Hands-on laboratory experience in teaching-learning physiology

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AFTER RETIRING from full-time teaching and research, we established residence on Taylor University's (1,600-1,700 students) campus. I (W. C. Randall) continue my research and assist in selected portions of the laboratory courses in anatomy and physiology. I have the opportunity to discuss the role of research in undergraduate education and how it contributes to preparation and background for medicine and for professional careers in the biomedical sciences. From my continuing grant support, I can hire one or two science majors to assist in my ongoing research program. Several of these students have enthusiastically and expertly presented their data before local, state, and/or national scientific meetings.

HANDS-ON LAB EXPERIENCE IN UNDERGRADUATE PHYSIOLOGY

Utilizing conventional didactic lectures, a physiograph, and excellent tapes available from commercial sources, the courses in physiology and anatomy were largely preparatory for premed students, and the laboratories were largely demonstrations with relatively little actual hands-on experience for the student. An excellent comprehensive textbook was ably supplemented by the instructor's daily lectures and physiograph demos, but the student's learning was almost entirely visual with memorization of functional concepts. Thus, from these initial impressions, it would appear that the first-year medical student from this institution (and presumably many others) will have been exposed to much of organ-systems physiology but with relatively little actual hands-on experience by the time he/she arrives in medical school. However, as a very recent participant in that med school teaching force, I know that whether or not that is true, he/she has, in fact, mastered little of it.

Before I left Loyola a couple of years ago, physiology laboratory teaching there was upgraded by conversion from the original model 5 Grass polygraphs to solid-state, model 7 Grass recorders. Each table of four to five students thus had opportunity, and obligation, to participate in each lab assignment. The medical students at Loyola enjoy an exceptionally low student-teacher ratio in the laboratory (1 instructor/table of 4-5 students) and can hardly fail to learn through the intimate interactions between excellent instrumentation, an animal model of the experiment, and interested, competing student peers, all under the thoughtful guidance of an experienced and committed teacher. Over the years, I was personally dedicated to, and actively involved in, this teaching effort and clearly saw positive results from the combined faculty-administration-student commitment to laboratory teaching and learning.

With the advent of the model 7 Grass polygraph in the student labs at Loyola, the original model 5 units (5) became expendable. With encouragement from the Physiology Chairman and faculty, eight of the units were trucked to the undergrad Biology Department at Taylor University. Our thought was that at least four or five of the old tube instruments could be restored to working condition and the remainder could be cannibalized for parts as necessary, (Dr. Grass assures me, however, that he still has replacement parts for many, perhaps most, of those used in the original model 5 polygraph). We now have a model 5 recorder for each table of four students in the undergraduate physiology course, and we have experienced anew the thrill of discovery that each student senses when he/she uncovers, with his/her own mind and hands, an important and demonstrable laboratory phenomenon. I remember Dr. Wiggers' admonition to his medical students, to "go ahead and experiment in the laboratory. True, what you see may have already been described in the literature, but it's new to you now. Enjoy the rewarding sense of discovery." An observant
instructor will also recall his initial learning experiences in the laboratory and actively reinforce such student’s “first-time” occurrences.

It was an exciting experiment for the college student to actually see and palpate a normally beating turtle heart and to record both the electrical and mechanical responses to carefully controlled perturbations. I clearly recall the early pilot experiences of our Loyola medical students when they first recorded the identical events from the exposed turtle’s heart back in 1956, actually with the same instruments. They brought their records to their instructors, puzzled because “they didn’t look like the illustrations in the textbook or those obtained by their neighbors who were still using smoked kymographs.” What pleasure it was to exult with them and to assure them that this was because their records were better than those in the textbook. We had no problem holding the student’s interest and excitement for learning under such circumstances. Neither was it a problem to encourage faculty to exploit this new tool to implement new and better experiments. Our major problem was in explaining to other department faculty why their students “stole time” from their courses to get back to physiology, “where the action was.” Retrospectively, I see a lesson for modern physiology laboratory teaching. "There must be mutual stimulation and excitement communicated between faculty member and student in the teaching laboratory process. And there must be a positive sense of “teaching and learning something worthwhile” for the time, money, and effort invested.

Most physiologists will agree that the classic turtle heart experiment offers as much insight to cardiovascular physiology, and to intimate understanding of cardiology, as any comparable 3- to 4-h commitment by students and faculty. Yet, the experiment requires close interaction between teacher and learner, and the former encounters perhaps the best opportunity of his professional career to implant solid fundamental information, as well as real excitement for learning. It is an experiment that works, and in a rugged, living preparation that does not defy comprehension by the neophyte. It is an experiment that combines theory and personal realization that if one can unravel its complexities in dysfunction, one can unravel its complexities in dysfunction.

I often told my freshman medical students (at the very beginning of their medical training) that if they thoroughly understood the turtle heart experiment, they were well along toward becoming accomplished cardiologists. Coming during the busiest, and often most frustrating, portion of their freshman year in med school, this invariably stood as an exhilarating reward for their hard work. In this setting, the student can successfully tie together theory and function; if he/she understands part I (theory of excitation and conduction), part II (failure to excite during refractory period but with a premature beat when stimulated during diastole) becomes reasonable and predictable. The straightforward logic of the protocol, an actual record of functional events in the living physiological system on the polygram add up to exciting and rewarding comprehension. Impact and retention derived from laboratory experiments that really work for the student are vastly different from those derived by rote memorization of lecture and/or textbook material. While we do not have objectively comparative data, examination performance over experiments (such as the turtle heart) carried out by the students themselves, with direct and accurate measurements from the polygraph, clearly revealed superior comprehension of the functional principles involved. Even more importantly, they reflected demonstrably greater enthusiasm for actively seeking a thorough understanding of the concepts.

We are seeing comparable awakening on the part of undergraduate students who are being introduced, for the first time, to a meaningful and highly personal hands-on experience, in a living physiological learning process (the beating turtle heart preparation, for example). They appreciate that learning need not be by pure memorization; that thought, touch, and feel actually do reinforce observation and memory. They appreciate, for perhaps the first time, the hands on philosophy of teaching, and they like it. They are thrilled to prove for themselves that the heart is absolutely refractory during systole. They can add time intervals to see what compensatory pause actually means. They often detect imperfections in or deviations from this additive process and begin to appreciate some of the fascinating byways in pursuing cardiac dysrhythmias. Such convincing “facts” about the heart come as a surge of excitement to the beginning student and often initiate the conviction that cardiology is the most exciting of all tracts in medicine; is it any wonder this becomes a favored specialty at this stage in training? An aside may be pertinent here. Two or three students who vigorously and vocally objected to using a “live animal” to learn something already described in their textbook were gently excused from actively participating in the experiment. However, they were invited and encouraged to remain and observe the procedures and results; an experienced instructor quietly and confidently explained why he believed animal experimentation was essential to learning biology and especially medicine and why it was inescapable in the pursuit of new knowledge of disease processes. By the end of the 4-h laboratory, they were actively involved and, indeed, excited with their learning experience. The course includes seven animal experiments, six using the polygraph to record physiological mechanisms demonstrating integrated interactions between different organ systems. To initially acquaint the student with the polygraph, each student recorded his own electrocardiogram (3 standard limb leads). Another experiment was dedicated to respiratory volumes, their quantitation and functional adaptations. A third procedure involved the exercise experiment described below. An adrenalectomy was performed under anesthesia, with 6- to 10-wk follow-up for quantitative observations on fluid and ion intakes. A closed-chest cardiovascular experiment was done in an anesthetized rabbit, the open plastron turtle heart experiment (pithed brain), and recording of skeletal muscle contractions plus sciatic nerve potentials in the pithed frog preparation. By the end of the course, there were no troubled “animal activists” to the knowledge of the instructor.

Success in this lab teaching effort is testimony to the value of personal participation in functional experiments.
in physiology. The first Grass instruments (model 5 polygraphs) introduced in our teaching program at Loyola more than 35 years ago, involved rewarding interactions with Albert and Ellen Grass and remain as a high point in the academic maturation of our Department during that period. Those first units are still in service, now functioning here in this undergraduate setting. They continue to implement learning at the work bench, where, in our opinion, physiology (medicine) must be learned. They simultaneously impress the student with the practicality of many lessons learned in physics, and, as the student becomes increasingly proficient in the lab, he/she realizes the truth of the adage that in physiology understanding and appreciation of chemistry, physics, math, and biology are all important. All of these disciplines must be integrated into their future lives as scientists. Thus far, we have managed to scrounge tubes and choppers, cables, and transducers sufficient to put together a stimulating course in animal physiology. Incidentally, we have employed the inexpensive, "disposable" Cobe pressure transducer (Cobe Laboratories, Lakewood, CO 80215) very successfully in these student lab exercises; when coupled to a small, membrane-covered capsule, such a capsule is easily converted to an inexpensive force transducer (as utilized in our turtle atrial and ventricular contractile force measurements). Our new problem is that the available laboratory space is inadequate to meet the needs of progressively increasing numbers of students who wish to enroll in the course.

A related problem involves a growing interest among students for a personal experience in research. They love to see things happen; they want to be a part of the action. Thus we set up an exercise experiment for the student laboratory, selecting well-trained athletes (male and female) as subjects. Each was seated on a stationary bicycle and instrumented for the recording of the electrocardiogram, psychogalvanic reflex, pneumogram, and temperature on the polygraph. Room temperature and humidity were systemically tabulated throughout the experiment. In addition, ausculatatory blood pressure and sweat counts (from 6 different bodily surfaces) were recorded throughout the experiment (carefully partitioned into control, experimental, and recovery periods, see Fig. 1). The sweat records were made by holding starch-sized papers over iodine-painted segments of the body (foot, calf, thigh, abdomen, arm, face) for 15-s exposures at the beginning of each successive minute. Each active sweat pore was identified as a minute, blue-black spot where water (sweat), iodine (on the skin), and starch (in the paper) combined (3-4). Room temperature was maintained at essentially nonsweating ambient temperature and humidity.

As the experiment evolved, we called attention to the particular recruitment patterns of separate sweating responses (rostrally, starting from the foot in all three subjects), as has been shown previously during exposure to a warm environment (6). We also noted that such experiments had not (to our knowledge) been reported during exercise. Attention was called to variations in individual subject responses during the control period, one sweating slightly on the palms, another on the forehead, early in the experiment. Interactions between thermoregulatory and psychic sweating, the cholinergic and possible adrenergic neurotransmitter mechanisms involved, and the roles of central and cutaneous body temperature control mechanisms were briefly reviewed. These insights, plus the possible research potential, provided added incentives and contributed substantially to interest in the experiment. The obvious recruitment patterns, beginning caudally (dorsum foot) with progressive recruitment rostrally during exercise, essentially duplicated that previously observed during exposure to a warm environment (3, 4). Note also that only the foot and forehead showed minimal sweating during the control period and that sweating did not simultaneously appear on all skin surfaces at onset of exercise. Note also that moderate sweating sequentially appeared on body surfaces as exercise progressed. While individual variations in recruitment were evident, an overall pattern of caudal-to-rostral recruitment became apparent. The question of how the nervous system mediates such differential responses effectively focused attention on the role of careful and accurate observation in laboratory physiology. It also illustrated the fact that many tangible questions of systems response remain unanswered in laboratory physiology.

An important aspect of student laboratory teaching is that task assignments were made such that all students were actively involved in the performance of the experiment (all sweat counts, blood pressure, heart and respiratory rates, etc., being numerically recorded at 1-min intervals), and data were tabulated so that a chart could be constructed to interrelate (integrate) all of the physiological events (Fig. 1) in a subsequent discussion ses-
sion. While all of the students were at least casually acquainted with the physical exercise involved, none had observed or participated in the combined physiological responses and all demonstrated alert and animated interest in the goals, collection of data, and especially in the interpretation session that followed. The students not only saw the performance of the experiment but they were an active part of it. They participated in it both physically and intellectually. They experienced a “controlled” experiment and understood the specific importance of each portion of it (control-experimental-recovery). Didactic lectures and study of the primary systems (circulation, respiration, temperature, nervous system, etc.) had previously covered the fundamental regulatory mechanisms observed in the experiment, which now served as a superb integrating exercise. Every member of the class was deeply engrossed in his/her own specific assigned task as well as in subsequent integrative discussion sessions that brought all of the observations and data together. The experience vividly illustrates the requirement that “students should be active, independent learners and problem solvers rather than passive recipients of information” (1).

Thus we remain unwilling to concede that laboratory teaching is outdated or unimportant in the process of preparation and learning by either undergraduate or graduate (medical) students. Some educational objectives can only be achieved through first-hand experience with live preparations (2). Students find organ system physiology as challenging as ever, and real, hands-on laboratory experiences remain the most effective learning tools in the early educational process. We believe such experience is especially important to the young physician preparing to interview, examine, diagnose, and treat his patients. However, laboratory teaching (and learning) is hard work. Both student and teacher must be deeply and personally involved; they have to be convinced it is worth while. A casual, superficial, or disinterested approach by personally involved; they have to be convinced it is worth while. A casual, superficial, or disinterested approach by

SUMMARY OF SOME FUNDAMENTAL PRINCIPLES OF EFFECTIVE LABORATORY TEACHING

Reactivation of a group of Grass model 5 polygraphs permitted personal, student hands-on performance of experiments in an undergraduate physiology laboratory setting. The change from conventional, demonstration film strip presentations to actual student performance of the experiments resulted in rejuvenation of interest and excitement for learning of physiology, with emergence of a concept of discovery in the student laboratory. Key elements in effective laboratory teaching are 1) sufficient number of experienced, well-trained, committed teachers; 2) the use of sound instrumentation; and 3) well-designed, meaningful experimental protocols. The student must be appropriately prepared and motivated to learn in a student-teacher ratio permitting reasonable one-on-one communication. Carefully selected animal experiments, designed so that the student learns important lessons as the fruit of his/her own physical and intellectual input, contribute to the maximum impact and excellent retention of important physiological principles. The incorporation of a research aspect into student lab experiments adds interest and incentive. The emphasis on personal applications and implications (personal electrocardiogram, blood pressure, incidence and meaning of cardiac dysrhythmias, respiratory volumes, etc.) always provides real “take-home” bonuses. When the student and the teacher leave the laboratory each day, both should be tired but intellectually gratified that the time and effort were well spent.

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