Assessing core manipulative skills in a large, first-year laboratory

Roger W. Moni,1 Deanne H. Hryciw,1 Philip Poronnik,1 Lesley J. Lluka,1 and Karen B. Moni1,2

1Educational Research Unit and 2Education, School of Biomedical Sciences, The University of Queensland, Brisbane, Queensland, Australia

Submitted 29 March 2007; accepted in final form 31 May 2007

WELL-DESIGNED PRACTICAL WORK has the potential to motivate students and support deeper learning of concepts, manipulative competencies, and cooperative approaches to learning (6). Indeed, completing laboratory-based work as a subset of science practical work that also includes field studies (5) is often perceived as being synonymous with “doing science.” However, while most courses require students to develop manipulative skills, perform accurate measurements, and master basic laboratory techniques, laboratory supervision often does not provide constructive feedback on skill development or systematically assess specific skills (8). In addition, the hours allotted to undergraduate laboratory work in universities has often been reduced as part of streamlining costs and mounting concerns over excessive use of animals in large physiology classes (12). While replacing traditional “wet” laboratory work with computer-assisted learning modules has educational and practical merits, there is general agreement among scientists that there can be no substitute for real wet laboratory experiments in physiology (3). Furthermore, students in large classes prefer authentic laboratory experiences over simulations (11).

At The University of Queensland, many of our physiology faculty members lament that the decreased opportunities to develop laboratory skills has affected the skill level of students entering research-based graduate degree programs and professional careers. Their complaint is that too many undergraduate students have not mastered basic laboratory manipulative skills. The authors surmised that it is incorrect to assume that completing the requirements of undergraduate laboratories would necessarily lead to competent skill development. First-year classes often present considerable challenges because students are relatively inexperienced with the apparatus and methods of physiology. Furthermore, enrolments are often large, making it difficult to ensure that all students have competently learned basic technical skills. The same is true for laboratory group work, in which students may not rotate roles (e.g., dissection, pipetting, measuring, and record keeping), and thus some may not develop all the basic skills that faculty members expect of them.

On that basis, the authors proposed that students would learn skills more effectively if they were individually assessed on core laboratory manipulative skills and that these skills should be assessed from their first-year of degree program. Consequently, we decided to introduce a stronger focus on manipulative skills into the laboratory sessions in the first-year Human Biology course, which has a large physiology component.

This article reports the findings of an initiative to improve laboratory skills through addressing the following research question: How can core manipulative skills be taught and assessed in large laboratory classes?

CONTEXTS

The Course and Students

The authors teach and/or advise on the annual revision of Human Biology, a first-year course delivered by the School of Biomedical Sciences at The University of Queensland. Human Biology was implemented in semester 1 of 2006 for students enrolled in Bachelor of Pharmacy (n = 126), Human Movement Studies (n = 205), Medicine and Surgery (n = 20), and Science (n = 14) degree programs. The course was taught again in semester 2, primarily for Science students (n = 854).

Laboratory Classes

Course lectures were complemented with five preexisting laboratory classes. These classes were delivered in the following sequence: Cell Membrane and Osmosis, The Human Nervous System, Action Potentials and Nerve Conduction, Skeletal Muscle Physiology, and Circulation and Blood. In each practical session, conceptual understanding was assessed and complemented with individualized skills assessment, the focus of this study. Students
worked in small groups to complete all laboratories, but their manipulative skills were individually assessed.

**Strategy to Teach and Assess Laboratory Skills**

The integration of skills development with conceptual learning was favored over implementing a separate, methods-only session because the skills would be developed in contexts of use. The employment-based requirement of knowing how to complete relevant skills—not merely know about them—has been described as an information gap between old and new academic competencies (4). Thus, students were initially taught the differences among “knowing about” a topic, “knowing how” to complete a skill, “showing how” to complete a skill, and “doing” the skill. Students were also informed that only the latter was considered as a measure of skill competency. Skills were considered as embedded elements of the more complex laboratory practices of problem-based or case-based inquiry learning tasks (9). In this context, skills represent “hands-on” or “doing” physiology, while practices represent “the combination of hands-on and minds-on,” as described by the National Research Council (10). This distinction enabled us to explicitly teach skills to students in the expectation that proficiency in core manipulative skills would support open-ended, student-driven explorations.

We implemented individualized testing of laboratory skills following the recommendations of Becker (1). First, we defined five core or enabling manipulative skills that supported key concepts in the course. These were 1) accurate and precise use of a micropipette, 2) calculation of dilutions and preparation of diluted samples of saline, 3) accurate representation of data using a graph, 4) use of a light microscope, and 5) acquisition of digital data by measuring the latent period for the Achilles reflex. Second, for each skill, we defined a standard operating procedure (SOP) consisting of clear and observable steps so that the skill could be reliably assessed. These SOPs are included below together with a brief description of the context of use for the laboratories in which manipulative skills were assessed. These skills were also required in later laboratories but were not individually reassessed in these different contexts. SOP1 and SOP2 were required in the laboratory for Cell Membrane and Osmosis. SOP3 was required for laboratories for Cell Membrane and Osmosis, Action Potentials and Nerve Conduction, Skeletal Muscle Physiology, and Circulation and Blood. SOP4 was required for laboratories for The Human Nervous System as well as Circulation and Blood. SOP5 was required for laboratories for The Human Nervous System, Action Potentials and Nerve Conduction, and Skeletal Muscle Physiology.

**SOP1: accurate and precise use of a micropipette (Cell Membrane and Osmosis).** As the first skill, basic use of a micropipette was assessed separately from how the micropipettes were used subsequently in the laboratory.

1. Choose the appropriate micropipette based on the volume to be dispensed.
2. Set the micropipette to the required volume.
3. Correctly choose and load a pipette tip based on the micropipette used.
4. Accurately and precisely deliver volumes using a micropipette; aspirate and dispense.
5. Repeat once.

**SOP2: calculation of dilutions and preparation of diluted samples of saline (Cell Membrane and Osmosis).** Following from SOP1, a stock of sodium chloride solution was diluted to specified final saline concentrations and osmolarities; 50 μl of sheep’s blood were suspended in each of four saline solutions.

1. Calculate the volume (V) or concentration (C) of stock based on the formula C1V1 = C2V2 or another valid mathematical method.
2. Make the dilution of stock by the accurate use of dispensing equipment.
3. Appropriately mix and dispense the stock to make the specified dilutions.
4. Complete four dilutions.

**SOP3: accurate representation of data using a graph (Cell Membrane and Osmosis).** Following from SOP2, samples from individual students were grouped and centrifuged. Students aspirated the supernatants and recorded the absorbance at 540 nm using a spectrophotometer. Each student constructed a hemolysis curve (540-nm absorbance against osmolarity). The uses of bench top centrifuges and spectrophotometers were not performed by each student and therefore were not individually assessed.

1. Write an appropriate title for the curve.
2. Select an appropriate scale for all axes.
3. Correctly label all axes.
4. Include units of each axis (correct units and appropriate style).
5. Accurately graph laboratory data.
6. Accurately describe trends in data.

**SOP4: use of a light microscope (The Human Nervous System).** As part of the laboratory exploring the sensation of touch, each student used a microscope and prepared a slide from human skin stained to identify Meissners’ corpuscles.

1. Set your microscope on a tabletop.
2. Switch on your microscope’s light source.
3. Adjust the disk diaphragm (condenser) to the largest hole diameter, allowing the greatest amount of light through.
4. Place a microscope slide on the stage and then move the slide until the specimen is under the objective lens.
5. Use the objective lens that gives the lowest magnification first to focus your slide.
6. Adjust the larger, coarse focus knob until the specimen is in focus.
7. Adjust the smaller, fine focus knob until the specimen is clearly in focus. Then, adjust the diaphragm to get the best lighting. Start with the most light and gradually lessen the light until the specimen image has clear, sharp contrast.

**SOP5: acquiring digital data by measuring the latent period for the Achilles reflex (The Human Nervous System).** As part of the laboratory exploring human reflexes, the latency between percussion of the Achilles tendon and beginning of the electrical response from the gastrocnemius muscle was recorded. This was subsequently used to calculate the motor nerve conduction velocity.
1. You will need one volunteer subject from your group. The university did not require ethical consent for volunteering students.

2. Place the two recording electrodes and an earth electrode in the appropriate positions on a subject and connect electrodes to the PowerLab.

3. Start the Chart recording software.

4. Using the microswitch hammer, tap the appropriate tendon of the subject to deliver a stretch stimulus.

5. Stop the Chart recording software.

6. Position the cursor in Chart precisely at the beginning of the recorded compound muscle action potential to accurately measure the delay to the development of the compound muscle action potential.

Seven tutors were selected and trained to teach and assess each skill. All tutors were completing research-based graduate degrees in the biosciences. Tutors were trained during a compulsory orientation for each new laboratory session, typically lasting 1 h. Initially, one of the authors (R. W. Moni) explained 1) the rationale for introducing the testing of manipulative laboratory skills; 2) why these particular five core skills were selected; 3) the responsibilities of tutors to demonstrate the required skills to their students; and 4) how to individually assess and record the skills of each student and monitor their subsequent use during laboratory sessions. Another author (D. H. Hryciw) was the senior tutor for each session. She organized the allocation of tutors to student groups and taught the other tutors how to demonstrate and record each of the skills. Tutors subsequently practiced these skills as part of their training. At the start of each practical, tutors taught each skill to their group of students. The SOP1 and SOP2 required one extra tutor per session.

We designed a form for tutors to record the skill level of each student. Three levels of skill attainment were defined: not proficient, toward proficiency, and proficient. Not proficient was recorded for students who could not complete the target skill or required considerable intervention by the assessor regarding accuracy, precision, independence, and/or speed or who acted in an unsafe manner. This descriptor affirms that these students could still demonstrate some elements of a skill, e.g., holding the micropipette in the recommended manner. Toward proficiency was recorded for students who could complete the target skill but only with intervention from the assessor regarding accuracy, precision, independence, and/or speed. Proficient was recorded for those students who could complete the target skill with the appropriate accuracy, preci-
sion, independence, and speed. Finally, because each skill was considered to be essential, students had the whole 3-h period of the practical session to demonstrate skill proficiency while also completing the other requirements of the laboratory. If students at first demonstrated a standard of not proficient or toward proficiency for a skill, they were give immediate feedback and further guidance as required. This teaching response to student learning needs was deemed “revision” (R), with each subsequent reattempt coded ordinarily as R1, R2, etc. Only if a student was proficient by the end of the session were they awarded 1% of the course. For research purposes, tutors recorded how many attempts students took to develop proficiency in each skill.

Each practical was allocated either seven tutors (Cell Membrane and Osmosis) or six tutors (for the remaining classes) with 60–73 students/class. The additional tutor for Cell Membrane and Osmosis was to assess the core competencies: basic use of micropipettes and using micropipettes to prepare diluted solutions.

RESULTS

Findings are summarized in Fig. 1.

All students mastered all of the five core skills. The rate of development of competency depended on both the skill and degree program in which students were enrolled. For the demonstration of the use of digital technology (i.e., measuring the delay between a stimulus and a response using PowerLab for later calculation of motor nerve conduction velocities), all students demonstrated competency on their first attempt. Therefore, graphs are not shown in Fig. 1. Depending on the degree program in which students were enrolled, students demonstrating proficient core laboratory skills on their first attempt varied by 77–90% for correct use of a micropipette, 62–83% for preparation of dilutions using a micropipette, 57–95% for correct construction of a standard curve, 75–93% for correct use of a light microscope, and 96–100% for proficient use of digital data. Thus, the most challenging skills for these first-year students were the preparation of dilutions using a micropipette and correctly constructing a standard curve.

The percentage of students who achieved toward proficiency (and therefore required revision after their attempts) differed across the degree program in which students were enrolled. Across all five core laboratory skills, Pharmacy students required a total of 95 reattempts to reach proficiency compared with Human Movements Studies students, which requiring 210 reattempts. Thus, students enrolled in Pharmacy generally developed laboratory skills faster. Very few students (0–7%) from any degree program required a second or third attempt for any of the five core laboratory skills.

DISCUSSION

Laboratory work can serve many educational purposes but is perhaps often best suited for the development of manipulative skills that require practice and feedback (7). We were able to train graduate tutors to teach and then individually assess core laboratory manipulative skills in a large, first-year class. Few extra tutors were required, with only one extra tutor for the skills that used a micropipette. This was possibly because most of the first-year students were unfamiliar with micropipettes. In contrast, many students would have constructed graphs, used light microscopes, and used computer software at high school.

Nevertheless, all students were able to rapidly achieve competency across core laboratory skills integrated in the context of use. That most students demonstrated competency for laboratory skills on their second attempt probably reflected the appropriate and timely feedback given by tutors.

Our results emphasize that teaching laboratory skills needs to consider both the skill and degree program in which students are enrolled. Making correct dilutions using a micropipette and correctly constructing a standard curve were the most challenging laboratory skills. This may reflect the challenge of learning quantitative skills in biology, a topic that has received recent attention from the National Academy of Sciences (10a). In general, Pharmacy students developed proficient laboratory skills faster than students enrolled in Human Movement Studies. The explanation for this difference was not evident, but, in subsequent years, more practical time may be required to teach the latter.

Finally, we used the same strategy in semester 2 of 2006 to train and assess 854 Science students to be proficient in these same core laboratory skills. We therefore argue that the assessment strategy is both scalable and transferrable to other courses across undergraduate physiology classes. It is encouraging that the 2007 Course Coordinator of second-year Physiology has reported that the students have better developed laboratory skills than in previous years. We are currently exploring how more complex laboratory skills might be progressively taught and assessed across the Bachelor of Science degree program. Clearly, the results reported here do not demonstrate long-term retention of skills. This would be an important extension of this study despite the challenging logistics afforded by large classes. The issue of whether students retain these core laboratory skills at the end of the course could be addressed by implementing a test/retest procedure. We are working toward this goal.

REFERENCES