Research Article American Journal of Science Education Research

The Microbial Art Plate: STEAMing Through Aseptic Technique with a Proper MAP

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Citation: Marsh M, Vanderlaan G, Gacura MD (2024) The Microbial Art Plate: STEAMing through Aseptic Technique with a Proper MAP. American J Sci Edu Re: AJSER-200.

Received Date: 11 July, 2024; **Accepted Date:** 26 July, 2024; **Published Date:** 01 August, 2024

Abstract

Engaging students in the modern-day classroom has become increasingly challenging in the post-Covid era. One way to facilitate student engagement is by incorporating art into traditionally STEM (science, technology, engineering, and mathematics) based activities. The microbial art plate (MAP) activity has been designed to instruct students in culturing techniques, focusing on aseptic technique, in a university microbiology lab. The MAP activity involves the use of naturally chromogenic bacterial organisms as living paint, while a nutrient agar plate serves as their canvas. In addition, students are required to use the tools of the microbiology lab, such as an inoculating loop, to create their artwork. Our activity was deployed in an introductory (freshman and sophomore) university microbiology lab focused on nursing majors. To gauge the effectiveness of this technique, a survey focused on student confidence in aseptic technique was administered before and after the activity. The MAP was met with a great deal of enthusiasm from students, and many expressed that it was their favorite activity of the semester. Our survey revealed a significant increase in student perceptions of their microbiological skills and their comfort with lab equipment post-activity. Thus, the MAP activity provides an effective and fun means to instruct students in aseptic technique. This highlights the effectiveness of incorporating artistic elements into activities in STEM, creating a STEAM classroom.

Keywords: *Aseptic technique, Creativity, Design-based learning, Microbiology, Pedagogy, STEAM, STEM.*

Introduction

The use of fun and active learning methods for student engagement is becoming increasingly important in modern classrooms and laboratories. This is due in part to recent drops in student engagement in STEM education, one of many pedagogical consequences of the recent COVID-19 pandemic [1]. One effective teaching strategy to increase engagement is to appeal to a student's creative side by incorporating additional visual and artistic activities in the classroom [2]. The utilization of art in the instruction of STEM is not a new concept and has been an effective focus of many lesson plans [3,4]. Such lessons focused on student creativity can increase student engagement and lead to more positive outcomes in classes [5,6]. Due to their success in other STEM fields, these artistic methods should greatly benefit educational labs involved in the instruction of microbiology concepts and learning objectives [7,8].

The goal of any educational microbiology laboratory is to provide students with a framework to appreciate the wonderfully, exquisite world populated by the tiniest creatures. To visualize such diminutive denizens, microbiology techniques typically involve light microscopy usage and proper aseptic technique, each of which can pose significant learning barriers for full student engagement [7,9,10]. Additional hurdles can arise in microbiology lab instruction due to specialized procedures for microbial isolation, growth, and downstream diagnostics for species validation, all of which collectively rely on the proper utilization of nutrient agar media, Bunsen burners, and inoculation filaments [11]. An absolute prerequisite for all microbial lab procedures is proper aseptic technique to limit contamination from a wide range of environmental sources [9,11]. In our experience teaching university microbiology labs, many students find the aseptic technique skill to be very intimidating to learn and practice. Like all things however, mastery requires a great deal of repetition and practice [12]. To teach this skill effectively, exploration of pedagogical methods and applying them to Microbiology instruction is thus greatly warranted.

The vibrantly colorful world of microbes can lend a helping hand. Many microbial species naturally present a rainbow spectrum of colors when grown under the right conditions and when fed the right formulation of nutrient agar [7,13]. Microorganisms create such pigments for a variety of biological reasons, including protection from various environmental pressures or to fight off potential competitors [14]. For instance, many bacterial organisms can produce a distinctively yellowish-orange carotenoid pigment which greatly helps protect them from harmful ultraviolet light and low temperatures [13,15]. Other microbes, such as *Chromobacterium violaceum*, can metabolically synthesize a purple antibiotic known as violacein to sustain their ecological niche in the soil pocket, and maintain organismal competitiveness [16,17].

Here we embrace the natural pigmentation of specific bacterial organisms as a sort of microbial paint. Students act as artists that paint microbial inoculum on canvases constructed of nutrient media. The exercise greatly fosters creative work, as students learn aseptic technique in a non-intimidating environment. To illustrate the effectiveness of our art-meets-science approach (i.e., STEAM), we provide qualitative, anecdotal examples of student work alongside quantitative, statistical analyses of student perception of the activity we endearingly call, the Microbial Art Plate (MAP).

Methods and Results

Classroom Composition

Students participating in the pedagogical assessment of the Microbial Art Plate (MAP) activity typically comprised of freshmen or sophomores majoring in the nursing program at Gannon University in the fall semester of 2022. For most of these students, our introductory microbiology lab course was their first STEM exposure at the university level. A total of 59 different students, drawn from three different BIOL 107 Introduction to Microbiology Lab course sections, were analyzed with respect to the efficacy of MAP as a pedagogical STEAM tool.

Class Session Prior to the MAP Activity

Students were instructed in the use of various methods for aseptically culturing bacteria using a combination of lab manual assigned readings [18,19] layered with customized pre-lab quiz assessments. This instructional material included proper usage of inoculation loops, Bunsen burner, and handling bacterial inoculum in liquid culture. Additionally, students were asked to take a pre-MAP survey assessing their comfort level with each of these techniques (**Supplementary File 1**). Students were also encouraged to plan ahead and design their artistic masterpiece. Prior art plate submissions as example creations were shown during lab class time by accessing archived online submissions to the American Society for Microbiology (*ASM Agar Art Contest*, n.d.)[20]. Students were encouraged to create their own microbial art plate designs, drawing inspiration from all walks of life. Educators can provide a rubric detailing the requirements of this activity; however, we chose to keep the lesson more casual by explaining verbally that they will be graded on effort and completion. After all, the value of art is in the eye of the beholder.

Deploying the Microbial Art Plate (MAP) Activity

At each lab bench, students received culturing tools consisting of inoculation loops, sterile toothpicks, and sterile cotton swabs. Students also received microbial cultures as solid slants, solid agar plates, and liquid broths. A full color palette of bacterial organisms was also supplied to serve as microbial paint (**Table 1**). To simplify the development of each student's microbial masterpiece, we chose bacterial organisms with shared incubation parameters, namely mesophiles that grow quickly at 37 °C (**Table 1**). Our university microbiology teaching lab employs a Biosafety-Level 2 (BSL-2) rating, and students were instructed to observe appropriate safety measures to accommodate proper handling of opportunistic pathogens. We encouraged solid inoculum (i.e., agar slants or agar plates) for drawing outlines and liquid inoculum (i.e., broth) for quickly filling in shapes. After students created their MAPs while observing sterile technique, each student's masterpiece was initially grown for 24-48 hours at 37 °C to encourage rapid mesophile growth, followed by a room temperature (24 °C) incubation that lasted for 1-2 weeks to help flesh out vibrant growth patterns.

Table 1: Suggested list of microbial paint, comprising chromogenic strains for use in the Microbial Art Plate (MAP) activity. Colors for each microbial organism are indicated in the table. Biosafety-level (BSL) ratings are also provided along with general bacteriology properties and vendor ordering information. All product catalog numbers refer to The American Type Culture Collection (ATCC), unless denoted by an asterisk (*, Carolina Biological Supply).

Species Name	Color	BSL	Cell Wall Type	Cell Morphology	Product #
Serratia marcescens	Red	1	Gram (-)	Bacillus	14756
Chromobacterium violaceum	Purplish-Black	2	Gram (-)	Coccobacillus	154931A*
Pseudomonas fluorescens	Bright Green	1	Gram (-)	Bacillus	13525
Escherichia coli	Cream	1	Gram (-)	Coccobacillus	35421
Kocuria rosea	Pink	1	Gram (+)	Cocci	186
Micrococcus luteus	Yellow	1	Gram (+)	Cocci	49732
Staphylococcus epidermidis	White	1	Gram (+)	Cocci	49461

Class Session After the MAP Activity

Following incubation, students were able to view and photograph their artistic creations. This typically involved making observations about how different chromogenic microbes competed with one another (i.e., microbial ecology and organismal interactions) alongside recording aseptic technique efficacy as measured by the presence or absence of contaminating colony morphologies. Artwork was graded based upon completion, effort, and whether the images were recorded and digitally submitted via the university's online learning management system (i.e., Blackboard). Grade rubrics did not stress the complexity of the image or artistic ability. Additional bonus points were awarded to students who submitted their creative works to the American Society of Microbiology (ASM) portal for the annual art plate competition held during the fall 2022 semester (*ASM Agar Art Contest*, n.d.)[20].

Student Reflection of the MAP Activity

Students created an impressive array of artworks during this activity, with many students bringing in images that they had sketched over the previous week (**Figure 1**).

Figure 1: Example artwork produced by students engaged in the Microbial Art Plate (MAP) activity as a STEAM approach to teaching microbial techniques.

Student engagement for the activity appeared to be very high, with each student being more focused during the activity and taking time to practice their technique to get images as clear and exact as possible. This was further reflected in end-of-the-semester evaluations detailing this activity as an overall favorite for many students. A post-activity reflection survey was given to quantify the effectiveness of this activity on the student's comfort and confidence in the use of aseptic technique (**Supplementary File 2**).

Survey Design to Statistically Assess MAP Efficacy

Survey question design for both the pre-MAP survey (**Supplementary File 1**) and post-MAP survey (**Supplementary File 2**) stressed three distinct categories: 1) artistic skills (ART), 2) microbial technique and culturing skill proficiency (CUL), and 3) microbial equipment comprehension (EQP). For each survey assessment tool, pre-MAP or post-MAP, a total of three questions were carefully designed to align with each of the three survey question categories. This provided the minimum sample size of three questions per survey question category to allow robust statistical analyses of student responses. Surveys were thus given to each student before and after the MAP exercise. In the survey, students were asked questions which focused on how comfortable they are with the use of various pieces of microbiology lab equipment (EQP), the handling of microorganisms, and their overall confidence in their microbiology lab procedures (CUL). As an added control, questions that focused on student artistic ability (ART) were included in the survey. Student response scores for confidence in their use of microbiological methods increased after performing the activity, while confidence in their artistic capabilities decreased (**Figure 2**). To assess the statistical significance of our categorical survey response data, we employed statistical procedures geared for ordinal data analyses.

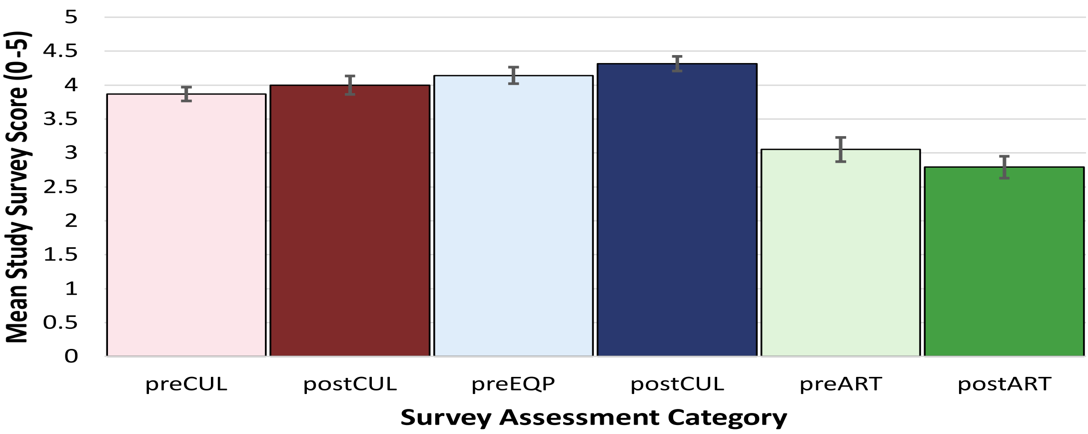

Figure 2. Mean student survey responses before and after the MAP activity parsed by question category type. Average survey scores for each class section, divided by class question type. Survey responses drew from three assessment categories: culturing (CUL) methods are shown in red, equipment (EQP) usage is in blue, and creativity and artistic (ART) skills are displayed in green. Lightly-shaded colors represent pre-MAP activity student survey responses while darkly-shaded colors track post-MAP activity responses.

We employed the Wilcoxon Signed-Ranks test to perform pairwise comparisons of pre-survey and post-survey responses for each of the three survey question categories (i.e., ART, CUL, and EQP) (**Table 2**). The Wilcoxon Signed-Ranks test is an excellent non-parametric statistical tool for pairwise comparisons, akin to the student t-Test for parametric datasets. We detected statistically significant responses suggestive that the MAP activity benefited student perception of questions related to equipment (EQP, $p < 0.05$) and creativity (ART, $p < 0.05$) (**Table 2**). Interestingly, we did not detect statistical significance with Wilcoxon Signed-Ranks tests when comparing survey responses centered around microbial culturing (CUL) techniques (**Table 2**). We next averaged student responses for both equipment (EQP) and culturing (CUL) questions to generate a science (SCI) category (**Table 2**). Statistical significance was detected for this science (SCI) category before and after the MAP activity, as measured by the Wilcoxon Signed-Ranks test ($p < 0.05$) (**Table 2**). We additionally performed the Friedman test, which is the non-parametric equivalent of ANOVA for parametric datasets. We performed four different Friedman tests and statistical significance ($p < 0.01$) was observed in all instances (**Table 2**). We first performed a six-way Friedman test involving all pre-MAP and post-MAP student survey responses ($p < 0.01$) (**Table 2**). We next observed that responses from within only pre-MAP survey question categories exhibited statistically significant differences ($p < 0.01$) (**Table 2**). This pattern was also observed for Friedman test statistics for post-MAP survey response categories as well ($p < 0.01$) (**Table 2**). Lastly, we averaged survey question category responses for culturing (CUL) and equipment (EQP) to generate a science (SCI) category and performed the Friedman test to compare SCI and ART, of which statistical significance was also detected ($p < 0.01$) (**Table 2**). Taken together, student perception of the MAP activity generally bolsters STEAM approaches, with statistical significance detected before and after MAP deployment in the microbiology laboratory for both ART and SCI categories.

Table 2: Summary of Friedman and Wilcoxon Signed-Ranks test statistics. The Friedman test and the Wilcoxon Signed-Ranks test was performed on categorial, ordinal data which comprised pre-MAP and post-MAP student responses. Survey questions related to culturing (CUL) techniques are shown in red, creativity and artistic (ART) skill in green, and equipment (EQP) usage in blue. The science (SCI) category represents the average of CUL (red) and EQP (blue) responses. Lightly-colored fills represent pre-MAP assessment while darkly-shaded hues track post-MAP responses.

Method	Statistical Comparison								Test statistic	p-value
Friedman	preCUL	preART	preEQP		postCUL	postART	postEQP		119.13	4.79E-24
Friedman	preCUL	preART	preEQP						42.67	5.42E-10
Friedman					postCUL	postART	postEQP		60.01	9.31E-14
Friedman		preART		preSCI		postART		postSCI	79.73	3.51E-17
Wilcoxon	preCUL				postCUL				489.5	Not Sig
Wilcoxon		preART				postART			336.5	0.009395
Wilcoxon			preEQP				postEQP		368	0.014667
Wilcoxon				preSCI				postSCI	446	0.016897

Discussion

Microbial techniques involving Bunsen burner usage and sterile technique are oftentimes intimidating. Incorporating and leveraging student creativity in the classroom (i.e., STEAM) offers great promise for student engagement and activity buy-in. We precisely measured student perception before and after performing the Microbial Art Plate (MAP) activity, and our carefully designed survey questions permitted tracking at least three categories, involving artistic skills (ART), equipment usage (EQP), and microbial culturing techniques (CUL). We found that students routinely benefitted from the MAP activity, as evidenced by statistically significant survey responses before and after the MAP, bolstering student confidence in not only their aseptic technique skills, but also in their excitement once their artistic masterpieces were given enough time to grow in the incubator.

The value of the MAP activity for student engagement in STEAM is thus very promising. In our experience, the MAP activity also offers a pedagogical platform to weave learning objectives across both microbiology lab and lecture content. For instance, the chromogenic *Micrococcus luteus* produces a yellow pigment that has been identified as a carotenoid [21] (**Figure 3A**). A discussion of carotenoids can then lead to ß-carotene and vitamin A synthesis, one of the essential fat-soluble vitamins with numerous documented dietary functions, including the prevention of night-blindness [22] (**Figure 3A**). This can be followed by a discussion of the global prevalence of vitamin A deficiency (VAD), which is estimated at ~15% in pediatric cases, especially in low-income regions of Africa and Asia [23] (**Figure 3A**). Lastly, a biotechnological solution can then be discussed in which the genes from the ß-carotene pathway of the bacterium, *Pantoea ananatis*, were recombined in the domesticated rice crop (*Oryza sativa*) to yield Golden Rice, a strain of recombinant rice that produces high levels of vitamin A to help combat VAD in afflicted regions [24,25,26] (**Figure 3A**).

The MAP activity can also be used as an intersecting gateway connecting lecture content on bacterial biofilms and resulting clinical manifestations (**Figure 3B-3C**). For example, the chromogenic *Pseudomonas aeruginosa* produces cyan pigments known as pyoverdine and pyocyanin, and this organism utilizes biofilms to effectively colonize not only breached epidermal surfaces of burn ward patients, but also the lower respiratory tract of cystic fibrosis patients afflicted with lesions at the human *CFTR* gene [27,28,29] (**Figure 3B**). Alternatively, the chromogenic *Serratia marcescens* produces the red pigment known as prodigiosin, and is often a driver of gram-negative sepsis in hospital-acquired (i.e., nosocomial) infections [30] (**Figure 3C**). The MAP activity can also be used as a pedagogical platform to stimulate student excitement and thus engagement regarding medical microbiology and pharmacology topics **(Figure 3D)**. For instance, the *Chromobacterium violaceum* naturally produces a purplish-black pigment molecule known as violacein which is a known antibiotic that the organism naturally uses in the soil to combat other microbial competitors [16,17] (**Figure 3D**). A discussion of violacein can thus act as a gateway leading to the discussion of other antibiotics and their associated mechanisms of killing action, including best pharmacological practices, while permitting discourse involving microbial antagonism as a function of the host commensalistic population [31,32] (**Figure 3D**).

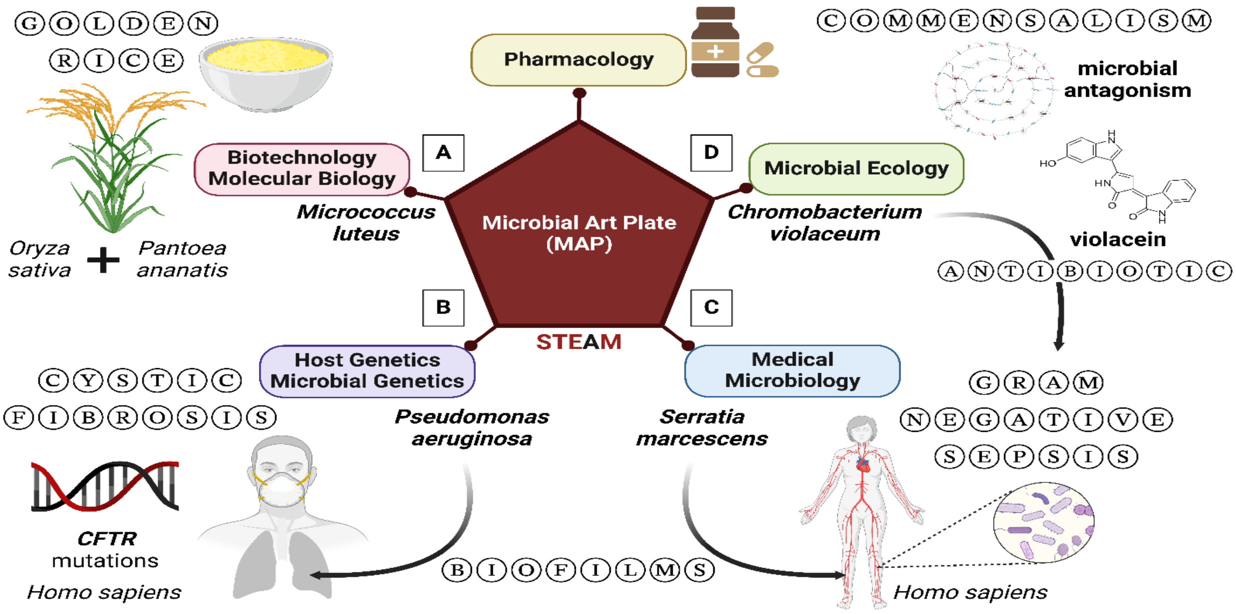

Figure 3: The Microbial Art Plate (MAP) is a useful pedagogical platform to launch key microbiology lecture and lab learning objectives.

The MAP activity effectively helps transform the STEM classroom into a STEAM environment [7]. Incorporating art into scientific lessons provides an opportunity for students who struggle with traditional STEM content and as reflected in our survey responses, enhances student confidence and agency in statistically significant ways. No two students are alike, and students learn in a myriad of ways; as educators, we must find effective ways to bridge apprehension to arrive at comprehension in our learning environments [2,33]. The MAP activity's reliance on microbial paint, in the form of naturally chromogenic bacterial organisms, is especially amenable to kinesthetic learning, as its hands-on nature can help to master methods such as aseptic technique in the microbiology lab setting [34]. Positive student feedback from the MAP activity thus reinforces student perception in their confidence towards active learning approaches in the STEM disciplines [5,6]. The MAP activity effectively places the paintbrush (i.e., inoculating filament), canvas (i.e., sterile nutrient agar plates), and paint (i.e., chromogenic bacteria) into the hands of the student, granting students free reign to manifest their artistic vision into a project-oriented goal.

Conflict of Interest Statement

The authors declare no conflict of interest.

Acknowledgements

The authors would like to thank both the faculty and the participating microbiology students in the biology department at Gannon University.

Funding

Lab materials for the MAP activity were collected from student lab fees. No other funding sources were used to generate the data in this report.

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Supplementary Files

Supplementary File 1. Pre-activity MAP survey questions.

Supplementary File 1. Pre-activity survey questions. Keyed (i.e., instructor-only) and non-keyed (i.e., given to students) pre-MAP activity survey questionnaires are provided in a single ZIP file for those interested in replicating MAP in their classrooms.

For Students: Please carefully read the questions and answer them as truthfully as possible. Answers for the questions are listed from 1 to 5. You will be awarded two bonus points for completing this quiz and turning it into your instructor.
For Instructors: Give a copy of this handout to each student and have them read the instructions. Please use a scantron sheet and give the students 5 minutes to complete the survey.

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1. What is your overall confidence in working with microorganisms?
1 = lowest | 5 = highest
a. 1 b. 2 c. 3 d. 4 e. 5

2. How much contamination do you feel occurs in your microbiology experiments when you use aseptic technique?
1 = very little | 5 = a lot
a. 1 b. 2 c. 3 d. 4 e. 5

3. Do you feel that you can work effectively with bacteria cultures?
1 = strongly disagree | 5 = strongly agree
a. 1 b. 2 c. 3 d. 4 e. 5

4. Are you good at drawing images?
1 = strongly disagree | 5 = strongly agree
a. 1 b. 2 c. 3 d. 4 e. 5

5. Overall, do you feel confident while working with equipment in the microbiology lab?
1 = lowest | 5 = highest
a. 1 b. 2 c. 3 d. 4 e. 5

6. Do you feel that you are unable to isolate pure cultures of microorganisms from mixed samples?
1 = strongly disagree | 5 = strongly agree
a. 1 b. 2 c. 3 d. 4 e. 5

7. In your spare time, do you like to make various arts and crafts?
1 = strongly disagree | 5 = strongly agree
a. 1 b. 2 c. 3 d. 4 e. 5

8. How sure of yourself do you feel in your ability to use a Bunsen burner?
1 = lowest | 5 = highest
a. 1 b. 2 c. 3 d. 4 e. 5

9. Do you agree with the following statement: "I am not generally an artsy person"
1 = strongly disagree | 5 = strongly agree
a. 1 b. 2 c. 3 d. 4 e. 5

For Students: Please carefully read the questions and answer them as truthfully as possible. Answers for the questions are listed from 1 to 5. You will be awarded two bonus points for completing this quiz and turning it into your instructor.
For Instructors: Give a copy of this handout to each student and have them read the instructions. Please use a scantron sheet and give the students 5 minutes to complete the survey.

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1. What is your overall confidence in working with microorganisms?
1 = lowest | 5 = highest
a. 1 b. 2 c. 3 d. 4 e. 5

2. How much contamination do you feel occurs in your microbiology experiments when you use aseptic technique?
1 = very little | 5 = a lot
a. 1 b. 2 c. 3 d. 4 e. 5

3. Do you feel that you can work effectively with bacteria cultures?
1 = strongly disagree | 5 = strongly agree
a. 1 b. 2 c. 3 d. 4 e. 5

4. Are you good at drawing images?
1 = strongly disagree | 5 = strongly agree
a. 1 b. 2 c. 3 d. 4 e. 5

5. Overall, do you feel confident while working with equipment in the microbiology lab?
1 = lowest | 5 = highest
a. 1 b. 2 c. 3 d. 4 e. 5

6. Do you feel that you are unable to isolate pure cultures of microorganisms from mixed samples?
1 = strongly disagree | 5 = strongly agree
a. 1 b. 2 c. 3 d. 4 e. 5

7. In your spare time, do you like to make various arts and crafts?
1 = strongly disagree | 5 = strongly agree
a. 1 b. 2 c. 3 d. 4 e. 5

8. How sure of yourself do you feel in your ability to use a Bunsen burner?
1 = lowest | 5 = highest
a. 1 b. 2 c. 3 d. 4 e. 5

9. Do you agree with the following statement: "I am not generally an artsy person"
1 = strongly disagree | 5 = strongly agree
a. 1 b. 2 c. 3 d. 4 e. 5

Supplementary File 2. Post-activity MAP survey questions.

Supplementary File 2. Post-activity survey questions. Keyed (i.e., instructor-only) and non-keyed (i.e., given to students) post-MAP activity survey questionnaires are provided in a single ZIP file for those interested in replicating MAP in their classrooms.

For Students: Please carefully read the questions and answer them as truthfully as possible. Answers for the questions are listed from 1 to 5. You will be awarded two bonus points for completing this quiz and turning it into your instructor.
For Instructors: Give a copy of this handout to each student and have them read the instructions. Please use a scantron sheet and give the students 5 minutes to complete the survey.

++

1. Do you view yourself as a generally artsy person.
1 = not at all | 5 = very much so
a. 1 b. 2 c. 3 d. 4 e. 5

2. How much do you agree with the following statement "I am confident that when I use aseptic technique my cultures will be free of contamination"?
1 = very little | 5 = a lot
a. 1 b. 2 c. 3 d. 4 e. 5

3. Do you agree with the following statement" No matter what I do, I cannot draw images clearly"?
1 = strongly disagree | 5 = strongly agree
a. 1 b. 2 c. 3 d. 4 e. 5

4. Do you feel confident while working with most of the basic equipment in the microbiology lab?
1 = lowest | 5 = highest
a. 1 b. 2 c. 3 d. 4 e. 5

5. How often do you make arts and crafts in your spare time?
1 = not often | 5 = very often
a. 1 b. 2 c. 3 d. 4 e. 5

6. Do you feel confident in your ability to isolate pure cultures of microorganisms from mixed samples?
1 = lowest | 5 = highest
a. 1 b. 2 c. 3 d. 4 e. 5

7. How worried are you that an accident will occur when using a Bunsen burner?
1 = lowest | 5 = highest
a. 1 b. 2 c. 3 d. 4 e. 5

8. How strongly do you agree with the following statement "I do not have confidence in my ability to work with microorganisms"?
1 = strongly disagree | 5 = strongly agree
a. 1 b. 2 c. 3 d. 4 e. 5

9. Are you not able to work confidently with bacteria cultures?
1 = strongly disagree | 5 = strongly agree
a. 1 b. 2 c. 3 d. 4 e. 5

For Students: Please carefully read the questions and answer them as truthfully as possible. Answers for the questions are listed from 1 to 5. You will be awarded two bonus points for completing this quiz and turning it into your instructor.
For Instructors: Give a copy of this handout to each student and have them read the instructions. Please use a scantron sheet and give the students 5 minutes to complete the survey.

++

1. Do you view yourself as a generally artsy person.
1 = not at all | 5 = very much so
a. 1 b. 2 c. 3 d. 4 e. 5

2. How much do you agree with the following statement "I am confident that when I use aseptic technique my cultures will be free of contamination"?
1 = very little | 5 = a lot
a. 1 b. 2 c. 3 d. 4 e. 5

3. Do you agree with the following statement" No matter what I do, I cannot draw images clearly"?
1 = strongly disagree | 5 = strongly agree
a. 1 b. 2 c. 3 d. 4 e. 5

4. Do you feel confident while working with most of the basic equipment in the microbiology lab?
1 = lowest | 5 = highest
a. 1 b. 2 c. 3 d. 4 e. 5

5. How often do you make arts and crafts in your spare time?
1 = not often | 5 = very often
a. 1 b. 2 c. 3 d. 4 e. 5

6. Do you feel confident in your ability to isolate pure cultures of microorganisms from mixed samples?
1 = lowest | 5 = highest
a. 1 b. 2 c. 3 d. 4 e. 5

7. How worried are you that an accident will occur when using a Bunsen burner?
1 = lowest | 5 = highest
a. 1 b. 2 c. 3 d. 4 e. 5

8. How strongly do you agree with the following statement "I do not have confidence in my ability to work with microorganisms"?
1 = strongly disagree | 5 = strongly agree
a. 1 b. 2 c. 3 d. 4 e. 5

9. Are you not able to work confidently with bacteria cultures?
1 = strongly disagree | 5 = strongly agree
a. 1 b. 2 c. 3 d. 4 e. 5

Supplementary File 3. Example student images for added MAP usage inspiration / ideas.

Supplementary File 3. Examples student images for added MAP usage inspiration / ideas. An example gallery of student work is provided for inspirational purposes. All work was completed by students from all microbiology lab sections from the fall 2022 semester at Gannon University.