Using nontoxic craft items and disposable lab consumables, we have developed nine modules to teach fundamental, hands-on microbiology lab skills safely at home. These “Crafty” teaching modules can be paired with virtual instruction and/or data collected by an instructor to replicate traditional microbiology lab exercises that characterize an unknown microbe. Materials and procedures used were carefully chosen to best mimic the texture of media, represent microbial diversity, assess aseptic technique, and produce analyzable data from results. Some protocols build upon and extend previously unpublished ideas, while others provide novel methods. The lab skills include proper personal protective equipment usage and basic biosafety, aseptic technique, microscopy and staining, streaking for isolation, spread plating, serial dilutions, filtering, disk diffusion method, and modeling an epidemic. Each protocol includes a student handout with background, links to videos of the methods performed with microbes, a rationale for the pairing of craft and consumable lab supplies along with technique used, a video or image demonstration of the “Crafty” technique when needed, postlab questions, and an instructor guide. This resource was developed for an undergraduate microbiology course, and each lab is aligned with learning outcomes within the American Society for Microbiology’s undergraduate curriculum guidelines. This work would also be useful for outreach and K–12 educators. The development of microbiology lab skills by all students, regardless of economic or health status, will lead to a more scientifically minded society.

INTRODUCTION

The COVID-19 pandemic forced microbiology teaching labs out of a directly supervised, controlled laboratory setting and into student homes. Current solutions have been to either send home preassembled kits with viable microbes or rely on virtual labs (1). Preassembled kits, whether commercially available or assembled by the instructor, typically contain live Risk Group Level 1 microbes that are safe to work with in a supervised lab yet could present a health risk in home environments with immunocompromised people, young children, or pets (2). Virtual labs do not rely on live microbes; however, they fail to provide hands-on skills practice and depend on Internet access and stability. Additionally, both preassembled kits and virtual labs are costly. Our goal was to teach essential microbiology skills at home using inexpensive craft supplies and disposable microbiology tools (Appendix 1).

With “Crafty Microbiology” kits (Fig. 1), students develop authentic motor skills for microbiology in a safe and economical fashion in their own home. While some of the methods have been used previously (3–5), we present improvements, extensions, or quantitative assessments. The personal protective equipment (PPE) removal exercise uses colored paint, glitter, and glow-in-the-dark paint. These different materials add multiple layers for students and professors reviewing student videos to assess glove removal issues. In isolating single colonies, students use three types of model media prior to using gelatin or agar-based media. Each model medium helps students assess appropriate streak pattern, sterile technique, loop angle, and pressure. Self-assessment guides, including assessing aseptic technique via the “bench space,” and quantification further deepen the “Crafty” methods. Modifications have been made to previously unpublished exercises, including (i) the pairing of serial dilutions with mock CFU calculations for mixed culture samples, (ii) filtering demonstrations using different weaves of fabrics and a heterogeneous-sized glitter mixture, (iii) microscopy exercises that incorporate artwork (modeling and collage) as a means to demonstrate outcomes of various staining techniques, and (iv) spread plating inoculation to provide immediate feedback on technique with biosafety incorporation. Some novel methods that attempt to
replicate the actual microbial technique as closely as possible include a mock Kirby-Bauer experience that uses disc-diffusion–based color changes via soluble marker ink or pH differences and an epidemic modeling exercise, which pairs computer modeling with a hands-on disease transmission demonstration. Throughout the techniques, special attention was paid to the texture of the “media,” representing microbial “diversity” and numbers, ability to assess aseptic technique, and the results produced by each procedure.

PROCEDURE

Student buy-in

To alleviate any concerns students might have in time or money being wasted on a box of craft supplies, teaching transparency is essential (6). Thus, each protocol includes a rationale on how the craft supply choice mimics the laboratory supplies. Exercises are paired with learning objectives (Table 1), with video or images demonstrating proper technique using the “Crafty supplies” (Appendix 1), a link to a demonstration and images using live microbes, and a standard microbiology lab textbook explanation. Comparing the “Crafty” versus standard methods side by side allows students to understand the fundamental learning objective and the motor skills and quantitative microbiology lab skills they gain.

Activities

Nine “Crafty” labs (Table 1) were created with full student handouts, instructor guides, suggested supply list (Appendices 2 and 3 and Table 2, respectively) and videos (Mostly Microbes’ “Crafty Microbiology” YouTube Playlist: https://www.youtube.com/playlist?list=PL-pe-Oi8vx5PskybWbnPC7lTEZsd5RETa) of certain techniques. For each exercise, students create their “bench space” using packing paper. They assemble the materials needed for that exercise, watch the live microscope and “Crafty” video and image demonstrations, and attempt the “Crafty” procedure. When they feel confident about their technique, they make a video of themselves performing the technique, upload the video to their electronic notebook, evaluate their technique, and then clean up any supplies for subsequent use. To address aseptic technique, students check their bench space (packing paper) for glitter or paint contamination after each procedure.

An example of the importance of material choice can be seen when conducting a quadrant streak to isolate individual CFU. We needed a proper medium mimic and microbial colony. Students often have trouble with holding the loop at the correct angle to prevent gouging the media while adequately spreading the cultures. The media needed to be slightly slippery, reducing friction between the media surface and the inoculation loop. After much experimentation with different paper types, we determined that our ideal material choice for “media” involved stretching paraffin over the edges of the bottom half of a petri dish. This allowed for a stable, but delicate surface that the loop could glide over, dispersing the microbial “culture.” The microbial “culture” sample was composed of two different commercially available glitter paints mixed together. These silver and gold paints (Table 2) have slightly different-sized glitter that allows them to be distinguished from each other. Finally, to assess aseptic technique, additional glow-in-the-dark paint can be added. To make the microbial sample more diverse, several colors of superfine glitter can be added to the mix. The glitter size is very important in this case. The glitter needs to be small enough so that it can be easily picked up and transferred by a loop tool.

These labs are designed to be modular, allowing instructors to include as many exercises as needed or to change the order to fit their course design. Each module is individually assessed using (i) post-lab questions included in each student handout (Appendix 2) and (ii) an image and/or video of the students’ technique(s) using the three-point (Poor, Adequate, Proficient) rubrics as a guide for grading (Appendix 4). Post-lab questions are intended to highlight the biological context of the lab technique covered in the module, connect a learning objective to the technique and/or provide exploration of the differences in the “Crafty” technique and the standard technique. Videos and images allow for personalized feedback not always available during
| Microbiology lab technique | Learning objectives | Curriculum guideline no. |
|----------------------------|---------------------|--------------------------|
| PPE and Aseptic Technique  | -Demonstrate and assess the proper use of PPE  
- Demonstrate the steps to follow for putting on and safely removing PPE  
- Recognize the importance of hand hygiene in aseptic technique  
- Recognize how to properly dispose of materials in the appropriate receptacles (general/universal trash, “biohazard”) | 36, 37 (22, 24) |
| Microscopy and Staining    | -Demonstrate understanding of light microscope total magnification relative to the microscope field of view and specimen type  
- Recognize the procedures and resulting microscopic images for simple, Gram, endospore, acid-fast, and negative capsule staining | 6, 32 (22, 23) |
| Streak for Isolation and Culture | -Display proper aseptic technique in sample transfer or inoculation  
- Demonstrate proper streaking for isolation using the quadrant method  
- Demonstrate skill in isolation of items from a mixed sample using different types of solid media  
- Learn the procedures used in preparing media needed for culturing microorganisms | 33, 36 (23) |
| Spread Plating             | -Demonstrate proper aseptic technique for transfer of samples to a plate  
- Learn a technique used to characterize and/or count the no. of microorganisms in a sample | 33, 34, 36 (23) |
| Inoculating Liquid and Slant Media | -Demonstrate proper aseptic technique for transfer of samples to a broth and slant | 33, 34, 36 (23) |
| Serial Dilutions, Plating, and Counting | -Practice and explain the importance of sterile technique  
- Calculate dilution factors and perform serial dilutions effectively | 29, 33, 35, 36 (23) |
| Filtering                  | -Understand the physical method of controlling microbial growth via filtration  
- Practice a technique to enrich for and isolate microorganisms | 14, 31, 33, 36 (15) |
| Disk Diffusion Method (Kirby Bauer) | -Demonstrate the disk diffusion method of antimicrobial susceptibility testing  
- Interpret zones of inhibition qualitatively as resistant, intermediate, or susceptible  
- Determine which agent(s) are best for “treatment” when multiple zones of inhibition are present | 29, 36 (25) |
| Epidemic Modeling          | -Understand that diseases spread more slowly when the rate of contact, and thus transmission, is lower | 23, 28, 31 (12, 13) |

*ASM undergraduate curriculum guidelines (7) and microbiology in nursing and allied health (MINAH) undergraduate curriculum guidelines in parentheses (8).

PPE = personal protective equipment.
in the in-person lab setting when one instructor may have many students in one lab section to monitor for technique.

Extension.

While these techniques were developed in response to the COVID-19 pandemic, they have numerous benefits and applications. During in-person teaching labs, students are often highly anxious about safely working with live microbes, their abilities, and the lag of 24 h or more before results are known. In particular, properly isolating single colonies is extremely problematic and may keep a student stuck at that skill set for weeks. When working with microscopic organisms, many students use too much inoculum since they are unsure that anything is being manipulated. Providing students with materials to work with in the comfort of their own home that closely mimic their in-lab

| TABLE 2 | Crafty microbiology student supplies and approximate costs |
|---------|-------------------------------------------------------------|
| Item    | Brand | Unit size | Cost per unit | Units to purchase | Total cost | Total cost for 50 students |
| ------- |------ |----------- |-------------- |------------------ |----------- |---------------------------|
| 2 oz plastic squeeze bottles for students | 25 | $7.29 | 2 | $14.58 | $29.16 |
| Washable Glitter Tempera 16 oz Gold | Sargent-Art Time | 1 | $8.43 | 1 | $8.43 | $8.43 |
| Washable Glitter Tempera 16 oz Silver or Red or Green | Sargent-Art Time | 1 | $11.22 | 1 | $11.22 | $11.22 |
| Super fine glitter | Creatology | 2.3 oz | $3.99 | 1 | $3.99 | $3.99 |
| Chunky Glitter | Creatology | 3.31 oz | $3.99 | 1 | $3.99 | $3.99 |
| Regular Glitter | Creatology | 2 oz | $2.99 | 1 | $2.99 | $2.99 |
| Squeeze bottle for dispensing paint | 1 | $2.49 | 1 | $2.49 | $2.49 |
| Roll of MALA art paper | IKEA | 1 roll | $4.99 | 1 | $4.99 | $2.50 |
| Washable markers | Rose Art | 100 | $13.50 | 1 | $13.50 | $6.75 |
| Permanent markers | Shuttle Art | 50 | $22 | 1 | $22.00 | $22.00 |
| Washable tempera paint | Crayola | 16 oz | $7.59 | 1 | $7.59 | $7.59 |
| Dried gelatin | Wincrest | 20 oz | $18.99 | 1 | $18.99 | $18.99 |
| Tulle Fabric | 1 yard | $1.49 | 3 | $4.47 | $4.47 |
| Net Fabric | 1 yard | $1.49 | 3 | $4.47 | $4.47 |
| Solid Cotton Fabric | 1 yard | $6.99 | 3 | $20.97 | $20.97 |
| Construction Paper, solid colors (8 colors) | Sunworks | 50 sheets | $2 | 8 | $16.00 | $16.00 |
| 16 oz red plastic cups | 50 cups | $2.88 | 1 | $2.88 | $2.88 |
| Playdough supplies (flour, cream of tartar, salt) | 50 balls | $16.45 | 1 | $16.45 | $16.45 |
| Aluminum foil 12 in × 10 in | 500 sheets | $16 | 1 | $16 | $16 |
| Waxed paper squares | Norpro | 250 sheets | $7 | 1 | $7 | $7 |
| Paraffin (5 sheets) | 250 squares | $46 | 1 | $46 | $46 |
| Filter paper | 100 filters | $8 | 3 | $24 | $24 |
| Blank filter paper disks Carolina Biological† | 50 | $12.85 | 5 | $64.25 | $64.25 |
| Pipe cleaners/chenille stems | Acerich | 600 | $10 | 1 | $10 | $5 |
| Paper rulers‡ | WinTape Educare | 100 | $16 | 1 | $16 | $8 |
| **Sum** | | | | **$363.25** | **$341.19** |
| **To reduce cost:** | | | **Cost per student** | **$7.27** | **$6.82** |

†use a hole puncher and white card stock or even printer paper.
‡print out rulers from (http://www.vendian.org/mncharity/dir3/paper_rulers/) on card stock.
resources gives them an opportunity to practice prior to coming into the lab and/or to supplement standard procedures. This should increase skill success and decrease waste of laboratory materials. An unintentional side benefit to conducting these skills at home is that others in the student's household may be inspired to try to learn more about microbiology. Indeed, students reported that parents and siblings were intrigued about the “Crafty” exercises.

“Crafty” Microbiology can easily be adopted for use with outreach activities and K–12 educators. Thus, the public can better understand, for example, the essential techniques that clinical microbiologists use to isolate microbes from clinical samples or how antibiotic resistance is determined.

Safety issues

There are no safety issues as no biological materials are used. “Crafty” materials are standard consumer art supplies and the consumable lab materials are plastic. The supplies suggested were chosen since they are nontoxic and washable.

CONCLUSION

Initial responses have shown these “Crafty” methods do provide real and immediate hands-on skills feedback. Assessment rubrics were created for the nine crafty labs (Appendix 4). Post-lab questions are included with each student handout to reinforce the learning objectives and assess students’ mastery of the material. The efficacy of the “Crafty Microbiology” exercises will be assessed in both intro and upper-level microbiology classes in spring 2021 (Goucher College IRB #20141673). We anticipate that these unique, crafty methods will provide a way to successfully engage students with hand-on skills without the need for live microorganisms, increase accessibility to microbiology protocols, and promote a critical thinking environment as students master learning objectives and essential motor skills safely at home.

SUPPLEMENTAL MATERIALS

Appendix 1: Master supplies list and recipes
Appendix 2: Student handouts
Appendix 3: Instructor guides
Appendix 4: Assessment rubric

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