



# Alternatives to Animal Experimentation in Biomedical Education

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## Summary

*In education, it is important that students are not put in a position in which they are forced to participate in animal experiments or to use dead animals, killed especially for such purposes. Continued use of animal experiments to demonstrate known facts or teach skills which can be taught using non-animal methods evidences only a lack of sensitivity towards students who still maintain respect for life. In countries where animal testing in education is reduced to close to zero, there is no evidence that the students who are being trained are less capable or qualified. There are sufficient alternatives available at relatively low-cost and with proven educational efficacy to allow the vast majority of students who study biomedical science courses to qualify without using animal experiments. However, in many universities across Europe, there is still a resistance to adoption of such methods amongst faculty. The global situation is probably worse with animals still being used in high school teaching in some countries such as the USA.*

**Zusammenfassung:** Alternativmethoden in der biomedizinischen Ausbildung

*In der Ausbildung muss es höchstes Gebot sein, niemanden gegen seinen Willen an Tierversuchen oder an der Arbeit mit eigens zu diesen Zwecken getöteten Tieren zu beteiligen. Banalstes Grundwissen mit einem Tierversuch zu erarbeiten, zeugt zudem von mangelnder Sensibilität gegenüber Studierenden, die noch Ehrfurcht vor dem Leben haben. In Ländern, in denen Tierversuche zu Ausbildungszwecken nahezu auf Null reduziert sind, werden nicht weniger gute Wissenschaftler an den Hochschulen herangebildet. Es gibt genügend preiswerte Methoden, deren Eignung nachgewiesen ist, um der überwiegenden Mehrheit der Studierenden in den biomedizinischen Wissenschaften die nötige Qualifikation zu vermitteln. An manchen Universitäten Europas sind jedoch immer noch Widerstände gegen eine Aufnahme alternativer Unterrichtsmethoden bei den Hochschullehrern festzustellen. Global gesehen ist die Situation noch viel unerfreulicher, da z.B. in Ländern wie den USA immer noch Tiere sogar für den Unterricht an Gymnasien getötet werden.*

**Keywords:** alternatives, education, biomedicine, efficacy

## 1 Introduction

### 1.1 Why do we use animals in biomedical education?

There are many cultural differences in relation to animal use between different

continents and countries. Animal use mainly includes the education and training of students in courses in biomedical sciences especially pharmacology and physiology. As part of this education, animals, mostly small rodents or amphib-

ians, are used for dissection and to study anatomy, as sources of organs or tissues for teaching physiological, pharmacological and surgical skills, procedures and principles, for observation of animal behaviour, and to teach animal handling.

Received 9 October 2002; received in final form and accepted for publication 26 November 2004



The learning objectives of classes using animals and animal tissue are often poorly defined, but may include

- 1) learning and practising laboratory skills, including:
  - generic laboratory skills (e.g. how to make up solutions, how to titrate, using a pipette, how to use data-recording equipment such as oscilloscopes, chart-recorders etc.),
  - preparation-specific skills (e.g. how to set up and maintain a Langendorff heart preparation),
  - animal handling skills, observational skills (e.g. for study of animal behaviour)
  - surgical or dissecting skills;
- 2) acquiring new factual knowledge and reinforcing existing factual knowledge;
- 3) learning and practising data-handling skills (taking measurements, recording, data presentation, analysis and interpretation skills);
- 4) learning and practising oral and written communication skills; and
- 5) developing responsible attitudes toward animal experimentation.

Clearly, these objectives are important, and any alternative should fulfil at least some of these objectives at least as effectively as the traditional approach. The challenge for those opposed to the use of animals in education is to convince biomedical science teachers, many of whom would have used animals in their own university/school education, that there are viable alternatives which can achieve the majority of these objectives.

## 1.2 What is the scale of animal use in biomedical education?

The number of animals used for educational purposes in the EU is small (Tab. 1,

see also Fig. 1 in Gruber and Hartung, p. 7 in this issue), i.e. 1% of the total used for research (Casati and Hartung, 2003); but at around several hundred thousand animals each year it is significant particularly as much of this use is unnecessary. This figure is also a gross underestimate as, in many countries, animals which are killed just prior to use would not be counted in the official figures. Thus, isolated tissue preparations from freshly killed animals, which form the mainstay of pharmacology practical teaching, would not be counted in the official figures. In the USA experiments on rats, mice and birds are not required to be recorded.

The reported animal use for education and training is declining even against a background of a large increase in student numbers and although this is due to several factors (e.g. economic pressures in that animal labs are expensive and a pedagogical shift away from didactic to student-centred, resource-based learning) the widespread availability of high-quality alternatives at relatively low cost has probably had a major impact. However, a significant number of animals are still being used unnecessarily.

In order to define a policy to reduce or replace the use of animals in biomedical education, and to evaluate the effects of such a policy, reliable and comprehensive data on animal use are required. These data are also needed to determine whether the use of non animal alternatives has any impact on the numbers of animals used. It is recommended that a standardised report form should be introduced by the EC, which records total animal use, including animals killed without prior procedures for educational and other purposes.

An ECVAM-sponsored workshop held in 1998 in Chania (Crete) addressed the use of alternatives in higher education (Valk et al., 1999). Fifteen participants from eight countries (including European Union countries, USA and German-speaking Switzerland) attended the workshop, which was the first official meeting of experts involved in developing, using and evaluating animal free models for educational purposes and promoting the use of these alternatives. One of the conclusions of the 1998 workshop was that:

*"Animals used in teaching should not be regarded as dispensable tools. If students are regularly confronted with animal use during their studies, they might not be able to develop a balanced attitude toward the use of animals in research. Giving students the choice in the early stages of their study between using animals or animal-free learning methods to gain knowledge also helps them to develop an appropriate attitude toward the use of animals. Ideally, students should always be offered alternatives, and should be offered the opportunity to decide whether or not to attend an animal laboratory class."*

This conclusion is supported by Article 25 of the European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes, the Council of Europe which states that *"procedures carried out for the purpose of education, training or further training of professionals ... shall be restricted to those absolutely necessary for the purpose of the education or training concerned and shall be permitted only if their objective cannot be achieved by comparably effective audiovisual or any other suitable method"*.

Tab. 1: Numbers of animals in biomedical education in some European countries

Country	Year	total number	most used animals	2nd most used animals	3rd most used animals	4th most used animals	5th most used animals
Germany	2003	41,498	19,824 mice	15,052 rats	1,606 swine	1,387 fish	1,229 amphibia
Great Britain	2002	3,658*	1,621 mice	937 rats	731 amphibia	121 guinea pigs	113 chickens
Switzerland	2003	5,070	3,634 amphibia/reptilia	1,976 rats	1,636 mice	954 cattle	114 guinea pigs
Sweden	2003	2,895	861 rats	811 mice	355 cattle	309 pigs	200 birds
The Netherlands	2003	13,340**	3,983 rats	2,990 mice	2,373 chicken and other birds	823 dogs	613 pigs

\* Note that in GB animals which are humanely killed prior to being used in teaching would not be counted in these figures

\*\* In 1997 there were used only 7.355 vertebrae in education in the Netherlands

In The Netherlands, science students must take a course on laboratory animal science as part of, or in addition to, their biomedical graduate programme. This course provides information on the proper design of animal experiments, but also covers alternatives, animal welfare issues and ethical aspects of animal experimentation. The Three Rs of Russell & Burch (1959) are the guiding principles of the course, during which participants are challenged to seek methods or techniques that can replace, reduce or refine the use of animals. Since 1985, more than 2500 people in The Netherlands have taken the course, and evaluations have indicated that a large majority of the participants appreciated this education as a contribution to both the quality of experiments and the welfare of the animals, and considered the course to be indispensable for those who are responsible for the design and performance of animal experiments (Zutphen and Valk, 1995).

The German constitution (1948) states that University professors have complete freedom in how they define and deliver their teaching, and that no other law or regulation may restrict this freedom (Rieg and Löblein, 1995). This unconditional academic freedom comes into conflict with the more recent Animal Welfare Law which e.g. restricts the use of animals for demonstration purposes. The incorporation of animal welfare as a national objective into the constitution should put a stop to the excessive use of animals in education. A first ruling declining an animal experiment as a result changes in the basic law gives hope in this regard (Scheiwiller, 2002; Ruhdel, 2004).

In the USA attitudes toward the Three Rs concept of replacement, reduction and refinement in research and education are widely divergent (Orlans, 1996). Positive responses have come from several sources, notably from four centres established to disseminate information about alternatives. In the field of education, student projects involving pain or death for sentient animals have been declined, and the right of students to object to participation in animal experiments on ethical grounds has been widely established. "However, there is still a long way to go" writes Orlans. The prestigious

National Association of Biology Teachers, which at first endorsed the use of alternatives in education, later rescinded this policy, because of opposition to it. An impediment to progress would be the extreme polarisation of viewpoints between the biomedical community and the animal protectionists.

The use of animals in education has a major impact on the total use of animals in science, since animals are frequently used in those university courses designed to prepare students for research careers or careers in industries such as the pharmaceutical industry where animals are used in drug development and legislation requires testing of drugs on animals. In the UK at least there is recognition that the pharmaceutical industry has a shortage of scientists with experience of working on whole animals and there is pressure on the educational system to ensure that graduates in pharmacology, for example, leave university with the appropriate skills to work on whole animal preparations. There are similar pressures from the academic research community and inevitably this means that there is pressure to maintain at least some animal experimentation in the undergraduate curriculum.

One view (e.g. InterNiche at [www.interniche.org](http://www.interniche.org); Jukes and Chiuiua, 2003) is that the use of animals in education and training is only acceptable when

- animals are observed in their natural setting or during brief periods of captivity;
- animals are obtained from an ethical source, for example, animals that have died naturally or those which have been humanely killed for other reasons;
- learning occurs in the clinical setting, where only animals in need of veterinary medical assistance are subjected to invasive procedures; or
- learning occurs by closely supervised apprenticeship in the research laboratory (specifically for students entering fields where they will need to use laboratory animals).

## 2 Examples of alternatives in education

There exists a wide range of animal-free models (alternatives) available for use in

life sciences education today. Collectively they can address the great majority of the learning objectives of a practical class which uses animals or animal tissue though no single alternatives is likely to be able to address them all (s. Tab. 2).

It is beyond the scope of this article to discuss each of these in any detail and we will focus only on: e-alternatives, self-experimentation and human experiments and models, mannequins and mechanical simulators since these may offer the most viable options for those biomedical science disciplines which use the majority of animals i.e. pharmacology and physiology. The extensive list does however highlight that there is a range of alternatives available to the teacher.

### 2.1 Human experiments, self-experimentation

The use of student volunteers as subjects in practical teaching of physiology is widespread. Many university courses in medicine, physiology, pharmacy, and healthcare include laboratory classes monitoring cardiovascular function (heart rate (pulse), blood pressure (sphygmomanometry), electrocardiograph, and blood flow (plethysmography)), respiratory function (peak flow, spirometry), exercise, renal function (diuresis and acid-base experiments), blood (red blood cell indices, blood grouping, blood coagulation testing), and special senses. In some countries the high cost of insurance restricts some of the experiments, particularly those that might involve administration of pharmacological agents, which can be taught in this way.

Teaching nerve and muscle physiology has traditionally involved experiments on isolated frog preparations – frog sciatic nerve, frog gastrocnemius or sartorius muscle. Many of these can be performed on human subjects using surface electrodes and instruments such as the myograph, the technical development and practical evaluation of which were funded by the German Ministry of Education and Research BMBF. First experiences with the myograph obtained during physiology teaching at four universities in Germany have been summarised and evaluated by Gruber and Spielmann (1996). The myograph was also tested in

**Tab. 2: List of alternatives in biomedical education and their advantages**

(The authors wish to thank Goran Knežević, University of Banja Luka, BiH, for his help)

alternatives	advantages
E-alternatives such as computer simulations, virtual laboratory environments, and virtual reality systems which are used to teach surgical skills often in postgraduate medicine	<ul style="list-style-type: none"> <li>- a wide range of use particularly as alternatives to animal labs in pharmacology, physiology, biochemistry, anatomy (dissection, vivisection, technical skills)</li> <li>- precise results</li> <li>- unlimited number of repetitions</li> <li>- learning can take place independent of tutor support</li> <li>- offer the ability to plan/design experiments (e.g. drug doses/combinations in pharmacology and physiology)</li> <li>- high technical possibilities (broadcasting, video-projector presentations, virtual conferences)</li> </ul>
Self-experimentation and human studies such as the myograph (described in 2.2)	<ul style="list-style-type: none"> <li>- promote understanding of human (animal) physiology</li> <li>- students enjoy doing experiments on themselves</li> <li>- develop teamwork and tolerance</li> <li>- non-invasive</li> <li>- real apprenticeship</li> </ul>
Models, mannequins (which for example, are used to teach anatomy and clinical skills), and mechanical simulators	<ul style="list-style-type: none"> <li>- good for illustrating the topography of organs and anatomy</li> <li>- animal handling without animal stress and student anxiety</li> <li>- teaching skills (intubation and catheterisation of animals, and critical care from resuscitation to thoracentesis)</li> </ul>
Films and interactive videos	<ul style="list-style-type: none"> <li>- passive but may be very effective in learning many important techniques in all field of biomedicine (dissection, experiments, etc.)</li> <li>- low cost</li> <li>- unlimited number of repetitions</li> <li>- lots of them</li> </ul>
Plant experiments such as the use of mitochondria isolated from plant tissue rather than obtained from liver from a freshly killed rat	<ul style="list-style-type: none"> <li>- high sensitivity to toxic chemicals</li> <li>- useful for studying cell respiration or electron transport for biochemistry</li> <li>- cheap and available material</li> <li>- easy to maintain and monitor the effects</li> </ul>
Observation and field studies	<ul style="list-style-type: none"> <li>- indispensable in studying animal behaviour</li> <li>- studying long-term activities and processes in living bodies</li> </ul>
Waste materials from slaughterhouses (such as used in the POP trainer, which has been successfully in microsurgical training and rectal examination in veterinary medicine, as described in 2.3), fisheries and ethically-sourced animal cadavers	<ul style="list-style-type: none"> <li>- non-invasive hands-on experience of animals and animal tissue</li> <li>- avoid the breeding and killing of animals for tissue or organs</li> <li>- a wide range of available bodies, organs and tissues</li> </ul>
<i>In vitro</i> studies on cell lines	<ul style="list-style-type: none"> <li>- preparations are highly sensitive to drugs and chemicals</li> <li>- easy to handle</li> <li>- little waste</li> <li>- the material may be obtained ethically</li> </ul>
Clinical practice	<ul style="list-style-type: none"> <li>- real animal handling</li> <li>- clinical skills</li> <li>- realistic and appropriate apprenticeship</li> <li>- provide the experience, confidence and competence</li> <li>- skills are learned in a real clinical environment</li> </ul>



four additional universities and proved to be superior to the classic frog experiments both from the scientific and educational point of view (Tab. 3). But the costs of purchasing and maintaining the myograph have been shown to be an obstacle for introducing the new teaching device into higher education.

## 2.2 Computer-based simulations of animal experiments/preparations (virtual animal labs)

Broadly, computer simulations of laboratory practical classes (animal labs) in physiology and pharmacology may be divided into two categories:

### 2.2.1 Simulations of preparations

– these use predictive algorithms to generate simulated tissue responses in response to the user selecting certain variables. They are extremely flexible in how they can be used giving the user control over experimental parameters such as: which drug to add to a tissue bath; what concentration of the drug; whether the drug is added alone or in the presence of an antagonist or potentiator; whether the tissue is electrically stimulated (perhaps to release endogenous substances); what electrical stimulation parameters are used. Thus, they may present the student with a “virtual” pharmacological preparation such as a cat anterior tibialis-sciatic nerve preparation *in vivo* where the animal is anaesthetised and set up such that electrical stimuli can be delivered to the sciatic nerve and contractions of the tibialis anterior muscle can be recorded. This preparation may be

used to teach students the pharmacology of neuromuscular transmission and the characteristics of depolarizing and non-depolarizing neuromuscular blocking agents. In the real and virtual preparation pharmacological agents can be administered by intravenous injection either alone or in combination with antagonists or potentiators. Students may choose a drug from an extensive list, the concentration at which it should be administered whether to add the test drug alone or in combination with an antagonist (again they will have a choice of a number of potential antagonists and concentrations at which they may be administered). Once these decisions have been made the student is presented with a tissue response (contraction of the tibialis anterior muscle if the chosen parameters of the experiment are suitable) which is generated from an algorithm, the development of which is based on data from previous experiments using this tissue.

Computer simulations of this type require significant tutor support to be useful. Tasks must be set for a worthwhile learning experience to be achieved. These may be fairly prescriptive (e.g. administer drug X at a dose of A mg/kg. Observe the pattern of muscular contractions until they have returned to control levels. Repeat the experiment with drug Y at a dose of B mg/kg. Repeat again administering drug X (A mg/kg) 5 minutes before drug Y (B mg/kg). Observe the effects of drug Y alone and compare the effects of drug X alone and after prior administration of drug Y), or more open-ended (e.g. design a range of experiments to identify the class of drugs

represented by Unknown drug U). This type of program is perhaps most appropriate to better prepare students who will later perform the “live” experiment e.g. students can do a “dry run” to try out drug doses, stimulation protocols, plan experiments etc. Alternatively, they allow students, who have already performed a limited range of experiments using the “live” preparation or seen it only as a tutor demonstration, to collect data from a greater range of experiments than the “live” experiment permitted. Similarly, the simulation may act as a “fallback” providing data for students whose experiments were not successful.

Examples include:

Guinea pig ileum; Frog Skin; Squid Axon; Exercise Physiology; Blood Physiology (<http://www.sheffbp.co.uk>); Simulated Vascular Rings; Sciatic nerve-anterior tibialis preparation, Simulated Water Maze (<http://www.bps.ac.uk/>) SimNerve, SimMuscle, SimHeart, SimVessel (<http://www.thieme.com/>)

### 2.2.2 Simulations of experiments

– here “real” data, collected from previous experiments, is used to reproduce simulated tissue responses. The focus is to present students with representative data from a defined series of experiments which have been designed by a tutor to ensure primary learning objectives are achieved and experiments are relevant. These programs are more akin to a virtual tutor-led demonstration where students collect the data from the monitor as they would from whatever output device was used in the “live” experiment. The

Tab. 3: Comparison of the “classical” frog trial (*m. gastrocnemius*) with the self trial at the myograph (*m. adductor pollicis*)

only possible with the frog	only possible with humans	possible with both
invasive nerve stimulation, influence on the reaction by Ca <sup>++</sup> , Mg <sup>++</sup> , Ba <sup>++</sup> , Curare, g-strophanthin, cyanide, drugs and poisons	electromyogram under strain, static and dynamic tonus with phonomyography (PMG), arbitrary stimulation, maximum potentiation, Hillsch' relation, electro-mechanical linkage, influence of caffeine, nicotine	electromyogram, muscle contraction vs. stimulating amplitude, threshold of contraction, isometric and isotonic maxima, potency of contraction, muscle shortening by contraction, duration of contraction, duration of relaxation, velocity of contraction, elasticity, max. potentiation, double stimulation, summation, fused and unfused tetanus, work of contraction, resting stretch, weakening of contraction, elongation of contraction time, diminution of atony



programs are often designed to offer a replacement for a laboratory session, suitable for learning independent of tutor support, under circumstances where the "live" experiment cannot be performed e.g. high cost of an animal laboratory (such as the traditional dog lab for teaching cardiovascular function), lack of specialist equipment or technical expertise. They often have built-in assignments and activities and provide on-screen support such as background information, and self-assessment activities. This type of program might also be used as an alternative to a cat anterior tibialis-sciatic nerve practical and in fact takes an approach to supporting learning similar to that employed by a tutor who prepares a worksheet or schedule for students to follow in the laboratory. Thus, the program would comprise a series of clearly defined experiments each designed by an experienced tutor to enable students to meet specific learning objectives which can be achieved using that preparation. Drug concentrations would be pre-determined to be optimal for that particular drug and only selected antagonists or potentiators would be available. Students would not have the same degree of flexibility in designing experiments but neither would they waste significant time trying out drug concentrations, drug combinations or electrical stimulus parameters which were inappropriate.

Examples include:

Nerve Physiology; Muscle Physiology; Frog Heart; Intestinal Absorption; Cat Nictitating Membrane; Langendorff Heart; Inflammation Pharmacology; Finkleman; Simulated experiments on sciatic nerve-anterior tibialis preparation; Respiratory Pharmacology; Intestinal Motility; Renal Function in Humans (<http://www.sheffbp.co.uk>)

Rat Blood Pressure (<http://www.bps.ac.uk/>) Simulations of pharmacological experiments on Guinea Pig ileum; Simulations of pharmacological experiments on Rabbit jejunum (<http://www.coacs.com>)

Virtual Dog Laboratory (Cardiovascular and Autonomic pharmacology) (<http://courses.washington.edu/chat543/cvans/>) There are also a number of pharmacokinetic simulation programs, e.g. Phar-

maSim (Keller, 1995); PK-SIMS (<http://www.sheffbp.co.uk>); Pharmacokinetics simulations (<http://www.coacs.com>). Using PharmaSim as an example, it focuses on the simulation of drug plasma levels based on compartment models. The major advantage lies in the easy visualisation of drug dose – plasma drug concentration curves and the high speed of the simulations. When the value of a parameter is changed the display of the corresponding curve reacts instantly (delay time < 0.1 sec.). This allows students to visualise the effects of changing one parameter in a formula, a concept which has been difficult to illustrate. The simulations are embedded in a HyperCard-like electronic book. The contents of the tutorial pages – texts and graphics – as well as the present values for the simulations can be saved in script files. This makes PharmaSim a tool with which many different tutorials can be created.

### 2.3 Alternatives to laboratory animals in microsurgical training and veterinary medicine

As early as 1994 Schöffl and Kröpfl showed the possibilities of reduction and replacement of laboratory animals in education and training in microsurgical techniques. They wrote that "*ethical viewpoints are more important for research, science, and medical and biomedical education now and that the necessity of laboratory animals for education and training in microsurgical techniques is to discuss*".

Also from Austria came the POP trainer (Pulsatile Organ Perfusion) which was first published by Szinicz et al. (1994) to assist in the training for minimally invasive surgery (MIS). POP simulates blood supply of organs or organ-systems and is a useful method for completing training in laparoscopic and thoracoscopic techniques. The quality of simulating operations is excellent, the method is cost effective and does not require the expense and infrastructure of the experimental animal laboratory. Furthermore the amount of animals required for advanced MIS-training will be greatly reduced.

At the Veterinary Surgery Clinic of the University of Zurich models were developed in co-operation with a surgery professor from the United States. These

models support student training in manual dexterity in basic surgical techniques. The models are easy to transport, made from a scent-free polyurethane and are suitable for students to practice surgical skills in their own time and in a location suitable to them. The result of this education, which was initiated at the begin of the 1990's, is better manual dexterity in surgical techniques, a dexterity which is achieved without sacrificing laboratory animals. This represents a big advantage for the students and later the veterinarian (Auer, 1994).

To teach rectal examination to veterinary medical students Künzel and Dier (1993) describe the hindquarters of a full size plastic horse in which plastic organs or organs from the slaughterhouse can be fixed.

By the initiative of the Microsurgical Developments Foundation, a PVC-Rat model was developed to enable students to master skills in microsurgery. The model, together with an interactive CD and video tape with explanations and surgery skills, gives the possibility of training approximately 25 different microsurgical techniques including anastomoses, cannulations and transplantations of vessels and organs ([www.microdev.nl/models.htm](http://www.microdev.nl/models.htm)).

In 2003, Reuthebuch et al. published a totally artificial training model for coronary heart surgery. The model is based on differentially hardened polyurethane. It is a 1:1 replica of the human thorax and has disposable coronary blood vessels which are integrated in the beating heart model. The degree of difficulty depends on stroke volume, heart rate, arrhythmia, vessel size and vessel quality. It facilitates a tutored training session for both the less trained as well as the skilled surgeon.

### 2.4 Survey of existing alternative methods in biomedical education

A survey of existing alternative methods with a short key description and the respective suppliers is given in Table 4 at the end of this article. For full descriptions and reviews please go to [www.eurca.org](http://www.eurca.org).

### 3 Overcoming difficulties and solutions in introducing animal-free alternatives

Availability of alternatives does not necessarily mean a significant fall in animal use for teaching purposes as this will not happen unless the alternatives are successfully integrated into mainstream teaching.

This is particularly true of computer-based alternatives where most have been developed by enthusiasts to support their own teaching in situations in which the pedagogical basis is well established. Some of these have been designed specifically to replace an animal lab., others are designed to offer a viable alternative to a class which for a variety of reasons has now been dropped from the curriculum – e.g. large animal practicals such as the traditional “dog lab” in pharmacology is now much too expensive. For many groups of students virtual animal labs would meet most, but perhaps not all, of the learning outcomes. In those exceptional circumstances where an animal lab has been deemed necessary then virtual animal labs can still be useful in reducing unnecessary animal use. Here a computer simulation of the experiment can be used to better prepare students, who will later perform those experiments on an animal preparation, e.g. help them to plan the experiments in a simulated environment (e.g. try out drug doses, drug combinations) rather than do this planning on an animal preparation. In addition the virtual lab could be used to obtain data should, for example, the preparation die before all experiments have been performed, or to debrief students after the animal class.

Where these programs have been developed by a teacher for their own use, they are usually well-integrated into the curriculum and they work well (see later) achieving those learning objectives for which they were designed.

However, the situation is sometimes quite different when these programs are made available to other teachers who are often resistant to using resources developed elsewhere particularly if using the “alternative” requires more time and effort than continuing to use the “traditional” way. They often consider alternatives

to be inferior, and the introduction of technology-based learning methods to be a retrograde step. “Often, they are not interested in the ethics of using animals. Textbooks, laboratories and equipment are still oriented toward animal experimentation. Convincing these teachers of the advantages and ethics of using alternatives is difficult, the situation being very much polarised. Incorporating the principles of the Three Rs into teachers’ initial training and post-qualification professional development would help to overcome some of these difficulties” (Valk et al., 1999).

There are several key steps in persuading teachers to use alternatives, they need to:

- be made aware that they exist. For example they should be provided with full descriptions of the alternative, the hardware requirements (if appropriate), independent reviews, details of cost and availability, and evidence of educational effectiveness. Information should be made available via electronic databases and Web sites, via discipline-based national and international scientific meetings, and via published articles about alternatives and workshops.
- be persuaded of their usefulness and advantages.
- be given advice and exemplars of strategies which will help them to integrate the alternatives into their teaching practice.

While those alternative test methods that are validated e.g. in the area of toxicological testing have to be evaluated against the “gold standard” animal test, the situation is completely different in the case of methods used for educational purposes. Here the “gold standard” is the question of how well students are able to learn the skills. Thus, human efforts are compared to human efforts and not to situations in animals. This makes it easier to demonstrate the advantages of the alternatives (Balcombe, 2003).

#### 3.1 Raising awareness and providing useful information

The most comprehensive current resource for alternatives in education is the NORINA database. This database is available via the Internet (<http://oslovet.veths.no/norina/>), and contains informa-

tion about over 3000 alternative models developed for all levels of education. The site contains a search engine for easy data retrieval. AVAR (Association of Veterinarians for Animal Rights) provides the Alternatives in Education Database (Alt-Ed), which gives a short description of most models. The database is updated monthly and has a built-in search engine. It can be downloaded from the Internet at [http://www.envirolink.org/arrs/avar/alted\\_db.htm](http://www.envirolink.org/arrs/avar/alted_db.htm). The Biology Education Software Taskforce of the University of Washington has an Internet site where information can be found on biology education software (<http://www.snarkware.net/bioedusoft/>). This site also contains reviews and comments. The German *Akademie für Tierschutz* has established a bibliographic database on alternatives. Its printed version, the *Gelbe Liste* also contains information on alternatives in education (Rusche und Sauer, 1994). Over 500 alternative methods in biomedical education are listed in the book “From guinea pig to computer mouse”, edited by Jukes and Chiulia (2003).

But despite of all these sources of information (the list is far from being complete) many teachers and students remain unaware of the existence of alternatives. Efforts should be focused on these groups to improve information flow.

One problem with all of these databases is that the information they provide is product-centred and probably of insufficient detail to enable teachers to decide whether a particular alternative is likely to be of real use to them. Assuming a teacher can identify a number of potential alternatives from these databases the next stage is to obtain copies so that they may evaluate them. This is time consuming and many teachers, given the numerous calls on their time, don’t get beyond this stage.

A project to actively promote the use of high quality alternatives (European Resource Centre for Alternatives to using animals in Higher Education: EURCA (<http://www.eurca.org>)) has been established (Valk and Dewhurst, 2001; Valk et al., 2001). The project has three major strands:

- a web-site containing a information-rich (e.g. product information plus com-



missioned reviews, additional support materials such as workbooks or study guides, learning objectives, educational level; results of evaluations, users comments, discussion area), searchable database of a relatively small number (currently ~50) of peer-reviewed alternatives suitable for university level teaching;

- outreach activities such as taking the EUCRA Resource Centre to relevant scientific meetings to promote the educational effectiveness of alternatives;
- establishing a network of teacher contacts in countries across Europe who will act as advocates for the project.

The strategy is to provide teachers with as much information as possible about selected alternatives to enable them to evaluate potential usefulness, and give them advice on how to successfully integrate alternatives into their teaching.

InterNICHE (<http://www.interniche.org>) also has a loan system which allows teachers or students to borrow a wide range of alternatives to assess their potential usefulness and they have InterNICHE representatives in many countries all over the world. They presented a video on alternatives in education which won the Swiss Egon Naef Prize given in Geneva 1999 and have also produced a book "From Guinea Pig to Computer Mouse" the second edition of which was released in 2003.

### **3.2 Persuading teachers that alternatives can be educationally effective**

One of the most effective ways of persuading teachers of the value of alternatives is to demonstrate how they can be used and to present evidence in a form relevant to them of their educational effectiveness. The key is the closeness of fit between the educational requirement, the context in which the alternative is to be used, and the choice of the medium (for example, computer or video). A number of studies have been conducted to measure the educational effectiveness of computer-based alternatives by comparing learning outcomes with those from traditional animal labs. In the main these demonstrate that high quality alternatives are able to achieve many of the

learning objectives and at the same time promote interactive, resource-based learning and the development of IT skills.

Clarke (1987) and Dewhurst et al. (1988) compared the laboratory report marks of different cohorts of undergraduate students. The "control" cohort performed a frog experiment (isolated sciatic nerve preparation) in the laboratory and the "test" cohort used a computer simulation of the same experiment. Both studies found no statistically significant difference in the marks for the laboratory report, the standard form of assessment for a "animal lab".

Another study (Dewhurst et al., 1994) compared a specific computer simulation program (simulating experiments to measure intestinal transport of nutrients) with a laboratory-based mini project using the isolated, everted intestinal sac of the rat preparation within a single cohort of undergraduate students in one UK University. They found that: knowledge gain of the two groups was equivalent (based on a pre- and post- knowledge test); student's who used the computer-based alternative to the animal experiment became more positive about the learning experience after they had used it; the cost of running the computer-based session was significantly lower than that for the laboratory session (the computer program was used with a printed workbook with no tutor support whereas the laboratory-based project required full tutor support and some technical support). Clearly the two groups achieved different objectives but interestingly the tutors who ran this teaching session did not identify laboratory/animal skills as being primary learning objectives.

A more recent study (Hughes, 2001) compared the academic performance of students doing animal labs (where students set up and manipulated their own tissue preparations, prepared their own solutions and calculated and prepared the doses and concentrations to be used as specified in the exercise schedule) with those who used a computer-based simulation. Academic performance was assessed by a write-up which measured theoretical knowledge of the practical. The study demonstrated that in each of 5 separate studies the assessed perfor-

mance of the students who did the simulated experiment was statistically significantly better than that of the students who did the animal lab. However, there was some evidence that some weeks later the animal lab group was better able to recall the practical details of the experiment they had performed.

Several other studies have also demonstrated the effectiveness of computer-based alternatives compared to the traditional approach using animals (Fawver et al., 1990; Guy and Frisby, 1992; Kinzie et al., 1993; Leathard and Dewhurst, 1995).

Clearly, in a virtual laboratory environment there are certain skills, which some teachers might deem to be essential to say a pharmacology lab class which used an animal preparation which cannot be adequately taught. These might include such things as animal handling, possible anaesthetisation of the animal, some surgery (perhaps tissue removal, blood vessel cannulation), monitoring physiological signs, making up solutions of test/control drugs (weighing, pipetting), administering test drugs, setting up and using specific recording equipment of various types, recording results, humane killing at the end of the experiment. Virtual laboratory environments are no substitute to a real laboratory to teach laboratory skills although the basics of using instrumentation e.g. the use of simulated oscilloscopes to practice manipulation of various controls can certainly be covered as can practicing calculations for making up solutions. However, many of the general laboratory skills can be taught very effectively without the use of animals. Of course, for the majority of students, skills specific to, for example, a Guinea Pig Ileum preparation which has been used for many years to teach pharmacology are not essential. Many courses retain animal labs to teach principles, factual knowledge and as a vehicle for producing data which can be used to teach data handling skills, communication skills etc. There is no doubt that these learning objectives can be addressed equally well (and sometimes better) using a virtual lab (computer simulation). Teachers are the ones who make the decisions about whether an animal lab is needed. In some





cases those decisions are made in the face of evidence which supports the view that many of the learning objectives of such labs can be achieved by alternative methods. For that minority of students for whom training in those laboratory skills, which can only be acquired from an animal lab, is deemed necessary, teachers should be required to provide a "robust" justification for their institution to agree to the animal lab taking place.

### 3.3 Integrating alternatives into mainstream practice

Experience suggests (Markham et al., 1998) that it is not sufficient for teachers to simply make computer-assisted learning programs, such as those described, available over a campus network. This would be analogous to providing students with an animal preparation and a selection of drugs and expecting them to learn something about drug action through non-structured investigation. This scenario would not happen – tutors would be present in the laboratory and would provide students with learning objectives, a practical schedule to give structure to the class and some sort of assessment. As students adopt much more strategic patterns of learning, assessment is the key to successful implementation (Dewhurst and Hughes, 1999).

In the same way the computer-based alternatives were designed to replace the animal preparation or to provide data from a tutor-determined set of experiments directed towards meeting certain learning goals. Some of them have exemplar support materials (workbooks/study guides) associated with them and some contain built-in learning objectives and self-assessments. They are designed to be used in a tutor-supported learning environment and if they are to be used for self-directed learning then tutors must provide adequate support materials and learning must be assessed. The support materials may be similar to the laboratory schedule they would have developed for the animal lab and would contain learning objectives, a series of tasks and exercises designed to focus students on achieving the learning objectives and some form of assessment. By designing the "wrap-around" support materials

themselves teachers acquire ownership of the teaching session and the computer-based alternative substitutes for the animal or animal tissue as the means of generating data. One of the problems with the alternatives which have been developed is that they are only available in one language. Support materials may be developed relatively easily in any language and this approach may well be successful in repurposing existing resources. Assessment is crucial if students are going to take the teaching session seriously whether it uses a live animal or an alternative.

A government-funded project in the UK under the Teaching & Learning Technology Programme investigated whether providing teachers with a set of exemplar support materials (consisting, for example, of workbooks, self-assessment activities, case-based and problem-based learning scenarios, and assessments) could facilitate integration of CAL resources into pharmacology teaching. The results of evaluation studies suggest that this approach can be successful (Hollingsworth et al., 1999, 2001; Norris and Dewhurst, 2002).

### 3.4 e-alternatives for the future

The impact the alternatives will have on animal use in other institutions depends on the closeness of fit of the alternative with the needs of other institutions and the willingness of academic teachers in those institutions to adopt materials developed elsewhere. Although the needs of different HE institutions are similar, each values the differences that identify their particular courses as being different and, in their view, superior to others. This academic diversity and institutional conservatism is a characteristic of universities worldwide and is often a barrier to introducing teaching materials that are "not invented here". Thus an e-alternative which addresses the learning goals of, for example, a specific animal lab may be the perfect solution for one university (usually the one which developed it) but less than perfect for others. Under these circumstances it is clear that although a proportion of the content of the alternative will be suitable for many universities, it will be rejected by them as it doesn't meet all of their needs.

Anecdotal feedback suggests that teachers would like to be able to use those components of the alternative CAL program which they like but they would also like the facility to add some of their own i.e. customise to their own needs. Thus for instance, in a pharmacology simulation program they might wish to add new or delete current test drugs, extend the dose range, add new tasks or delete current ones, display the data in a different format (e.g. extend the time-base), translate the text into a language other than English, add summative assignments etc. Similarly small clips from videos of animal dissection or anatomy might be more useful and usable than the whole. To date the constraints of the authoring tools used to create the CAL programs described above make this very difficult if not impossible: institutions would have to purchase the authoring software, and they would need staff with the skills, time and experience to modify an existing learning resource.

Usually a multimedia CAL program would be developed by a small team comprising a content expert (e.g. an academic pharmacologist), a learning technologist and an educational designer adept at transforming traditional materials into an interactive format suitable for on-line delivery and student-centred learning. The content provider and the educational designer would assemble the components of that material – write the text, define what media they needed, find data traces, create self-assessment activities, suggest ideas for animations, produce video/audio clips etc. to produce a storyboard which would then be developed into a CAL package by the learning technologist using a multimedia authoring tool. This process, which is time-consuming and therefore expensive, also means that all of the components of the multimedia CAL are "locked into" the application and linked intrinsically to its delivery mechanism. While the educational content and learning design may still be valid, often changes in technology (such as we have seen in the move from DOS to successive versions of Windows) result in the delivery mechanism becoming obsolete with the result that the content and learning design are lost too.



The CAL program, which results from this development process, is very much the authors view of how the lab class, on which the CAL package is based, should be taught (what experiments the user should do, what tasks they should be set, how it is assessed). It may not suit everybody, it may not fit well with the diverse curricula in different institutions, there may be language problems if it were used in countries in which education is not conducted in English, there may be problems with the delivery platform (delivery may be restricted to stand-alone machines or a local area network/intranet), and updating or modification to suit "local" needs may not be easy.

Under these circumstances it is clear that although a proportion of the content of the alternative will be suitable for many universities, the CAL program may well be rejected by them as it doesn't meet all of their needs. This in the worst case may lead to the continued use of animals in teaching.

Developing a workable solution to these problems has now become possible with developments in Internet technologies and the concept of digital (reusable learning objects – RLOs) and repositories and is the subject of a research project (ReCAL) at the University of Edinburgh (Ellaway et al., 2004). Thus, it is possible to give teachers the building blocks and tools to create their own learning resources. The building blocks (digital RLOs) are stored in a digital repository which can be searched and suitable RLOs can be downloaded. The vision is that these can then be aggregated using easy-to-use tools and learning design templates in a way analogous to creating a PowerPoint presentation thus obviating the need to use complex authoring software.

In terms of alternatives, many of the digital building blocks already exist – locked inside the plethora of CAL programs already developed. These could be made accessible by disaggregating the CAL programs into their component learning objects, "revitalising" components where necessary e.g. recreating an animation for platform-independent delivery, updating textual content. The objects can then be stored in a digital repository, appropriate descriptive meta-

data can be added, to allow the repository to be intuitively searched by teachers, and tools and learning design templates can be developed to make it relatively simple for the non-technologist (teacher) to re-aggregate the learning objects. Teachers could select the RLOs they wanted and combine them with new components of their own to create teaching materials customized to their own needs. For example, blocks of text in English could be readily translated into any other language and incorporated into a new CAL package as necessary, new experiments could be added (provided the data existed) and unwanted ones could be removed, new animations, videoclips and assessments which suited the needs of the course could be incorporated.

It is now possible to purchase off-the-shelf LO repositories which will store RLOs and their metadata and which will package them in a form (IMS content packaging) that will allow them to be transferred into any technology platform for delivery such as a Virtual Learning Environment (VLE) which is IMS compliant.

Teachers wishing to use alternatives, and thus save animals, will have a choice. They will be able to use the existing CAL programs, which can be seen as exemplars of a tutor-prepared learning design populated from an array of digital components, or they can create their own from the repository of RLOs.

#### 4 Discussion

In contrast to the areas of research and development or the pharmacological and toxicological testing of drugs and chemicals, education in biomedicine has methods, which do not require animal experiments or animals killed specifically for their purpose, at its disposal for all learning objectives and learning contents. Thus, the problem lies not in the need to develop new recognised methods; rather in making teachers in higher education more aware, and convincing them of the merits, of the existing methods. There is no single valid strategy to solve this problem in all countries where culture and tradition as well as financial and technical constraints differ greatly. In many troubled countries animal protection simply

does not enjoy a high enough priority. The question of whether students of medicine learn muscle-nerve physiology using frog legs or their own thumb muscles often pales in light of the problems of daily existence.

Human vanity is also a factor that should not be underestimated. For many university teachers it is not acceptable to diverge from the methods one was taught and which one has always used in a life of teaching. Aversion towards accepting alternatives that were not developed in ones own country also plays a role. Sometimes it appears that German, American and Japanese medicines are different entities.

How can we promote alternatives when all attempts to convince university teachers of the didactic advantages of an alternative method fail? We must realise that it is not a question of education with or without animals. It is a question of good or bad education. Methods that cause repulsion in students cannot be didactically good. Medical students, who must learn muscle physiology with a frog leg, are learning with the wrong model, as they will not be treating any frogs. They will likely remember more about the negative mood of fellow students or the decapitation of the frog using scissors than about the results of the experiment.

What can be done? It is recommended that all countries introduce a requirement for prior approval of the use of animals in education. The decision on which education methods are suitable should no longer be left to individual preferences. Waiting until all teachers who think education requires the use of animals have left the education system is not an option.

A further important point addresses institutions that support alternatives. Set backs resulting from the support of the development of alternative teaching methods (the development of a myograph was financed with 900,000 DM by the German Research Ministry, but its production was stopped due to a lack of demand) may not lead to neglect of the cause. The introduction of alternatives may not fail due to a lack of money. A fine example was set by the *Ligue Suisse contre la Vivisection* that purchased a POP-Trainer for all Swiss edu-



education facilities for microsurgery training. We need many more POP-Trainers – in Russia, India and Brasil and we need to encourage continued financial donations to enable students a humane education.











Another important point is that those animals, which are truly necessary for education, must be treated and handled humanely. Veterinary medicine cannot be studied without animals. We are very thankful to InterNICHE for policy development work

in this regard (see appendix to the book "From guinea pig to computer mouse").












As mentioned at the start, alternatives in education are available. We should use them to make the education of biomedical scientists a humane experience.

**Tab. 4: Survey about existing alternative methods in biomedical education**













(Most information was taken from www.eurca.org. The authors wish to thank Goran Knežević, University of Banja Luka, BiH, for his help)

Name of the alternative	Supplier	Key description	Medium
<b>Anatomy/dissection</b>			
Comparative anatomy	UC Davis (USA)	- a collection of nine interactive learning modules covering the organ systems and related structures of mammals, birds and fish - each module contains gross, histologic and electron microscopic images	
The rat – a functional anatomy	University of Portsmouth (England)	- understanding of anatomy and physiology in mammals from gross morphology to microscopic detail - position of mammals and other classes within the vertebrate kingdom	
The rat – a practical dissection guide	Sheffield BioScience Programs (Scotland)	- a highly professional twenty minute full colour video of a practical dissection of rat	
Vertebrate dissection guides – the pigeon	University of Portsmouth (England)	- examines the live pigeon, the external features and initial dissection techniques - provides a detailed investigation of the external and internal features	
Vertebrate dissection guides – the dogfish	University of Portsmouth (England)	- examines the live dogfish, the external features and initial dissection techniques - provides a detailed investigation of the external and internal features	
<b>Anaesthesia</b>			
Anaesthesia of rats	BSL Publishers (The Netherlands)	- teaches students the basics and advanced skills of anaesthetics - simulates the complex technique of anaesthetics	
Careful how you hold me	Melbourne University Press (Australia)	- developed for new investigators and technical staff commencing work with animals in bio-medical research	
Laboratory animal anaesthesia non human primates – Part 1	Comparative Biology Centre, the Medical School, University of Newcastle upon Tyne (England)	- contains quicktime movies illustrating some anaesthetic techniques for use in non-human primates	
Remote	Microsurgical Developments (The Netherlands)	- trains the skills needed for patient monitoring during several (micro) surgical techniques	
Virtual anesthesia machine	University of Florida, Department of Anesthesiology (USA)	- web-based simulation of the flow of oxygen, nitrous oxide, carbon dioxide and volatile anaesthetics in an anaesthesia machine to help students learn how an anaesthesia machine functions	

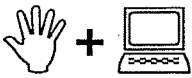



















Name of the alternative	Supplier	Key description	Medium
<b>Animal behaviour</b>			
Observing and recording mouse behaviours – mouse watch	Henk van Wilgenburg, (The Netherlands)	- helps the students to identify characteristics of the appearance of a normal or a drug treated mouse	
Simulated water maze	British Pharmacological Society (England)	- explains the importance of memory defects, illustrates different types of maze and gives a detailed description of the nature and use of a water maze	
Sniffy – the virtual rat	Thomson Learning (United Kingdom)	- a fun and interactive software program that gives undergraduate students a virtual laboratory experience	
<b>Laboratory animal science</b>			
Animal experiment	Bundesamt für Veterinärwesen (BVET, Switzerland)	- provide research personnel with background information on animal experiments and alternatives - supports researchers to carefully plan an experiment, including taking the steps of thinking of alternatives	
Koken rat	B & K Universal Limited (UK)	- a look alike of a real rat in silicone texture with similar weight and resembles the anatomy of a pharynx, trachea, stomach and tail vein. By practising the handling of look alike laboratory rats, unnecessary stress and pain can be reduced in real animals	
Pictures instead of animals	Comparative Biology Centre, the Medical School, University of Newcastle upon Tyne (England)	- provides moving pictures of laboratory animals displaying typical symptoms after being injected with pharmacological substances	
PVC rat	Microsurgical Developments (The Netherlands)	- mannequin model provides adequate education of researchers and technicians using microsurgical techniques	
Rat tail venepuncture simulator	Bell Isolation Systems Ltd (Scotland, UK)	- a silicone rat looking like a giant neonate, but with the weight of a real adult, and consists of a simulated blood solution and three different tails, which can be used to practice venepuncture skills	
<b>Pharmacology/toxicology</b>			
Autonomic pharmacology	Sheffield BioScience Programs (Scotland)	- simulates experiments on the human eye to teach the effects of autonomic drugs (useful replacement for the Finkleman preparation)	
Cardiovascular and autonomic pharmacology	University of Washington (USA)	- provides students with tutorial material about the autonomic nervous system (ANS) and drugs that affect it	
Cat nictitating membrane	Sheffield BioScience Programs (Scotland)	- simulates experiments on the superior cervical ganglion-nictitating membrane preparation of the cat ( <i>in vivo</i> ) to teach the pharmacology of ganglionic transmission and sympathetically innervated smooth muscle	



Name of the alternative	Supplier	Key description	Medium
Inflammation pharmacology	Sheffield BioScience Programs (Scotland)	- simulates a range of experiments designed to demonstrate the action of inflammatory mediators and pharmacological agents on the <i>in vivo</i> inflammatory response in the anaesthetised rabbit	
Intestinal absorption	Sheffield BioScience Programs (Scotland)	- simulates experiments designed to demonstrate by investigation the important characteristics of the transport of two important nutrients – hexoses and amino acids, in the small intestine	
Langendorff heart	Sheffield BioScience Programs (Scotland)	- highly interactive and simulates experiments which may be performed on the isolated perfused mammalian heart (Langendorff preparation)	
Macdope	<a href="http://www.chime.ucl.ac.uk/Models">www.chime.ucl.ac.uk/Models</a>	- a simulation of pharmacokinetics	
Neuromuscular pharmacology: Simulated sciatic nerve-anterior muscle preparation of the cat	Sheffield BioScience Programs (Scotland)	- simulates experiments performed on the sciatic nerve-anterior tibialis muscle preparation of the cat ( <i>in vivo</i> ) to illustrate the important differences in the pharmacological action of depolarizing and non-depolarizing blocking agents	
Frog skin	Sheffield BioScience Programs (Scotland)	- simulates experiments, which may be performed on the frog skin preparation to teach the principles of the epithelial transport of ions	
Respiration pharmacology	Sheffield BioScience Programs (Scotland)	- based on pulmonary function data obtained from guinea pig to teach the fundamental pharmacology of the airways	
SimHeart	Georg Thieme Verlag (Germany)	- simulates classic experiments with the so-called "Langendorff heart" - program offers a virtual laboratory with an isolated heart of a rat which is attached to the Langendorff apparatus	
SimPatch	Georg Thieme Verlag (Germany)	- providing a fully equipped virtual patch-clamp laboratory to perform electrophysiological experiments on neurons of the mammalian retina	
Simulations of pharmacological experiments on rabbit jejunum	Commercial and Academic Services Ltd (CoAcS) (England)	- rabbit jejunum <i>in vitro</i> is exposed to a range of drugs (agonists and antagonists) and the responses, pharmacological properties of the drugs and different types of receptor are studied	
Simulations of pharmacological experiments on the guinea pig ileum	Commercial and Academic Services Ltd (CoAcS) (England)	- covers basic receptor theory, including occupancy and how response size is related to occupancy - user is introduced to dose-response curves through simulated experiments of the action of drugs on isolated guinea pig ileum	
SimVessel	Georg Thieme Verlag (Germany)	- simulates classic experiments with isolated smooth muscles strips from blood vessels (aorta) and the stomach (antrum)	



Name of the alternative	Supplier	Key description	Medium
<b>Physiology/biochemistry/ molecular studies</b>			
Biopac Student Lab	Biopac student lab (USA)	- includes hardware and software that students use to record data from their own bodies, animals or tissue preparations - mainly focussed on physiology, but also cover pharmacology, toxicology and psychophysiology	
Blood coagulation	Sheffield BioScience Programs (Scotland)	- teach the physiology and laboratory assessment of haemostatic function and the use of the haemostatic profile in diagnosis of common clinical disorders	
Blood physiology	Sheffield BioScience Programs (Scotland)	- teaches the principles of the laboratory determination of red blood cell indices and blood group and their use in the diagnosis of anaemias	
Frog heart	Sheffield BioScience Programs (Scotland)	- simulates a number of experiments which can be performed on the <i>in situ</i> heart of a pithed frog	
Muscle physiology	Sheffield BioScience Programs (Scotland)	- simulates experiments on the frog sciatic nerve – gastrocnemius muscle preparation to illustrate physiological properties of skeletal muscle	
Nerve physiology	Sheffield BioScience Programs (Scotland)	- simulates a number of experiments performed on the frog sciatic nerve preparation to illustrate some of the important properties of mixed nerves	
Renal function in humans	Sheffield BioScience Programs (Scotland)	- simulates experiments to study the renal function in humans	
SimMuscle	Georg Thieme Verlag (Germany)	- simulates the classic experiment on the leg muscular of a frog (musc. gastrocnemius)	
SimNerv	Georg Thieme Verlag (Germany)	- simulates the classic experiment on the sciatic nerve of a frog (nerve stimulation and recordings of compound action potentials (CAP)) - offers a completely equipped virtual laboratory in a realistically looking 3D framework on the computer screen	
Squid axon	Sheffield BioScience Programs (Scotland)	- simulates a number of experiments on the isolated giant axon of the squid, which may be performed to investigate the biophysical properties of nerve	
Biochemical simulations (enzyme assay, urea synthesis, peptide sequence, oxygen electrode, radio-immunoassay, nitrogen balance and energy balance)	David A Bender (UK)	- contains seven simulated programs: enzyme assay, urea synthesis, peptide sequence, oxygen electrode, radio-immunoassay, nitrogen balance and energy balance	
Cellular Respiration	Sheffield BioScience Programs (Scotland)	- program designed to teach, by investigation, the important principles of cellular respiration and is based on a series of experiments which may be performed on isolated rat liver mitochondria <i>in vitro</i>	

Name of the alternative	Supplier	Key description	Medium
Experiments in human neuro-muscular physiology	Commercial and Academic Services Ltd (CoAcS) (England)	- introduces the student to some of the apparatus (oscilloscope, stimulator) and the experimental techniques used to examine resting potential, action potential and nerve conduction	
Veterinary physiology	Peter Rudas (Hungary)	- can be used as a teaching material in the lecture theatre by the professor *serve the needs of a student who prefers learning independently	
<b>Surgery/clinical training</b>			
Pulsatile organ perfusion, POP trainer	Optimist HgmbH, Bregenz, Austria	- simulates blood supply of organs from slaughterhouse - excellent training in laparoscopic and thoracoscopic techniques - assists training in minimal invasive surgery (MIS)	
Beating heart	Dani Frei, Buchs, Switzerland	- totally artificial training model for coronary heart surgery - based on differentially hardened polyurethane - 1:1 replica of human thorax - disposable coronaries	
Critical care fluffy	Rescue Critters! brand (USA)	- a full-size cat mannequin and is designed for the CPR or anaesthesia trainee to perform mouth-to-mouth rescue breathing, endotracheal tube placement and manual ventilation, and chest compressions	
Critical care jerry	Rescue Critters! brand (USA)	- the ability to aspirate air & fluid from the thoracic cavity to simulate trauma as well as jugular vascular access - it features a realistic airway, representations of trachea, esophagus, and epiglottis, working lungs and an artificial pulse	



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