Adv Physiol Educ 47: 652–656, 2023.
First published July 6, 2023; doi:10.1152/advan.00047.2023

american physiological society

ADVANCES IN PHYSIOLOGY EDUCATION

ILLUMINATIONS

Interactive classroom: from motoneuron activity to skeletal muscle contraction and relaxation

Luca Todini and Laura Menchetti

Veterinary Physiology, School of Biosciences and Veterinary Medicine, University of Camerino, Matelica, Macerata (MC), Italy

Abstract

Active learning and practices are strongly encouraged or made mandatory by local, national, and European organizations. Therefore, we set up an interactive practical classroom, engaging all of the attending students of the year ($n = 47$). Each student was assigned a physiological role (marked on a cardboard sign) in the following events: stimulation on motoneuron dendrites, sodium ions (Na^+) influx and potassium ions (K^+) efflux, action potentials onset and saltatory conduction along the axon, acetylcholine (ACh) neurotransmitter exocytosis following Ca^{2+} influx, ACh binding to postsynaptic membrane receptors, ACh-esterase action, excitatory postsynaptic potential, release of Ca^{2+} from the sarcoplasmic reticulum, mechanism of muscular contraction and relaxation, and rigor mortis. A sketch was drawn with colored chalks on the ground outside the room: the motoneuron with its dendrites, cell body, initial segment, myelinated axon, and synaptic bouton; the postsynaptic plasma membrane of the muscle fiber; and the sarcoplasmic reticulum. Students each had their own role and were asked to position themselves and move, accordingly. This resulted in a complete, dynamic, and fluid representation being performed. The evaluation of the effectiveness of the students' learning was limited at this pilot stage. However, positive feedback was received in the self-evaluation reports that were written by students on the physiological meaning of their own role, as well as in the satisfaction questionnaires requested by the University. The rate of students who successfully passed the written exam and the rate of correct answers that included the specific topics addressed in this practice were reported.

NEW & NOTEWORTHY We set up an interactive practical classroom, engaging all the attending students of the year ($n = 47$). Each student was assigned a physiological role marked on a cardboard sign, starting from motoneuron stimulation up to skeletal muscle contraction and relaxation. Students were asked to actively reproduce physiological events, positioning themselves and moving around and onto drawings on the ground (motoneuron, synapsis, sarcoplasmic reticulum, etc.). Finally, a complete, dynamic, and fluid representation was performed.

active learning; electrophysiology; motoneuron; skeletal muscle; synapse

INTRODUCTION

The European System of Evaluation of Veterinary Training (ESEVT) standards strongly encourage practice and active learning, so that "the number of hours of practical (non-clinical) training" is the ESEVT indicator "I4" (1). The internal regulation of the degree course in veterinary medicine of the University of Camerino (Italy) outlines that 20% of the hours in physiology teaching courses should be dedicated to practical activity. Many activities, such as laboratory practice, require setting up numerous small groups of students, which can result in an excessive workload for teachers. Shortages of staff and resources can limit the implementation of interactive sessions, and practices that involve large groups of students should be considered, as long as an acceptable level of teaching effectiveness is maintained throughout. It should be underlined that the effectiveness of active learning in improving student performance is widely recognized (2, 3). When students engage in both mental and physical activities, they are obliged to reflect on ideas and how they are using those ideas, to think about the real action mechanism of the process, and to then put it into practice. This improves the memorizing process and subsequently leads to long-lasting, meaningful learning (2, 3). Traditional passively observed classroom demonstrations have no significant effect on the improvement of students' understanding and learning, while active student engagement has been proven to be very effective (4). A more interactive and collaborative course format provides higher learning gains and better conceptual understanding (5). Active student participation in the lesson and more direct interactions with teachers could also help break down the barriers that come between them (6). Moreover, as a result of the years of pandemic and lockdowns, during which practical didactic activities were suspended, the desire and need of the students to socialize were easily perceived. Socialization can focus on the organization and specific tasks or roles in groups: socialization-related learning is the learning associated with becoming a functioning member of a culture (7).

Correspondence: L. Todini (luca.todini@unicam.it).
Submitted 22 March 2023 / Revised 30 May 2023 / Accepted 28 June 2023

Thus the aim of the work outlined in this report was to set up an interactive practical classroom, at no extra cost, which would engage a large group of students and would address the learning goals of the physiology course that are traditionally considered to be complex and that cause difficulty in understanding (8). We developed an interactive classroom, inspired by Meeking and Hoehn (9). In that very effective illumination article, the mechanism of skeletal muscle contraction was actively represented by students which mimicked troponin-tropomyosin interaction, functions of calcium, and cross bridges. In the same year 2002, Goodman and Waller (10) reported that the instructor finely demonstrated propagation of action potentials in myelinated versus unmyelinated neurons, by leaping or walking, respectively. The use of common objects (a fluorescent stretchy ball sold as a "Halloween wig," a pipe insulation, and a garden hose, as demonstrated in "garage demos") has been reported to illustrate fundamental processes of cell biology, such as dynamic features of exocytosis (6). We thought to extend those representations, starting upstream from motoneuron stimulation. The following steps were represented: stimulation on motoneuron dendrites, sodium ions (Na^+) influx and potassium ions (K^+) efflux, action potentials onset and saltatory conduction along the axon, acetylcholine (ACh) neurotransmitter exocytosis following Ca^{2+} influx, ACh binding to postsynaptic membrane receptors, ACh-esterase action, excitatory postsynaptic potential, release of Ca^{2+} from the sarcoplasmic reticulum, mechanism of muscular contraction [the latter as described by Meeking and Hoehn (9)] and relaxation, and rigor mortis.

METHODS

A sketch was painted with colored chalks on the ground outside the room: the motoneuron with its dendrites, cell body, initial segment, myelinated axon, and synaptic bouton; the postsynaptic plasma membrane of the muscle fiber; and the sarcoplasmic reticulum (Fig. 1). All attending students from the lessons during the year were involved in a single session (Fig. 2*A*), which lasted ~2 h.

Each student randomly received one of the roles listed in Fig. 3 (as shown in Fig.2*A*), marked on a cardboard sign. The topics had been previously approached during the traditional classroom lectures, as it is essential to cover the related subjects and concepts before doing the practical activity. Students were not aware in advance of the format of the activity. At first, when they received the roles, they were each asked to position themselves and move to the drawing painted on the ground accordingly, relying on their knowledge, without any further guidance. Therefore, this first part of the activity also functioned as an ongoing assessment of students' learning. Afterward, following verbal directions by the instructors and discussing each step, students took care of perfecting and coordinating positions and movements sequentially, until a complete, dynamic, and fluid representation was performed (Fig. 2, *B–D*).

In the following days, students were asked to produce a brief written report on the physiological meaning of their own role. The reports were written by groups of students who had the same role (n = 2–4/group). The reports were ungraded, since the aim was to use the exercise as a self-

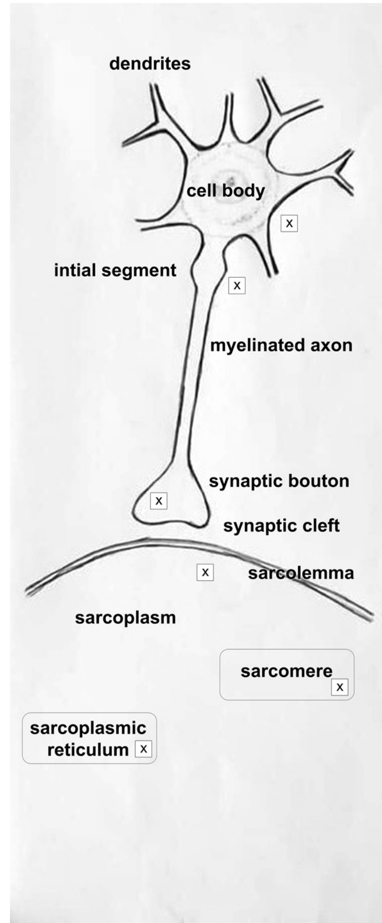


Figure 1. The sketch was painted on the ground with colored chalk. X marks the dimensions of a student relative to the size of the diagram drawn on the ground to show relative scale.

evaluation tool and to deepen the study of the physiological roles interpreted. The report included a space where comments could be added and the comments section was optional for all students, except the two who were photographers/video operators and coordinators. For these students, it was mandatory to complete the comments section, instead of referring to the physiological role of a particular subject.

RESULTS

The feedback signals on teaching/learning effectiveness were taken from empirical tools (not systematic indicators). The outcomes that could be reported after this first implementation, i.e., qualitative and descriptive indicators, are listed below.

1) During and soon after the session, the students verbally commented on the experience stating that they were surprised to "learn a lot whilst having a lot of fun."
2) Among the reports by students who received a physiological role (n = 45), only one group (4 students) provided optional comments; in particular reported the following sentence: "We really appreciated this exercise, since these alternative methods allow a clear visual and concrete idea of what had been taught in lectures." The

Figure 2. Frames from the execution of the practice. *A*: students attending the classroom. *B*: saltatory conduction along the axon. *C*: ACh binding to its postsynaptic receptors, Na^+-channel opening, Na^+ entry into the sarcoplasm. *D*: Each ATP-ase transports two Ca ions into the sarcoplasmic reticulum.

two students for whom the comments were mandatory, answered: 'Watching the entire exercise from the outside allowed for a better understanding of the topic in a much more direct way. Practical activities like this provide the opportunity to learn in a more dynamic and enjoyable way, in comparison to the more traditional learning methods in the classroom. The active "doing" is the best way to learn.'

3) The Quality Assessment policy in our University requires the students, at the end of each semester, to fill in a (rather detailed) questionnaire for each discipline and each teacher. More specifically, when asked the question "are supplementary teaching activities (exercises, tutoring, laboratories, etc…) useful to the subject learning?" The present practice received an average score of 3.27 (on a 1–4 scale, $n = 44$).

4) After the end of the classroom cycle (1st semester of the 2nd year), the attending students can take the first exam (written) of "Veterinary Physiology 1." On the earliest two dates (about one week and one month after the end of the classroom cycle), 38 students took the exam, and, among them, 31 passed the exam successfully (82% of the 38 candidates, 66% of the 47 students attending the class).

5) Regarding the topics addressed by the present practice, the related questions of the exams were 7 or 5 (in the first and the second exam session, respectively), out of the 60 questions on the entire teaching course, which formed each exam. In the overall exams of all the candidates, there were 240 questions related to the present practice, and 206 (86%) of the answers were correct.

Unfortunately, comparisons with previous years of the scores reported in *outcome 5* are not feasible and for those in *outcome 4* are not very reliable: in fact, besides the pandemic, in the current year, one of the two physiology teachers has changed, and moreover, the exam modality has changed from an oral to written exam. However, in the previous year, of 41 students attending the classroom cycle, 16 (39%) successfully passed the exam (oral) in the first two sessions (within about 1 mo after the end of the classroom cycle).

DISCUSSION

The main advantage of the current activity is being able to have the right perception of the overall chronological and causal sequence of events. It comes at no extra cost for the faculty and the long-lasting and meaningful learning of the neurophysiology could benefit the understanding of the subsequent subjects of the veterinary medicine course. Moreover, such practices provide opportunities to increase student-teacher interactions,

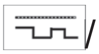
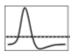
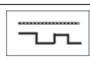
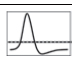
REPRESENTATION OF ROLE MARKED ON THE CARDBOARD SIGN (FRONT/BACK)	ROLE	N of marks/students
Na^+	Sodium enters and depolarizes the motoneuron membrane	2
K^+	Potassium efflux and repolarization of motoneuron membrane	2
 / 	Resting/action membrane potential (with threshold indicated) of the motoneuron	2
Ca^{++}	Calcium enters in the synaptic terminal, unbinds the synaptic vesicles	3
(Ach) / **Ach**	Acetylcholine inside the synaptic vesicles / free in the synaptic cleft	4
Synapsin	As representative of the protein complex regulating vesicles' arrangement and exocytosis	4
AchR	Ach postsynaptic receptors	4
AchE	Acetylcholinesterase	2
Na^+	Na^+ enters through the sarcoplasm channels and induces Excitatory Post Synaptic Potential	2
K^+	Repolarization of postsynaptic membrane	2
 / 	Resting/action membrane potential (with threshold indicated) of the sarcoplasm	2
Calsequestrin	Binding Ca^{++} inside the sarcoplasmic reticulum	2
Apple*§	Actin. The student's head was the Troponin C. The students forearms formed tropomyosin	4
Banana*§	Myosin cross-bridges	4
ATP / ADP + P§	Held by the same students with bananas (actin)	(4)
Ca^{++}	From the sarcoplasmic reticulum to the troponin	4
ATP transport Ca^{++}	ATP-ase transports Ca^{++} inside the sarcoplasmic reticulum	2

Figure 3. Marks assigned and physiological roles performed by students. The number of students for each role was set for a class of 45 students. *Held by each student instead of a cardboard sign. §Following Meeking and Hoehn (9).

in a positive learning environment. Indeed, the outcomes evaluated seem to indicate the effectiveness of the method, although, at this pilot stage, the reliability of the feedback can only be partial and repetitions are needed in the future.

Some limitations can already be identified. One flaw could be the simplification, with the unavoidable risk of superficiality. For example, the actual quote of ions moving across the membrane in comparison with the total ones was not precisely perceived, as well as the differentiation between ligand-gated or chemically gated ion channels. Moreover, the number of students who could simultaneously engage in the activity can be limited by the space available and the number of teachers who should direct and eventually correct the actions of each participant.

A potential improvement could include the increase of space available and the number of participants so that more subjects could be added to the representation, such as Na^+/K^+ pumps, ionic channels opening and closing, proteins forming the SNARE complex, etc. Finally, the activity could be further developed with the representation of defects in the process involved in diseases, including the roles of toxins at various points or sites of drug action.

DATA AVAILABILITY

Data will be made available upon reasonable request.

ACKNOWLEDGMENTS

The authors thank the 47 students attending the second year of the Degree Course in Veterinary Medicine of Camerino University, academic year 2022–2023, who actively and nicely carried out the practice described in this paper. Dr. Lauren Purkiss is gratefully acknowledged for the revision of the English language. Many thanks to Dr. Flavio Todini and Dr. Anna Russo for preparing the figures. The authors also thank two anonymous reviewers, whose skilled suggestions and comments substantially improved the paper.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

L.T. and L.M. conceived and designed research; L.T. and L.M. performed experiments; L.T. and L.M. analyzed data; L.T. and L.M. interpreted results of experiments; L.T. drafted manuscript; L.T. and L.M. edited and revised manuscript; L.T. and L.M. approved final version of manuscript.

REFERENCES

1. **ESEVT (European System of Evaluation of Veterinary Training).** Manual of Standard Operating Procedure. 2019, p. 36 (amended Dec 2020 and Sep 2021). https://www.eaeve.org/fileadmin/downloads/SOP/ESEVT_SOP_2019_As_amended_in_September_2021.pdf.
2. **Michael J.** Where's the evidence that active learning works? *Adv Physiol Educ* 30: 159–167, 2006. doi:10.1152/advan.00053.2006.
3. **Freeman S**, **Eddy SL**, **McDonough M**, **Smith MK**, **Okoroafor N**, **Jordt H**, **Wenderoth MP.** Active learning increases student performance in science, engineering, and mathematics. *Proc Natl Acad Sci U S A* 111: 8410–8415, 2014. doi:10.1073/pnas.1319030111.
4. **Crouch CH**, **Fagen AP**, **Callan JP**, **Mazur E.** Classroom demonstrations: learning tools or entertainment? *Am J Phys* 72: 835–838, 2004. doi:10.1119/1.1707018.
5. **Knight JK**, **Wood WB.** Teaching more by lecturing less. *Cell Biol Educ* 4: 298–310, 2005. doi:10.1187/05-06-0082.
6. **O'Dowd DK**, **Aguilar-Roca N.** Garage demos: using physical models to illustrate dynamic aspects of microscopic biological processes. *CBE Life Sci Educ* 8: 118–122, 2009. doi:10.1187/cbe.09-01-0001.
7. **Reio TG.** Socialization-related learning. In: *Encyclopedia of the Sciences of Learning*, edited by Seel NM. Springer: Boston, MA, 2012. doi:10.1007/978-1-4419-1428-6_333.
8. **Slominski T**, **Grindberg S**, **Momsen J.** Physiology is hard: a replication study of students' perceived learning difficulties. *Adv Physiol Educ* 43: 121–127, 2019. doi:10.1152/advan.00040.2018.
9. **Meeking J**, **Hoehn K.** Interactive classroom demonstration of skeletal muscle contraction. *Adv Physiol Educ* 26: 344–345, 2002. doi:10.1152/advances.2002.26.4.344.
10. **Goodman BE**, **Waller SB.** Propagation of action potentials in myelinated vs. unmyelinated neurons. *Adv Physiol Educ* 26: 223–223, 2002. doi:10.1152/advan.00023.2002.