, requiring the utilization of an ANOVA over a *t*-test.

An ANOVA with Tukey post hoc analyses and a Cohen's *d* analysis were used to compare the average MCI scores of students in EP to MP and FP. When conducting this analysis, data from all 5 years was utilized for the MP and FP categories, whereas the EP course only contained data from 2 years (2021–2022). Statistically significant differences were found regarding *P*-values and *d* estimates across all courses, as demonstrated in Table 3. The analysis of EP and MP courses yielded a large effect size of 1.2209 (P = 0.0002), the analysis of MP and FP yielded a large effect size of 1.1038 ($P < 0.0001$), and the analysis of EP and FP yielded a large effect size of 1.2997 ($P < 0.0001$). These results are further reflected in Table S1; Fig. S1**,** which show the average performances of each course level on each question. FP scored the highest on 15 of the 23 questions and both MP and EP each scored highest on four of the questions. Fig. 3B and C shows a visual comparison of all course levels.

Cumulative GPA range

Students self-identified their cumulative GPAs into one of five ranges: below 2.0, 2.0–2.49, 2.5–2.99, 3.0–3.49, and 3.5–4.0. No students selected either of the lowest intervals. Therefore, only the latter three were utilized in the ANOVA and Cohen's *d* analyses. A total of three analyses were run on the cumulative GPA data, the results can be found in Table 2. We found significant differences in MCI scores between students with a cumulative GPA of 2.5–2.99 and students with a cumulative GPA of 3.5–4.0 ($P < 0.001$). We also found significant differences in MCI scores between students with GPAs of 3.0–3.49 and students with GPAs 3.5–4.0 ($P < 0.01$).

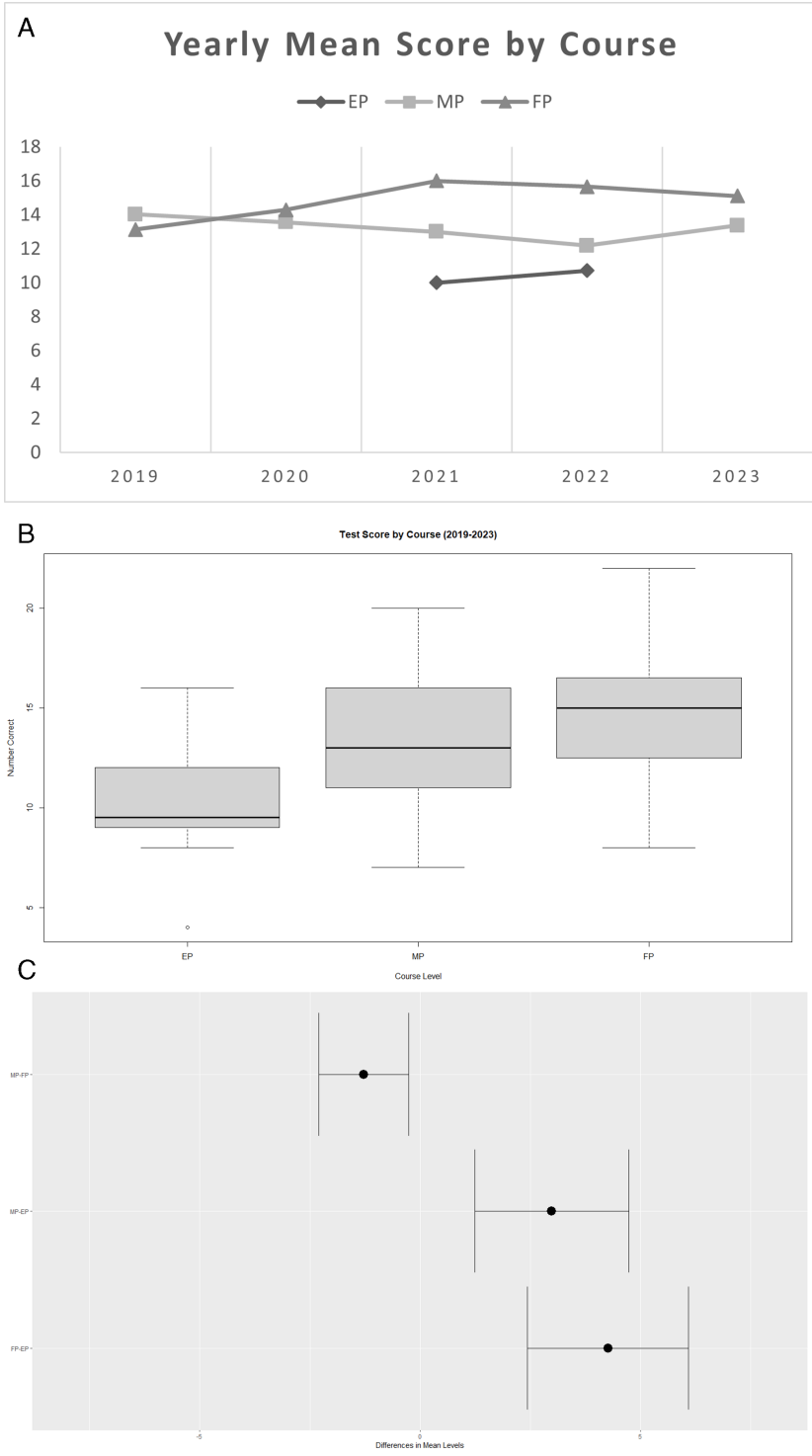

FIG 3 (A) Average MCI results comparing course and year. This plot shows the yearly average performance of each course (EP, MP, and FP). At the time of writing, the MCI has not yet been administered to the EP 2023 course. (B) Test results comparing course data. This plot shows the distribution of scores from 2019 to 2023 across all EP (n = 20), MP (n = 128), and FP (n = 72) course levels. (C) ANOVA results by course. An ANOVA was completed to determine any statistically significant results between the data of the EP (n = 20), MP (n = 128), and FP (n = 72) courses ($P < 0.0002$, $d > 1.1$).

DISCUSSION

Major or minor—no correlation to MCI score

Statistical analyses comparing microbiology majors and minors revealed no statistically significant differences in MCI outcomes. It is important to note that the FP course data were removed from these analyses because no microbiology minors enrolled in this course. It was expected that we would not determine any statistical differences in the data because regardless of whether a student was a major or minor at the point of MCI administration, these two groups would likely have taken a similar number of microbiology courses.

Split presence of gender and ethnic bias observed

Statistical analyses of gender revealed no significant differences in MCI outcomes in our data. Although the ratio of females to males is approximately one to one, we believe that the overall sample size (n = 220) may not fairly constitute a fully accurate analysis between gender. An increase in sample size may reveal trends not seen in our aggregated data. In contrast, there were significant differences between ethnicity groups of nonwhite and white. These results were somewhat expected as research has shown that other concept inventories indicate bias toward males and white individuals. Due to grouping all nonwhite individuals into one category we also lose the ability to distinguish biases of the MCI between nonwhite ethnic groups.

Higher MCI scores in newer mid-program cohorts suggest effective curricular changes

Statistical analyses of student MCI outcomes by year revealed 14 statistically significant differences. Among those comparisons, 2021 MP and 2022 MP were showing higher performances than the likes of several FP cohorts and a previous 2019 MP cohort. 2021–2023 FP cohorts showed increasing gains compared to earlier FP cohorts. This is both promising and expected, as it suggests the curricular changes that went into effect in 2019 are beginning to produce tangible results. The MCI administration, prior to programmatic change and ongoing student matriculation to the new curriculum, will take time to yield more specific results. However, we believe that continued administration of the MCI will capture an increase in student outcomes and learning gains to provide statistically significant differences in our course comparison data.

Score differences across course levels indicate learning gains

The decision to administer the MCI to an early curriculum course stemmed from the desire to confirm the level of understanding at which students started our program. After doing so, we saw a significant difference between EP and MP and EP and FP, indicating that students were making progress on understanding of fundamental concepts as they neared the end of the curriculum.

Higher cumulative GPA correlates to higher MCI score

Statistical analyses of cumulative GPA revealed statistically significant data between students with a cumulative GPA within 2.5–2.99 and students with a cumulative GPA within 3.5–4.0. Likewise, there were significant differences in scores of students with a cumulative GPA within 3.0–3.49 and students with a cumulative GPA within 3.5–4.0. These results are encouraging and reinforce our expectations that the MCI scores will reflect the students' cumulative GPA and a higher cumulative GPA equates to earning a higher MCI score. This is indicative of the MCI's ability to distinguish between low- and high-performing students.

Pandemic study caveats

Due to the COVID-19 pandemic, the university moved all courses online in spring and summer of 2020. Courses offered from fall 2020 to summer 2021 used the HyFlex model, meaning that there was a combination of online or in-person class delivery depending on instructor preference, or in-person class delivery depending on instructor preference. By fall of 2021, classes had largely moved back in person with some HyFlex model options. The courses where the MCI was administered were moved online in spring of 2020. In spring of 2021, the MP course was moved to HyFlex model and the FP course was in-person. Ib fall of 2021 the EP course was also in-person. Due to these changes in course delivery, beginning in 2021 administration of the MCI was moved from a paper format to an online format. Students took the MCI during a class period and were expected to follow the honor code; however, we understand that this does not always happen as students could have used outside resources rather than their sole knowledge when completing the MCI.

We would also like to acknowledge the impact of the "infodemic" that exacerbated the knowledge related to the pandemic that may have influenced, positively or negatively, students' understanding of MCI-related content (27). Faculty in the microbiology curriculum attempted to address common misconceptions related to media coverage of the pandemic; however, the inundation of information may have outweighed faculty attempts. Overall, data trends indicate no negative effect on student understanding; however, future analysis of individual questions may show differently.

Implications for research

As previously discussed, several approaches have been taken in concept inventory research, but none have been published concerning analysis of the MCI itself. We plan to continue analysis of student outcomes through previously discussed categorical analyses as well as novel variables such as English language proficiency. In future administration of the MCI in our program, the gender category will have selections of female, male, and non-binary, as well as a question to access first-generation status. Additional data collection may also allow us to detect more detailed ethnic biases. These categorical analyses can be utilized to improve the MCI and reduce bias to create a more accurate picture of what our students understand. Or further bias analysis of the MCI may reveal the bias is in our curriculum instruction instead of the MCI itself.

Our future studies will also dive further into student justifications and misconceptions by statistically comparing students' scores and their coded reasonings over time. These future studies will lead us and other researchers to understand if students are developing a surface-level understanding or a deeper level of comprehension in their microbiology courses. Analysis of misconceptions also allows us to compare programs across universities to identify national trends in microbiological understanding.

Implications for student learning outcomes

The data we have analyzed thus far has led us to propose a few possible changes in our university's microbiology curriculum and data collection. For example, we have recommended it would be best to give the FP students the MCI at the end of their semester as a post-test, instead of in the beginning of the course. Some of these students were still taking their content-specific courses at that time, so giving them the MCI anywhere except at the end of the semester does not accurately reflect student learning from the entire program of study. This change was implemented in collecting the 2022 data and beyond.

With each new semester we continue collecting data on the MCI to assess the implemented curriculum changes and propose new modifications. We hope to see the trend identified in our data of improved FP scores continue. Future studies will focus on qualitative data collected from the MCI to identify and explore individual question responses. This will allow us to further recognize biases in individual questions of the

MCI as well as student misconceptions. These misconceptions will be mapped back to the ASM learning objectives and tracked through a course map to determine where they should be addressed in the curriculum.

Conclusion

The MCI data that has been collected thus far and the data that will be collected in the future continues to encourage changes that will promote student engagement and understanding of microbiology. Our research has identified possible holes in the microbiology curricula at our institution. By recognizing these holes in the curricula, we have been able to suggest changes. In future research, we will continue to use each year's results to track trends and progression of student learning as the result of curricula changes. The focus of our research on a variety of demographic categories to evaluate bias in the MCI is a step to elucidate whether the MCI itself has biases or biases are present in the student learning process at our institution. This is an important distinction to understand the data generated by the MCI to improve the equitability of programmatic curricula. A larger sample size of data will provide a more precise picture of our students' understanding and the potential biases of the MCI. We also believe that this research must be continued to ensure that this concept inventory is inclusive to all and provides accurate and equitable results for researchers and educators.

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The authors declare that there are no conflicts of interest.

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ADDITIONAL FILES

The following material is available online.

Supplemental Material

Fig. S1 (jmbe00110-22-s0001.tif). Per question class performance.
Fig. S2 (jmbe00110-22-s0002.tif). ANOVA by course and year.

Supplemental material legends (jmbe00110-22-s0003.docx). Legends of Fig. S1 and S2 and Tables S1 and S2.
Table S1 (jmbe00110-22-s0004.docx). Class performance per question.
Table S2 (jmbe00110-22-s0005.docx). ANOVA by course and year.

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