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Microbiology at Home (M@H): an Online, Self-Paced Solution To Enhance Practical Skills in Foundation Microbiology

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INTRODUCTION

The higher education sector is experiencing a growing need to offer science education outside the conventional university laboratory environment. It is forecasted that the higher education online market share will see a 20% growth in the period 2022 to 2028, with a projected value of over US$1 trillion by 2028 (1). Science educators are faced with the challenge and onus to rethink practical classes traditionally conducted in a university laboratory environment and create quality alternatives to traditional on-campus practical experience. In microbiology, the hands-on experience is best described as "visceral." It is a vital component for the fundamental development of both intellectual and competence-based engagement with the topic at the very fundamental level at which the subject is introduced and for creating life-lasting learning experiences.

Current solutions for outside the laboratory practical experience include virtual laboratories (2, 3), which work well to provide a theoretical basis of the applications, while lacking in the hands-on component. Another alternative is preassembled kits that may be purchased from commercial suppliers, containing live microbes and usually aimed to demonstrate a limited number of techniques (4, 5). Some kits on the market include craft accessories that are aimed at mimicking microbial lab procedures (6, 7). Importantly, none of these options offers an integrative experience, which would encompass a full curriculum using a variety of techniques and learning resources.

Here, we present Microbiology at Home (M@H), a novel approach that integrates hands-on microbiology experimentation with online interactive simulations using authentic scenarios in microbiology in a regular home environment. The M@H program includes eight practical activities aligned to the ASM curriculum guidelines for practical skills at an introductory level (8). The practical activities were assembled as separate kits that are suitable for providing strong foundation-level practical skills for students at their introductory stages of microbiology studies. M@H kits are mailed to students, with each practical activity prepacked individually, containing the required consumables. These practicals are self-paced, and each activity is facilitated using a two-dimensional simulation package with prerecorded videos, protocols, and interactive activities. The students receive both synchronous and asynchronous support and guidance through online learning management system fora and virtual gatherings.

M@H biosafety was addressed through mandatory online training and risk assessment, which was designed in accordance with the ASM Biosafety Guidelines and Biosafety for At-Home or DIY Microbiology Lab Kits (9, 10) (see Text S1 the supplemental material), and was completed by students prior to the dispatch of the kits. Students were provided with personal protective equipment, including gloves and disposable lab coats, and were instructed to use safety goggles. The only microorganism included in the kit was baker's yeast, purchased in the supermarket. This was used in Practical 1 to practice streak plating. Waste materials, including petri dishes, were disinfected using 10% bleach (included in the kits as tablets) for 2 h prior to disposal. The content of the kit and the procedures were also assessed and approved by the University of New England (UNE) institutional biosafety committee. The full practical curriculum, including learning objectives of each practical component and its alignment with ASM curriculum guidelines for microbiology laboratory skills and concepts in microbiology (9), are outlined in Table 1. The kit content as well as further materials that students need to arrange for the activities are listed in Text S2.

PROCEDURE

Exemplar capstone activity: Practical 4

The capstone activity Practical 4 integrates techniques practiced earlier in the program, including the use of aseptic

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TABLE 1
M@H practical activities and learning objectives

Practical no. and activity	Description	Learning objectives	Curriculum guideline nos.
Practical 1: Fundamental Microbiological Techniques	Hands-on practical where students learn and practice aseptic technique, make agar plates, and prepare streak plates and spread plates with the yeast *Saccharomyces cerevisiae*. Students culture microorganisms from their household environment and are provided with virtual demonstrations of microscopy and staining techniques, including the Gram stain.	• Practice aseptic technique • Prepare and use solid media • Perform streak plating to obtain single colonies • Describe colony morphology • Describe the steps in preparing simple and Gram stains • Use compound microscope to evaluate and describe cell morphology and interpret Gram stain	32, 36, 37 6, 7
Practical 2: Microbial Properties—Motility, Flagella, Capsules, and Antibiotic Sensitivity	A fully online module looking at important microbial properties, such as motility and flagella in bacteria, bacterial capsules, and antibiotic sensitivity. The materials include video demonstrations and micrographs.	• Test and recognize bacterial motility using the hanging drop method • Recognize Brownian motion • Interpret and describe steps in preparing an agar stab test for bacterial motility • Recognize bacterial capsules and flagella in previously prepared slides • Interpret and describe the steps in preparing a disk diffusion assay for antimicrobial testing	32 8, 14
Practical 3: Estimation of Microbial Number	This practical contains both hands-on and online components. Students dilute a sample of *S. cerevisiae*, prepare a spread plate, and count the colonies that form (viable cell plate count).	• Outline the steps to undertake a direct cell count • Prepare spread plates for viable cell counts • Interpret the results of a viable cell plate count • Conduct dilutions and factor these into calculations	35
Practical 4: Microbial Media (Food Microbiology)[a]	In this hands-on activity students are making sauerkraut and plating up samples of the sauerkraut on both nonselective and lactic acid bacteria media at the start and end of the fermentation. This activity will apply skills in dilutions, spread plating, and interpreting viable cell plate counts. Students will also monitor the pH as the fermentation progresses.	• Explain why the fermentation of foods developed as a food preservation method • Prepare a fermented food product • Describe the changes occurring in the microbial community during sauerkraut fermentation • Apply viable cell count method to a practical scenario • Use selective culturing techniques to enrich for and isolate microorganisms	34, 35 11, 12, 13, 14
Practical 5: Examination of Fungi	In this fully online module, students explore both yeast and fascinating filamentous fungi under the microscope.	• Recognize basic features of fungi under the microscope • Use morphological clues to identify fungi • Outline the steps in preparing a sticky tape impression of filamentous fungi • Outline the steps in preparing a simple wet slide of yeast	32 9
Practical 6: Identification of Bacteria	This fully online activity will introduce students to bacterial identification using miniature biochemical tests on an API strip.	• Outline the steps in setting up an API strip • Interpret SPI 20 E results and enter them into the APIWEB database • Identify a mystery Gram-negative organism using the API 20 E system	34 11
Practical 7: Microbial Control	This practical is a combination of hands-on and online activities. Students culture bacteria from their unwashed and washed hands to see	• Describe different sterilization methods • Describe and interpret tests for checking autoclave function • Discuss the importance of hand washing	33 14

(Continued on next page)

TABLE 1 (Continued)

Practical no. and activity	Description	Learning objectives	Curriculum guideline nos.
	how soap and/or alcohol sanitizer can control organisms. Students are also provided with an online demonstration showing how some bacteria produce resistant endospores, making them difficult to control.	• Outline an experiment to compare the heat resistance of vegetative cells and endospores • Outline the steps in doing a spore stain • Interpret a spore stain slide	
Practical 8: Bacterial Growth Curve	In this final activity, students are provided with data to construct a bacterial growth curve. They use the data to estimate the generation time of a strain of *Escherichia coli* under given conditions.	• Outline the steps involved in a growth curve experiment, using optical density to measure growth • Construct a growth curve with experimental data • Identify the exponential phase on a growth curve and use it to calculate the generation time of bacteria	35

[a]A capstone activity.

techniques (Practical 1) and bacterial enumeration (Practical 3), with theoretical concepts on microbial interactions and the effect of metabolic capacity on microbial growth. The activity uses food microbiology to extend the acquired skills and demonstrate the principle of microbial selection based on metabolic properties.

In this activity, students prepare sauerkraut fermentation while monitoring the microbial process through sampling from the beginning to the completion of the fermentation process. A typical sauerkraut fermentation begins with the proliferation of the salt-tolerant lactic acid bacterium (LAB), *Leuconostoc mesenteroides*, a facultative anaerobe capable of performing a heterolactic fermentation that is visually observed with the release of CO_2 into the fermentation medium (11, 12). This fermentation quickly lowers the environmental pH, so that it favors the succession of other LAB. The activity includes daily sampling, including pH measurement, as well as bacterial enumeration using rich and selective LAB media. Students are required to calculate the bacterial concentration using serial dilutions and viable cell counts. By comparing the growth observed using the two different media, students learn about selection using different metabolic characteristics of microorganisms. In addition to the multiple learning outcomes of this activity (Table 1), students have the option to prepare simultaneously an additional sauerkraut fermentation that is left unopened during the entire process, which would enable them to relish the resultant sauerkraut and share with others if they so wished.

Consumables in a kit format (Fig. 1) are assembled in a conventional university laboratory and mailed to all students for this activity. The teaching protocol for this M@H activity is provided in Text S3.

Course implementation and assessments

Prior to mailing the M@H kits to each student enrolled in the unit, it was mandatory that all students successfully complete a biosafety module by the end of week 2 of the learning period; Text S4 outlines the study timetable. The biosafety module was delivered as an interactive session which included text and video footage outlining safety procedures. As part of the biosafety module students were also provided with a risk assessment (Text S4) for the procedures that were required for the use of the kit. At the end of the session, students were required to sign a statement of competency in the safe use of the kit. In addition to this, students were required to complete the UNE laboratory biosafety and microbiology biosafety training modules.

Our learning period included 13 weeks of teaching, and students were instructed to complete all activities by week 11. The assessment for this component of the course included an online quiz and the electronic submission of lab notes (see Text S4).

Student feedback

A total of 171 M@H kits were sent to students during the years 2020 to 2021. Of those participating in the course, 23 students offered to provide formal feedback on the activities (UNE Human Ethics Research Committee [HREC] approval HE20-212) (Fig. 1B). All respondents scored 5/5 for the question on whether they felt that "the practical component was valuable for their learning of microbiology." When commenting on the microbiological techniques that the students were confident in performing, the most prominent answers included microbial plating techniques, serial dilutions, and the use of aseptic technique. When asked to comment regarding the "best features of the practical component," students highlighted the use of standard household items in the practical work as beneficial and that the resources provided with the kit were supportive and useful.

CONCLUSION

Hands-on practical experience is fundamental for microbiology students at an early stage of undergraduate learning. The increasing demand for alternatives to face-to-face education in

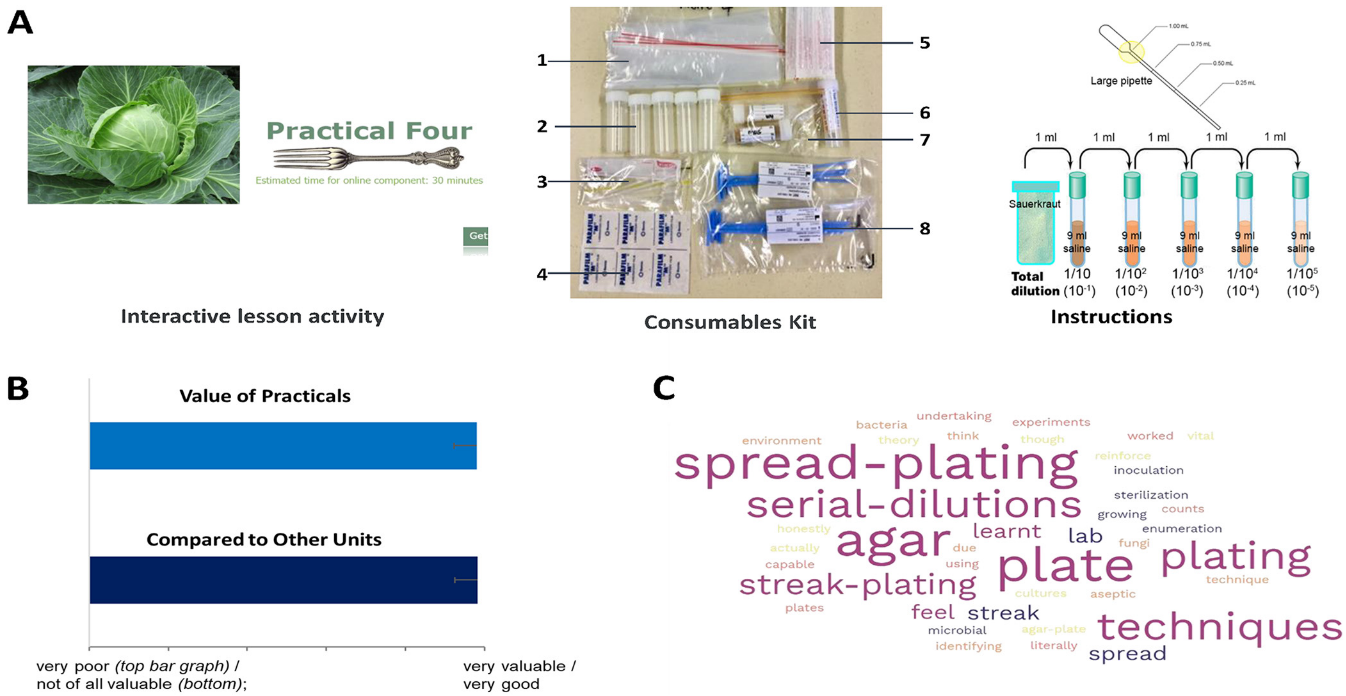

FIG 1. M@H example activity kit and student feedback. (A) Example of M@H practical activity, including online interactive module, consumables kit, and step-by-step instructions. Items in the consumables kit included the following: 1, Ziplock bags for waste; 2, sterile tubes; 3, transfer pipettes (100 μL); 4, parafilm; 5, transfer pipettes (1 mL); 6, pH strips; 7, MRS agar; 8, sterile disposable spreaders. (B) Ratings obtained in a Qualtrics assessment (UNE HREC approval HE20-212) conducted in 2020 to 2021 to evaluate student feedback on M@H. (C) Word cloud representing students responses to the question "What (if any) microbiological techniques do you feel more confident in undertaking after completing the practical component?"

microbiology can be accommodated using the integrative approach offered with the M@H kits. Student feedback has demonstrated that the M@H program not only provides real hands-on experience in microbiology but also acts to cement the emotional engagement with the content by contextualizing it to the surrounding home environment. We anticipate that these activities will provide a way to successfully engage students at an early stage of their undergraduate education with hands-on microbiology without the need for actual laboratory attendance, thus increasing accessibility to microbial protocols and applications.

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, PDF file, 0.3 MB.

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