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Remote Laboratory Exercise to Develop Micropipetting Skills†

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The rapid spread of COVID-19 has fundamentally transformed our educational system. The need to protect both students and instructors from exposure to viral infection has required the implementation of remote instructional models. Although this alternative delivery approach can be successfully implemented to teach the theoretical foundations of multiple disciplines, teaching technical skills poses a major challenge, particularly in various biology fields, where observation of biological safety guidelines and the high cost of analytical equipment represent major impediments for remote instruction. To overcome this problem, we have developed a laboratory exercise to teach students how to use micropipettes that can be completed remotely using materials that can be purchased at a fraction of the cost of the instructional equipment normally reserved for in-person instruction. Our evaluation of the effectiveness of this remote lab indicated that the majority of students who participated in a survey believed they attained the learning objectives and felt confident in their lab technique after completing the exercises. The simplicity, relatively low cost, and effectiveness of this approach makes it highly adaptable for other classrooms and educational settings.

INTRODUCTION

The COVID-19 pandemic has severely restricted instruction of in-person laboratory classes. Virtual and remote instructional formats can be incompatible with development of technical skills, which studies have identified as a key learning competency (1, 2). Hands-on laboratory activities have been shown to improve both student engagement and assessment scores (3–5), and there exists a critical need to develop effective methods for teaching technical skills through the implementation of laboratory activities that can be completed remotely.

While in many disciplines this can be accomplished by sending students tools and supplies to perform experiments at home, for biological sciences, several obstacles prevent experimentation in non-laboratory settings. The first and foremost of these is biological safety. It is imperative to eliminate any potential risks to students and their families. The second is cost. It is important to ensure that every student receives equipment in functioning condition and that can be purchased at a reasonable cost.

TABLE 1.
Lab activity learning objectives.

1) Use micropipettes and pipet aids
2) Define the importance of replicates, standard deviation, and standard error
3) Mix samples properly
4) Create serial dilutions
5) Identify a linear range of measurements
6) Describe types of measurement error
7) Document lab data and observations
8) Create figures from experimental data

Operating within these constraints and driven by the need to teach pipetting skills in our course, we created a novel remote lab module that requires students to develop good pipetting practices and includes self-assessment

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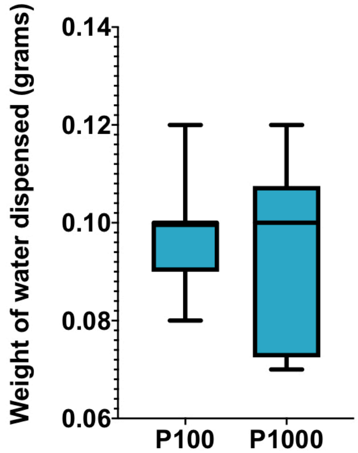

FIGURE 1. Mass of water dispensed by P100 and P1000 micropipettes. One hundred μL of water were dispensed from the two pipettes onto a scale to measure pipetting precision and accuracy (n = 12). Error bars indicate SD.

activities to determine the accuracy and reproducibility of their technique. Importantly, in addition to micropipetting, the activity taught important experimental topics (Table 1). The data obtained by students was homogeneous and our evaluation indicated that most students achieved the learning objectives and felt confident in their technique. Here, we describe the equipment and protocol provided to the students and share the results of our internal evaluation of instruction followed by a discussion of strategies for future refinement.

PROCEDURE

Materials and supplies

A detailed list of materials that were sent to students is included in Appendix 1. The laboratory protocol is provided in Appendix 2. Briefly, the equipment necessary to complete the laboratory exercise includes a mini-scale, a glucose meter, pipet-aid, and a set of micropipettes. Reagents to prepare for the remote lab include a 4,000-mg/dL glucose solution with 5% (w/v) bovine serum albumin (BSA) and a BSA resuspension solution (5% w/v). Glucose and BSA resuspension solutions were refrigerated after shipping to prevent contamination. The glucose oxidase detection mechanism normally implemented by glucose meters is calibrated for use with blood samples with high protein content. The 5% (w/v) BSA enables detection using a specific brand of glucose meter (OhCare Lite system, OSANG Healthcare Co., Ltd.). The concentration of glucose needs to be optimized to ensure readings within the dynamic range of the glucose meter. The materials for each student were packed into a single cardboard box, and we arranged for on-campus students to pick up their supplies while off-campus students received their box by mail. The department covered the costs of supplies and shipping.

Remote laboratory session

To accomplish the lab learning objectives (Table 1), each student was provided with a lab kit (Appendix 1), an instructional video, and the student laboratory manual (Appendix 2). The lab activities were completed asynchronously over 2 weeks. Students were required to follow the protocol step by step, which included exercises to: (i) dispense small volumes with micropipettes using a miniature digital scale to measure the accuracy and precision of their technique (Fig. 1); (ii) measure with micropipettes; (iii) mix with micropipettes; and (iv) create serial dilutions of a glucose solution while validating their pipetting accuracy using a glucose meter (Fig. 2 and 3). Students recorded their measurements and responded to 22 questions in the lab manual that prompted them to analyze their data and consider the implications of their experiments. Students uploaded all data and their responses to the questions in electronic laboratory notebooks, which were shared with instructors for feedback and grading.

FIGURE 2. P10 micropipette used to load glucose solution into test strip. The glucose meter provides a measurement of glucose concentration in milligrams per deciliter after a short countdown.

Post-lab exercises

Following data collection, students were required to analyze variation in micropipette measurements from pooled data and perform statistical analyses to quantify variability across measurements. Questions and text embedded in the lab protocol prompted students to research the concepts of linear range and error propagation.

Safety issues

Prior to participating in this course, students were required to complete online laboratory and biosafety training and to complete an acknowledgment that they had reviewed general and lab-specific safety information. While

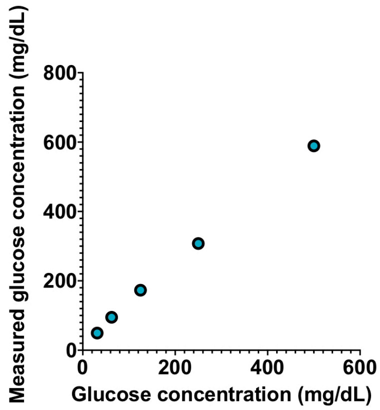

FIGURE 3. Glucose concentrations at various dilution steps. During the eight-step serial twofold dilution, the concentration of glucose in solution was measured at each step. For the data that were within the range of the glucose meter, the graph represents the relationship between actual and measured glucose concentrations (*n* = 2).

the glucose and BSA solutions are nonhazardous, students were advised to wear gloves while performing the experiments. Since the provided glucose meter contains a lithium coin battery, students were advised to keep the device away from small children. All parts of this exercise conform to the recommendations set by the ASM Guidelines for Biosafety in Teaching Laboratories. Students were instructed that all reagents could be disposed of in the regular trash. Returned equipment was tested for proper functionality and decontaminated with 70% isopropanol as approved by the campus Division of Research Safety before reuse.

Student feedback

After completion of the lab, a short survey was distributed to the 28 students enrolled in the course (Appendix 3). The survey was approved by the University of Illinois Urbana-Champaign (IRB #21224). A total of eight students provided feedback (approximately 29% response rate). Overall, 75% of students who responded reported previous experience using micropipettes. When asked about the most useful part of the lab, the most common response was the micropipette exercises (75%). Of the eight students who participated in the survey, seven indicated that they felt they were confident in their micropipetting technique after completing the lab and that they achieved the learning objectives. Potential challenges identified are addressed in Table 2.

DISCUSSION

Here we report the development of a remote laboratory exercise to teach students how to use micropipettes with materials that can be purchased at a fraction of the cost of the equipment for in-person instruction. The most expensive items were the miniature scale ($12), glucose meter ($15), test strips ($10), pipet-aid ($7), and the micropipette set, which costs $135 per student (Appendix 1). The cost of tips, gloves, microcentrifuge tubes, and other nonreusable supplies was minimal. Instructors could implement all or sections of the Student Lab Manual and associated exercises to meet the needs of their course. We also provide potential solutions to the challenges identified in this pilot offering (Table 2).

CONCLUSION

We believe that the instructional materials developed will still be relevant even after the COVID-19 pandemic as a way to increase accessibility of laboratory equipment for students unable to attend class in person and to supplement the in-person learning experience (6). Finally, since this activity teaches transferable skills, it can be used in a variety of contexts, such as high school classes and summer STEM camps, which are increasingly using lab kits, both as a response to COVID-19 and as a means of increasing STEM accessibility (7).

TABLE 2.
Summary of concerns and potential solutions.

Potential Challenge	Mitigation Strategy
Cost	- Adapt the activity to use a single micropipette, instead of a three-micropipette set - Rotate equipment sets among students - Require student pickup and return of kits on campus (if students are on campus or local) to reduce shipping costs
Lack of feedback about pipetting technique	Include more detailed instructional videos and provide opportunities to perform the experiment described with remote live feedback from instructors
Activity was too long	Offer the activity over several weeks and deliver some parts during the live class sessions
Difficulties using Excel	Provide resources to students who may not be familiar with Excel, particularly for creating graphs and conducting *t* tests

SUPPLEMENTAL MATERIALS

Appendix 1: Materials list with suppliers and cost
Appendix 2: Student lab manual
Appendix 3: Student survey

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