The evolving role of animal laboratories in physiology instruction

Alice W. Ra’ananan
American Physiological Society, Bethesda, Maryland

Submitted 16 March 2005; accepted in final form 30 May 2005

Ra’ananan, Alice W. The evolving role of animal laboratories in physiology instruction. Adv Physiol Educ 29: 144–150, 2005; doi: 10.1152/advan.00017.2005.—Laboratory exercises are intended to illustrate concepts and add an active learning component to courses. Since the 1980s, there has been a decline in animal laboratories offered in conjunction with medical physiology courses. The most important single reason for this is cost, but other contributing factors include the development of computer simulations, changes in medical education, and pressure from antivivisectionists. Unfortunately, the elimination of animal laboratories has occurred with relatively little consideration of the educational impact of this change. Although computer simulations are considered effective in helping students acquire basic physiological concepts, there is evidence some students acquire a more thorough understanding of the material through the more advanced and challenging experience of an animal laboratory. The fact that such laboratories offer distinct educational advantages should be taken into account when courses are designed.

A DOWNWARD TREND

A steady decline in the use of animal laboratories in medical training has been documented since the early 1980s. Trends in the use of animal laboratories in medical physiology courses between 1983 and 2001 are summarized in Table 1.

In 1982, the Association of Chairs of Departments of Physiology (ACDP) surveyed its members about how they taught physiology courses. Rothe (23) reported these results along with data from similar studies undertaken in 1969 and 1973. A total of 139 department chairs was polled in the 1982 survey, with 107 department chairs (77%) responding. Rothe compared these data with the earlier surveys, with the caution that the response rate to the 1973 survey was only 38%.

Although the physiology chairs were “not unanimous in their opinions or approaches,” Rothe noted that it was “clear that the use of classical, animal-lab experiments is waning.” Rothe found that “[c]lassical, student laboratory experiences were used by only 64% of the 107 departments responding—a marked decrease from 90% reported in the earlier surveys.” Because the data tables were presented as an aggregate of all laboratories, there is some ambiguity about whether this refers to animal laboratories alone or whether it might also include other kinds of “classical” experiments in which the students themselves were subjects. In any case, Rothe (23) reported that there was a clear trend away from physiology laboratories of all kinds.

During the period from 1973 to 1982, 64 departments (60% of respondents) had “decreased the emphasis on laboratory experiences for their medical students,” whereas only 11 department (10% of respondents) had increased such experiences. Between 1969 and 1982, the average amount of time available for lectures increased from an average of 85 h in 1969 to an average of 105 h in 1982, but the number of nonlecture hours decreased from 113 h in 1969 to 68 h in 1982. Most departments were replacing laboratories with problem sets, videos, or slide-tape packages. Eleven departments (10%) reported that students were using computer-assisted instruction, although 23 departments (21%) reported making computer simulations or computer-assisted instruction materials available. Rothe (23), who was already experimenting with computer simulations as an instructional tool, noted that computers were “not yet widely used” at the time of the survey. The Association of American Medical Schools (AAMC) undertook a comprehensive survey of the use of animals in medical education around 1990 (13). At that time, 92 of 126 medical schools offered live animal laboratories as a regular part of the medical curriculum. Data from partial surveys both before and after the 1990 AAMC survey confirmed this trend (1, 19).
Table 1. Animal laboratories in medical physiology (1983–2001)

<table>
<thead>
<tr>
<th>Source</th>
<th>Sample Size</th>
<th>Number of Schools</th>
<th>Courses With Animal Laboratories</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983–1984 AAMC survey</td>
<td>16 Selected medical schools</td>
<td>10</td>
<td>63</td>
</tr>
<tr>
<td>1984 ACDP survey</td>
<td>88 Departments of physiology</td>
<td>66</td>
<td>75</td>
</tr>
<tr>
<td>1987 PCRM/AMSA survey</td>
<td>93 Departments of physiology</td>
<td>49</td>
<td>53</td>
</tr>
<tr>
<td>1994 AAMC survey</td>
<td>125 Medical schools</td>
<td>49</td>
<td>39</td>
</tr>
<tr>
<td>2001 Hansen and Boss survey</td>
<td>121 Departments of physiology</td>
<td>22</td>
<td>18</td>
</tr>
</tbody>
</table>

\( n \), Number of courses. AAMC, Association of American Medical Colleges; ACDP, Association of Chairs of Departments of Physiology; PCRM, Physicians Committee for Responsible Medicine; AMSA, American Medical Student Association; OTA, Office of Technology Assessment.

Although animal laboratories are heavily associated with the fields of physiology, pharmacology, and surgery, there has always been considerable variability from department to department and from school to school in terms of how animal laboratories are incorporated into the curriculum. Several partial surveys were done that focused only on physiology, pharmacology, and surgery courses, but without comprehensive information it is not possible to determine whether animal laboratories may also have been offered in conjunction with other basic or clinical science courses. Nevertheless, the overall trend is clear: the most recent survey (12) involved only physiology, pharmacology, and surgery courses and found that only 37 of 127 medical schools (29%) offered an animal laboratory in any of these three courses.

UNDERSTANDING THE TREND

1983–1984 AAMC survey/Office of Technology Assessment report. For a 1986 report, the Congressional Office of Technology Assessment (OTA) asked the AAMC to survey its members on their use of animals in medical education (19). The AAMC asked 16 of 127 medical schools to provide animal use data for the 1983–1984 academic year. The sample was selected to achieve a balance between public and private institutions and in geographical location as well as degree of research intensity. Questionnaires were distributed to all departments in the selected schools. However, due to differences in departmental responsibility for the curriculum, the responses were presented by discipline rather than by department.

The OTA report noted that the use of animals in medical training was “common in only a few disciplines, although all 16 institutions used animals in some discipline.” The disciplines in which animal laboratories were offered most frequently were physiology, surgery, and pharmacology. Only seven schools offered courses in advanced trauma life support, but all seven included an animal laboratory component. (The latter courses were typically offered to house staff rather than medical students.) The report (19) also noted that, although nonanimal alternatives seemed promising, “expectations for computer simulations still outdistance[d] actual performance.”

Table 2 summarizes the 1983–1984 AAMC data.

1984 ACDP survey. The OTA also asked the ACDP to provide data on the use of animals in physiology education. The ACDP circulated a survey to 135 physiology chairs at schools of health sciences and received responses from 76 medical schools, 3 veterinary schools, 2 osteopathic schools, 2 dental schools, and 1 university in the United States as well as 3 Canadian medical schools and 1 medical school from an unspecified country. Although there was only 1 mo available to collect these data, the response rate was 65% (11).

Of the 88 institutions represented in the 1984 ACDP survey, 66 institutions (75%) offered animal laboratories in physiology courses. Fifty-two (59%) of these departments noted that the numbers of animals used in laboratory exercises had decreased during the preceding decade, and six (7%) of these departments reported that animal laboratories had been eliminated during that period. Cost was the factor most frequently cited for these changes, along with faculty attitudes and the availability of acceptable alternative methods. Pressure from students and the public also played a role. Table 3 lists the reasons that ACDP chairs gave for the decline in animal usage.

The survey asked physiology chairs to provide their assessment of the advantages and disadvantages of using alternatives in physiology instruction. The advantages mentioned most frequently were savings in cost and savings in time, whereas the main disadvantages cited were the loss of student experi-

Table 2. Animal laboratories in 16 selected United States medical schools by discipline (AAMC, 1983–1984)

<table>
<thead>
<tr>
<th>Course</th>
<th>Number of Schools With the Discipline</th>
<th>Courses With Animal Laboratories</th>
<th>%Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiology</td>
<td>16</td>
<td>10</td>
<td>63</td>
</tr>
<tr>
<td>Surgery</td>
<td>16</td>
<td>10</td>
<td>63</td>
</tr>
<tr>
<td>Pharmacology</td>
<td>16</td>
<td>8</td>
<td>50</td>
</tr>
<tr>
<td>Neurosurgery</td>
<td>16</td>
<td>5</td>
<td>32</td>
</tr>
<tr>
<td>Microbiology</td>
<td>16</td>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td>Orthopedic surgery</td>
<td>16</td>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td>Biochemistry</td>
<td>16</td>
<td>3</td>
<td>19</td>
</tr>
<tr>
<td>Ophthalmology</td>
<td>16</td>
<td>3</td>
<td>19</td>
</tr>
<tr>
<td>Pediatrics</td>
<td>16</td>
<td>3</td>
<td>19</td>
</tr>
<tr>
<td>Advanced trauma life support</td>
<td>7</td>
<td>7</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: OTA, Alternatives to Animal Use in Research, Testing, and Education. Data are from AAMC. Used with permission.

Table 3. 1984 ACDP Survey of Physiology Chairs: reasons cited for declining animal usage

<table>
<thead>
<tr>
<th>Reason Cited</th>
<th>Number of Mentions</th>
<th>%Citing This Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>43</td>
<td>83</td>
</tr>
<tr>
<td>Faculty attitudes</td>
<td>24</td>
<td>46</td>
</tr>
<tr>
<td>Development of valid alternatives</td>
<td>23</td>
<td>44</td>
</tr>
<tr>
<td>Student pressure</td>
<td>16</td>
<td>31</td>
</tr>
<tr>
<td>Public pressure</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Other</td>
<td>20</td>
<td>38</td>
</tr>
</tbody>
</table>

\( n = 52 \) physiology chairs. Source: adapted from Greenwald (11); American Physiology Society (APS), The Physiologist. Used with permission.
ence of working with live subjects along with further distancing from the ultimate goal, working with human patients. Overall, disadvantages were mentioned more frequently than advantages. Table 4 lists the frequency with which various advantages and disadvantages were mentioned.

1987 Physicians Committee for Responsible Medicine/American Medical Student Association survey. In 1987, the Physicians Committee for Responsible Medicine (PCRM) and the American Medical Student Association (AMSA) surveyed the chairs of departments of physiology, pharmacology, and surgery at 127 United States medical schools about their use of animal laboratories. Responses were provided by 110 departments of pharmacology (87%), 93 departments of physiology (73%), and 81 departments of surgery (64%) (2). Among the 93 departments of physiology, 49 departments (53%) offered animal laboratories as part of the regular curriculum. In contrast, only 27 pharmacology departments (25%) and 15 surgery departments (19%) reported using animal laboratories.

1990 AAMC survey. The AAMC conducted a comprehensive survey of the use of animals in medical education around 1990. The AAMC Vice President for Biomedical Research, Douglas Kelly, presented these findings at a March 1991 conference, and the information was subsequently published in The Physiologist (13). Kelly reported that that 92 of 126 medical schools (73%) offered animal laboratories in the medical curriculum. Of these schools, 61 schools also offered alternatives for students who objected to direct participation, but it was determined in follow-up telephone interviews that only 5–10% of students took advantage of this option, whereas 90–95% did participate in the laboratory exercises.

The AAMC also conducted follow-up interviews with the 34 schools that had discontinued animal laboratories. “No single answers [sic] characterized any of the decisions to move away from animal use,” Kelly wrote (13). Rather, it was possible to “construct a number of scenarios that have influenced the 34 schools,” which he summarized as follows:

“At one extreme, research-intensive institutions, deeply involved in the explosion of new biology and technology and highly dependent on research funding since the 1960s, have found it desirable to convert teaching space to research laboratories and encourage curricular structure that has preserved faculty time for research activity and competition for funding. Their students can find an outlet for laboratory experiences (often involving animals) in the research venue. At the other extreme, some institutions less devoted to research and formed for, or recently dedicated to, the production of a large proportion of primary-care physicians among their graduates argue that the use of laboratory animal exercises is superfluous for the development of the empathetic skills they wish to emphasize. Many schools present intermediate rationales.” (13)

Kelly noted further that the “response to the survey illustrates well that there is no single mission or product that is characteristic of all or perhaps even a majority of medical schools.”

Kelly (13) also pointed out that since the 1960s, pressures on the medical school curriculum have tended to discourage any kind of laboratory experience.

1994 AAMC survey. In 1994, the AAMC conducted a third survey of live animal use in medical education (1). This survey found that 77 of 125 medical schools offered animal laboratories in one or more of their regular courses (62%), with physiology, surgery, and pharmacology courses (or their equivalents) still the disciplines most likely to incorporate them. Forty-nine medical schools offered animal laboratories in conjunction with physiology courses (39%). Of these, the laboratories were required at 23 schools and optional at 26 others. Twenty-one schools offered animal laboratories as part of surgical clerkships (17%), with the laboratories required at 8 schools and optional at 13 others. Thirteen schools offered animal laboratories in pharmacology courses (10%), which were required at 5 schools and optional at 8 others. In addition, 16 schools reported other courses with required or optional animal laboratory components, most of which could be loosely characterized as clinically related. These included courses such as integrated functions, anesthesiology, introduction to clinical sciences, and advanced trauma.

The 1994 AAMC survey also asked the 48 schools that had discontinued the use of live animals to indicate their reasons for doing so. The two reasons reported most frequently were the expense of live animal laboratories and changes in the curriculum. Table 5 summarizes the responses to this question.

Ammons (1) noted that medical schools’ decisions regarding the use of live animal laboratories “were highly dependent upon the conditions within individual institutions” and were made based on “combinations of factors [that] have made alternatives to teaching with live animals more attractive, including: the expense of providing and maintaining animals; the compression of students’ time spent in courses; the larger class sizes; and a loss of skilled faculty.”

2001 Hansen and Boss survey. In 2001, Hansen and Boss (12) asked departments of physiology, pharmacology, and surgery at 125 United States medical schools whether animal laboratories were part of their course requirements. Through rigorous follow-up, they achieved a 97% response rate for departments of physiology and surgery and a 100% response rate for departments of pharmacology. This survey found that

### Table 4. 1984 ACDP Survey of Physiology Chairs: advantages and disadvantages in the use of alternatives in medical education

<table>
<thead>
<tr>
<th>Advantage/Mention</th>
<th>Number of Mentions</th>
<th>%Citing This Issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>savings in cost</td>
<td>50</td>
<td>57</td>
</tr>
<tr>
<td>savings in time</td>
<td>35</td>
<td>40</td>
</tr>
<tr>
<td>reduction in number of animals</td>
<td>31</td>
<td>35</td>
</tr>
<tr>
<td>greater control over variables</td>
<td>23</td>
<td>26</td>
</tr>
<tr>
<td>ability to isolate mechanisms/events</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>reduction in pain for the animals</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>other</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>disadvantage/mention</td>
<td>73</td>
<td>83</td>
</tr>
<tr>
<td>further distancing the teaching from the ultimate subject (humans)</td>
<td>63</td>
<td>72</td>
</tr>
<tr>
<td>loss of student exposure to practicality and complications of gathering valid data</td>
<td>60</td>
<td>68</td>
</tr>
<tr>
<td>artificial nature of the system</td>
<td>55</td>
<td>63</td>
</tr>
<tr>
<td>inability to study interactions in the complex system</td>
<td>53</td>
<td>60</td>
</tr>
<tr>
<td>inability to study species-specific response</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>other</td>
<td>15</td>
<td>17</td>
</tr>
</tbody>
</table>

n = 88 physiology chairs. Source: adapted from Greenwald (11); APS, The Physiologist. Used with permission.
only 32% of medical schools still offered live animal laboratories in physiology, pharmacology, or surgery courses. In addition, in 38 of 50 courses offering animal laboratories, student participation was optional.

“Proponents of using live animals emphasize that there is no substitute for the educational experience of seeing and touching living tissue while manipulating physiologic or pharmacologic variables,” according to Hansen and Boss (12). However, pointing to educational experiments conducted by Fawver et al. (10) and Samsel et al. (27), they (12) asserted that “exercises using live animals have shown no measurable advantage over more recently developed alternative educational modalities, such as computer simulations and videos.” This assessment is challenged in THREE COMPARISONS OF ANIMAL LABORATORIES AND SIMULATIONS and the DISCUSSION below.

COMPUTER SIMULATIONS IN PHYSIOLOGY INSTRUCTION

Mathematical models and computer programs simulating physiological processes were developed first and foremost as research tools, but the application of these tools to physiology instruction was a logical next step. Interest in educational applications of computer simulations was no doubt accelerated by the several factors: the advent of more powerful personal computers, increasing time and resource pressures on the curriculum, and a growing sensitivity to animal welfare concerns. Respected physiologists who led the way in adapting computer models and simulations for instructional purposes included Dickinson (MacMan) (9), Coleman and Randall (HU-MAN) (5), Michael and Rovick (Heartsim, CIRCSIM and CIRCSIM-Tutor) (14, 15, 26), Rothe (Cardiovascular Interactions) (22, 24, 25), and Modell (16–18).

Coleman and Randall (6) offered a critique of several early mathematical models and computer simulations in which they acknowledged the inherent difficulties of producing them. Challenges included the limitations of existing hardware and software as well as the “uncertainties and ambiguities” about the very phenomena to be simulated. They also noted the limited pool of individuals able to develop simulations for the kinds of complex physiological phenomena that would be most educationally valuable. Such people would have to be familiar with physiological concepts as well as “skilled in the mathematical description of physical phenomena, computer programming, and the numerical methods needed to produce accurate solutions in a reasonable amount of time” (6).

Michael’s first experience adapting a computer simulation for use in medical physiology instruction was with MacMan, Dickinson’s mathematical model of the baroreceptor reflex system. MacMan consisted of a large number of equations and data tables so that the program could simulate the behavior of the cardiovascular system (15). Michael and Rovick developed a laboratory manual describing several student experiments. In classroom use, however, they found that the simulation produced a disappointing experience—as had the animal laboratories they previously conducted—because the students simply followed the laboratory book instructions without considering what they might learn about the cardiovascular system. In addition, the students found it difficult to arrive at an understanding of physiological phenomena from the data they gathered (15).

In an abstract presented at the 1974 Federation of American Societies for Experimental Biology meeting, Modell and his colleagues from the State University of New York-Buffalo described their use of computer exercises simulating laboratory and clinical situations involving respiratory physiology. Modell noted the “decline in emphasis on laboratory exercises in physiology [that] has curtailed students’ opportunities to enhance their ability to reason from facts to principles.” They also set forth some guidelines for the development of simulations as educational tools (16). In a 1983 paper, Modell et al. (17) further elaborated on the use of computer simulations in teaching physiology. They noted that the goal of adjunct teaching aids “was to promote an active learning experience for the individual student” by providing “an additional aid to the student’s conceptualization of the physiological system” (17).

Rothe took a computer model of the cardiovascular system developed for his own research and adapted it for physiology instruction. He first created a “pencil and paper” laboratory book and later a computerized one for the program, which he called Cardiovascular Interactions (22). More recently, Rothe collaborated with Gersting to develop a Windows version of Cardiovascular Interactions that runs from a CD and includes hypertext links to explanations of the terms used in the laboratory (25).

SELECTING A PEDAGOGICAL APPROACH

The Medical Physiology Learning Objectives developed by the ACDP and the American Physiological Society suggest physiological concepts that should be part of the medical curriculum. However, the introduction of this report (4) states clearly that it is up to the institution to determine what didactic approaches to use to impart to students the understanding of these concepts they will need as the foundation for their
subsequent studies of pharmacology, pathology, pathophysiology, and medicine.

In his article “Can technology replace live preparations in student laboratories?,” Modell (18) suggested criteria for selecting laboratory exercises emphasizing the role of educational goals in determining what kind of exercise is most appropriate. Modell pointed out that the first goal of all laboratory exercises should be to provide an active learning experience, but beyond that the instructor should define educational objectives. Modell (18) was critical of the fact that this “is a task, that, historically, many physiologists have not addressed adequately.”

Modell went on to suggest a number of possible educational goals for laboratory exercises, one of which was the demonstration of basic physiological principles that students can use to build their own conceptual models of physiological systems. He then considered the relative merits of animal laboratories and technological simulations in achieving this objective and suggested that, although technology can partially replace animal laboratories in achieving this goal, simulations have certain inherent limitations because they are based on “a series of simplifying assumptions” (18). Consequently, “no model is sufficient to predict the behavior of the system under all conditions.” At the same time, Modell (18) suggested that the “most effective way to help students understand physiological interactions on a systemic basis is to first use technological approaches to proceed from simple to more complex models and then to test hypotheses based on model behavior in an investigative experience with a living preparation.”

THREE COMPARISONS OF ANIMAL LABORATORIES AND SIMULATIONS

A limited amount of research has been done to compare the educational outcomes of animal laboratories and computer simulations for the teaching of medical and veterinary physiology. The comparisons discussed here represent studies of existing classroom practices that were not necessarily rigorous educational research involving full randomization and the use of assessment instruments that have documented reliability and validity. Fawver et al. (10) and Samsel et al. (27) conducted comparative studies that have been cited as evidence that simulations produce equivalent learning, are more cost effective than animal laboratories, and are viewed more favorably by students (12). However, these are oversimplifications of what these groups have reported. More recently, a comparative study (7) involving students in high school Advanced Placement (AP) biology classes showed that mastery of material in a laboratory practical exam differed significantly depending on whether the students’ learning experience involved virtual or actual dissection.

Fawver and other members of the Departments of Physiology, Pharmacology, and Education at Auburn University conducted a study (10) to compare the “effectiveness and efficiency” of animal laboratories and computer simulations in teaching physiology to veterinary students. The authors divided a group of 85 first-year veterinary students into 12 laboratory groups of 3–4 students and randomly assigned them to either a traditional live animal laboratory or an interactive videodisc simulation. Student mastery of course material was assessed through a 22-item, multiple-choice/short-answer test.

The authors reported “no significant difference between group test scores.” However, because both students and instructors spent more time in animal laboratories than in the simulation exercises, the authors concluded that the “interactive videodisc-simulated lab was as effective as the traditional live animal labs and was more time efficient than the traditional participation lab” (10).

This study provoked controversy because of the narrow way in which mastery was measured. Dawson and several colleagues from the Department of Physiology at the Medical College of Wisconsin wrote to the editor of Advances in Physiology Education raising questions about the use of a multiple-choice/short-answer test to evaluate student learning (8). “Exposure to the conceptual material within the highly stimulating environment of the animal laboratory results in a level of understanding that is different from that taught by other valuable but fundamentally different teaching methods,” they noted. They also pointed out that medical and veterinary schools typically provide “varied kinds of learning experiences” that “help accommodate different learning strategies among students” and “take advantage of the fact that different approaches tend to stress different aspects of the material, thus helping the student to obtain a broader perspective and deeper understanding of the material” (8).

Branch (3) responded on behalf of the Fawver group in a letter in which he called the study “simply an attempt to provide at least some objective information regarding the understanding of physiological concepts achieved by the two groups of students in one specific laboratory experience.” Interactive video programs “have the potential of addressing some, but not all, of the issues raised by Dawson et al.:

“In a demonstration laboratory it is difficult for all students to observe the fibrillation and defibrillation, much less study the relationships of the fibrillation to blood pressure, cardiac output, or the electrical activity of the heart. In contrast, the videodisc, while not providing all the sensory input associated with a live preparation, does permit all students to observe the heart in detail in real time or slow motion, repeat the experiment at will, and study the physiology.” (3)

Branch said that his group was not arguing for the elimination of animal laboratories but rather for greater consideration of educational goals in determining course content:

“We would hope that such decisions would be made by educators based on educational goals, including those goals addressed by [Dawson et al.]. Instead, we have observed that the decisions are often made based on criteria other than educational goals. This has resulted in many schools deleting animal experiments with little or no attempt to either provide alternatives or even measure the effects of their decisions on education.” (3)

Samsel and his colleagues at the University of Chicago also sought to determine whether computer software was as effective as animal laboratories in cardiovascular physiology instruction (27). The authors divided 110 medical and graduate school students in a first-year cardiovascular physiology course into 2 cohorts that were further divided into small groups. All students attended both an animal laboratory demonstration and a computer simulation. In the animal laboratory demonstrations, instructors led a group of 8–12 students through “a planned sequence of interventions and measurements” that were conducted by the staff while “involv[ing] the students directly through question and
answer interactions.” The students “were encouraged to look and touch,” but “direct management of the preparation was carried out primarily by the instructors.” The students in one cohort attended the animal laboratory demonstration first, whereas the members of the other cohort first attended the computer simulation. The students were surveyed after each demonstration, and the faculty members who conducted the demonstrations were also surveyed.

When asked to assess the usefulness of each demonstration in “complementing the lectures and the text,” both the animal laboratory and the computer simulation were highly rated, but the computer laboratories received slightly higher overall ratings. Samsel et al. (27) ascribed the difference in preferences to “the significant minority of students who either objected to animal use in principle, or were distracted by it in practice.” Among the rest of the students, “one distinct group seemed to prefer the computer laboratory because it was simpler, and another preferred the animal laboratory because it was more challenging” (27). Faculty comments about the usefulness of the two demonstrations similarly reflect the trade-offs between the two approaches. The faculty reported that the computer demonstrations were “simpler than the animal demonstration, because it allowed students to focus on one question at a time.” On the other hand,

“In the animal laboratory, students were faced with relatively more information at each stage. Although the faculty did act to focus the students’ attention on one issue at a time, students were expected to integrate more concepts, changes, and observations at once. In this sense, the animal demonstrations were more ‘advanced’ than the computer demonstration. Accordingly, its greatest benefit was for those students who had the greatest prior mastery of the elementary concepts.” (27)

The faculty agreed on the following points: “Most students benefited from the computer demonstrations, but a few floundered in the animal laboratory, mainly because of the challenge of integrating a broad array of information.” The faculty recommended that computer laboratories should optimally be presented “before the animal lab as a partial bridge to the experimental manipulation” (27).

More recently, a comparison of the educational effectiveness of virtual versus actual dissection showed that that a hands-on learning experience produced better mastery (7). Cross and Cross (7) compared the test scores of 11th- and 12th-grade AP biology students who had been randomly selected for a dissection unit that used either the Biolab Frog Dissection computer program or a preserved frog specimen. The same teacher provided instruction in each instance, and the experiment involved a total of 74 students over 2 successive school years. In the second year only, the evaluation included both a virtual dissection and a laboratory practical. There were no significant differences in the test scores in the virtual dissection, but students who worked with frog specimens performed “significantly better” on a laboratory practical examination than those whose instruction involved a virtual dissection. Cross and Cross (7) therefore concluded that “students who dissect preserved frogs are capable of transferring information to the virtual format, but that transfer of information does not occur from virtual frog to preserved frog.” Although this involves AP high school biology rather than medical or veterinary physiology, the finding supports the conclusion that hands-on exercises add depth to the learning experience.

**DISCUSSION**

It was clear by the early 1980s that classical animal laboratories in physiology were on the decline. In 1994, 39% of medical schools surveyed still offered animal laboratories as part of physiology courses, but by 2001, that percentage had declined to 18%. This trend was the product of many factors, but cost featured prominently. Cost embraces multiple components, such as the cost of the animals, equipment, and supplies; the cost of complying with new animal welfare oversight requirements; the cost of allocating potential research space for educational purposes; and the cost of staff time for faculty, instructors, and laboratory assistants to provide students with an appropriate pedagogical experience. Contributing factors in addition to cost include faculty attitudes (which may be related to the decline in the numbers of faculty trained to work with whole animals and therefore able to lead students through such exercises), advances in technology such as computer-assisted instruction, animal welfare concerns, and external pressures including from groups opposed to the use of animals in education. People for the Ethical Treatment of Animals and the Physicians Committee for Responsible Medicine in particular have been in the forefront of highly publicized campaigns to eliminate animal laboratories from the medical curriculum (20, 21). Moreover, when these groups target an institution, they bring to bear an intense public relations campaign that overrides reasoned considerations about what educational approach would contribute most to student learning.

Broader changes in medical education have also come into play. With the increasingly crowded curriculum, there is less instructional time available for each subject. The efforts of the Liaison Committee on Medical Education have led schools to centralize curriculum design responsibilities that formerly rested with individual departments in a curriculum committee, which increased the burden of proof to justify time- and resource-intensive activities such as animal laboratory exercises. In addition, the 1985 amendments to the Animal Welfare Act required protocols for the use of animals in educational activities to be approved by an Institutional Animal Care and Use Committee. Because it can be difficult to demonstrate affirmatively and measurably how animal laboratories contribute to student learning, this added hurdle further contributed to the decline.

Nevertheless, even as animal laboratories were being eliminated, concerns were raised about what educational impact this would have. Respondents to the 1984 ACDP survey expressed concern that students would no longer have the experience of working with live subjects and that they would not have the opportunity to observe interactions in a complex living system.

Respected physiologists led the way in adapting computer models as simulations for instructional purposes and also offered ongoing critiques of their efficacy. Michael (15) pointed out that the value of a laboratory is largely dependent on how well the exercise is constructed. Students need to learn how to go beyond the acquisition of information to learn how to think about relationships between physiological phenomena (15). Modell (15) suggested a framework to evaluate the selection of appropriate laboratory exercises based on relevant educational goals including the demonstration of physiological principles to assist students in acquiring conceptual models of physiological systems. He also pointed out that simulations necessarily reduce the complexity of the phenomenon being
demonstrated and that, under some conditions, the simulation will no longer provide an accurate representation of reality. Modell (18) argued that students would be best served by a graduated set of exercises: “The most effective way to help students understand physiological interactions on a systemic basis is to first use technological approaches to proceed from simple to more complex models and then to test hypotheses based on model behavior in an investigative experience with a living preparation.”

Fawver et al. (10) and Samsel et al. (27) reported studies comparing the educational value of animal laboratory exercises and computer simulations. These studies have sometimes been misused to bolster the notion that students can learn all they need to know about physiology from computer simulations. However, whereas Fawver et al. found that students who participated in animal laboratories and interactive videodisc simulations scored equally well on multiple-choice/short-answer examinations, this study did not address broader questions about additional understanding that may be acquired through direct experience with a living organism. Faculty comments that were collected as part of Samsel et al.’s study identified three subgroups of students with different responses and preferences. The faculty reported that the computer demonstration made it easier for students to focus on specific aspects of the phenomenon being studied. Virtually all the students reported that they benefited from this exercise, and a large number expressed a preference for the simulation. However, another group preferred the animal demonstration, which was characterized as more complex and in some sense more advanced. However, Samsel et al. (27) also identified a subgroup of students who expressed a preference for the computer simulation either because they objected to the animal laboratory in principle or were overwhelmed by the experience. The observation that subsets of students have markedly different responses to these exercises is a notion that merits careful consideration. Student preference has been used to justify the elimination of animal laboratories, but this notion that merits careful consideration.

Laboratory exercises should always be designed to help fulfill learning objectives such as those defined in the Medical Physiology Learning Objectives (4). Although interactive technologies such as computer simulations are clearly very useful and have been widely adopted for various reasons, it is incorrect to assert that simulations can offer an accurate representation of reality. Modell (18) argued that students would be best served by a graduated set of exercises: “The most effective way to help students understand physiological interactions on a systemic basis is to first use technological approaches to proceed from simple to more complex models and then to test hypotheses based on model behavior in an investigative experience with a living preparation.”

Fawver et al. (10) and Samsel et al. (27) reported studies comparing the educational value of animal laboratory exercises and computer simulations. These studies have sometimes been misused to bolster the notion that students can learn all they need to know about physiology from computer simulations. However, whereas Fawver et al. found that students who participated in animal laboratories and interactive videodisc simulations scored equally well on multiple-choice/short-answer examinations, this study did not address broader questions about additional understanding that may be acquired through direct experience with a living organism. Faculty comments that were collected as part of Samsel et al.’s study identified three subgroups of students with different responses and preferences. The faculty reported that the computer demonstration made it easier for students to focus on specific aspects of the phenomenon being studied. Virtually all the students reported that they benefited from this exercise, and a large number expressed a preference for the simulation. However, another group preferred the animal demonstration, which was characterized as more complex and in some sense more advanced. However, Samsel et al. (27) also identified a subgroup of students who expressed a preference for the computer simulation either because they objected to the animal laboratory in principle or were overwhelmed by the experience. The observation that subsets of students have markedly different responses to these exercises is a notion that merits careful consideration. Student preference has been used to justify the elimination of animal laboratories, but this notion that merits careful consideration. Student preference has been used to justify the elimination of animal laboratories, but this notion that merits careful consideration.

Laboratory exercises should always be designed to help fulfill learning objectives such as those defined in the Medical Physiology Learning Objectives (4). Although interactive technologies such as computer simulations are clearly very useful and have been widely adopted for various reasons, it is incorrect to assert that they in fact represent a complete educational replacement for animal laboratories. Rather, there is evidence suggesting that at least for some students, animal laboratories provide opportunities to integrate an understanding of complex physiological concepts above and beyond what simulations can offer.

ACKNOWLEDGMENTS

The comments of Drs. Robert Carroll, Joel Michael, Martin Frank, and Marsha Matyas are gratefully acknowledged.

REFERENCES


