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from guinea pig to computer mouse

alternative methods for a progressive, humane education

InterNICHE

Nick Jukes
Mihnea Chiuia

Foreword by Gill Langley

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part b **case studies**

1. Virtual versus real laboratories in life science education: Concepts and experiences

Hans A. Braun

Institute of Physiology, University of Marburg, Germany

This report is based on many semesters' teaching experience with both 'real' and 'virtual' laboratories in practical courses for medical and human biology students at the University of Marburg. When massive student protest in the early 1990s led us to stop using animal preparations in practical courses, classical experiments like those with the frog sciatic nerve and others which we considered of high educational value were eliminated. In our search for alternatives we created virtual realisations of the original experiments. These are the computer programs *SimNerv, SimMuscle*, *SimVessel, SimHeart* and *SimPatch*, together called the *Virtual Physiology* series. The programs are distributed by Thieme Publ., Stuttgart/New York and have been in regular use for several years not only in Marburg but also in medical, biological science and related faculties at several hundred universities and high schools across the world. They are used in lectures, seminars, and - most widely - in practical courses, and they often have replaced the original experiments which used animal preparations.

This report therefore also considers comments from other colleges with a similar teaching background, as well as students' assessment of the virtual labs, specifically referring to an evaluation of *SimNerv* with a detailed questionnaire. As one of the developers of the *Virtual Physiology* series, I will also give some background information about the history of these programs, and explain how they reflect our principal philosophy - that educational software packages can and must be more than animated textbooks. I also describe our new series of virtual computer laboratories, called *cLabs*. More detailed information is given at our homepage www.cLabs.de, with free access to several applets of our latest release *cLabs-Neuron*.

History of the *Virtual Physiology* series

Our first teaching program, *SimNerv* (originally called *MacFrog*), was developed in the mid-1990s. At that time, the medical faculty in Marburg had already stopped using animal preparations in physiology courses. This was a consequence of massive, sometimes aggressive student protests against animal use which finally made regular teaching with animal preparations impossible. In our faculty I was probably most strongly exposed to the student protest because I was teaching the remaining two courses which involved animal preparations - the classical frog nerve and muscle experiments. I was heavily defending these experiments because I considered them to be the best examples for effective practice-oriented learning.

We therefore looked for alternatives, and saw that they did not exist. But we soon recognised that rapidly developing computer techniques could provide an opportunity to make virtual laboratories where the students can do experiments similar to the real lab. These ideas were realised in collaboration with our then students Martin Hirsch, an expert in multimedia design, and Martin Huber, a specialist in computer modeling for neurodynamics. As a private venture, but with support from the Director of our institute, Karlheinz Voigt, we developed our first virtual lab, *MacFrog*, which later, as part of the *Virtual Physiology* series, was renamed *SimNerv*. Coverage of the program in diverse media (newspapers, TV) led to external support from Apple Computers and the Hessian State Ministry of Science and Arts (HMWK).

The program was winning awards almost from its inception. In 1994 *MacFrog* won the German/Austrian Software Award for the Best Teaching Software in Biology and Medicine, the Award for the Best Multimedia Application, and the MacWorld Editors Award for Trendsetting Multimedia Software. With this background we received, in contract with Thieme Publishers (Stuttgart /New York), a substantial grant from the German Ministry of Education and Science (BMBF). This support allowed us to take *SimNerv* into its final form for public distribution, and to develop three more programs, *SimMuscle*, *SimVessel* and *SimHeart*.

These programs together reproduce exactly the experiments which before had been done with real animal preparations in integrated physiology / pharmacology courses for medical students in Marburg. A fifth and final program, *SimPatch*, was added by Horst Schneider and Martin Hirsch, completing the *Virtual Physiology* series.

Martin Hirsch is now the owner of a successful multimedia company (iAS, Marburg/Berlin, see www.brainmedia.de). Martin Huber is successfully continuing his scientific computer modeling studies at the Department of Psychiatry and Psychotherapy, still in close co-operation with us. Horst Schneider had left the university for industry but recently came back to our group and has contributed to our new series of teaching software *cLabs*.

Background and concepts of the virtual labs

The development of our virtual computer laboratories was guided by the same criteria which had previously led me to defend the 'real' experiments. The criteria are related to the high teaching impact of practical courses which can be achieved when well-prepared students do the experiments on their own. The prerequisites are that the students understand the experimental set-up, i.e. they don't have to deal with over-complicated devices, and that the physiological tasks are practice-oriented but closely related to the theoretical knowledge. The ideal situation would be 'learning by doing', with free experimentation by students.

Therefore, we designed a user-friendly computer interface where fully equipped labs appear on the computer screen and where all instrument settings are freely adjustable by mouse-clicks. In parallel, we developed mathematical algorithms for the heart of the program, which, according to the device settings chosen, reproduce realistic responses from the preparations. Moreover, we use random variables to account for the natural variability of the preparations, which also has the advantage that no student will have the same preparation or the same results as his/her neighbour. In this way we came very close to the situation in the real lab, and, in addition, could take advantage of some specific features of the virtual world, as described below.

The programs allow students to perform experiments at different levels of complexity. There is the experimental situation, which is relatively easy to grasp - for example, when students have to reproduce classical textbook illustrations like isotonic and isometric maxima of muscle contractions.

The idea is that students who successfully do these recordings on their own will never again have problems with the understanding of basic biological characteristics. They will also be well practised in procedural skills. Additionally, as a more general aspect, the students will learn (sometimes the hard way) that successful experimentation also requires profound theoretical knowledge. They will see that this is needed for the systematic collection of problem-relevant data as well as for critical, qualified data analysis and appropriate presentations of the results. It is also needed for correct interpretation of the experiment itself. For example, interpretations of most recordings in the nerve experiment require theoretical knowledge about ion channel gating, which means that the students, in a more demanding task, have to bring together knowledge from quite different physiological levels.

These teaching aims go far beyond learning and reproducing factual textbook knowledge. Here, students learn how to make use of their knowledge, and this is certainly much more closely related to the problems that they will have to face later in their career - for example, as a medical doctor who has to decide about the appropriate treatment of a patient on the basis of systematic inspection and correct diagnosis. It is worth noting that this is exactly the area where the 'Program for International Student Assessment' (PISA) only recently detected major educational deficiencies in Germany and internationally.

Teaching experiences with real and virtual labs

The main argument against the virtual labs generally is that students cannot practice the preparation of living biological tissue with mouse-clicks. Indeed, this cannot be achieved even with the most excellent computer simulation. When this is the objective of a course the experiments necessarily have to be done with animal preparations. However, the major question is how far it is justified to practice these specific skills in regular biology, physiology and pharmacology courses or at high schools.

The answer essentially depends on the need and the efficiency of such training. I myself often have argued that at least medical students, before they treat patients, should know from their own experience how sensitive living tissue reacts and how easily proper functioning can be destroyed by improper handling. But I am no longer sure about these arguments because medical doctors are becoming more and more specialised and those who perform operations will be trained in this respect anyway. The efficiency is also questionable, specifically in relation to the actual situation at our university where we now have 16 students in one practical group, compared with the 6 or 8 when I last did experiments with animal preparations in a student lab.

It is hard to do such work with a group of 16 inexperienced students. Indeed, I know of several departments where the students receive ready-prepared tissue from the tutors. Hence, many courses which involve the use of animal tissue do not in fact include preparation of that tissue by students. The experiments following the preparation, however, can be done better in the virtual lab. In the following I am going to illustrate this specifically referring to our and others' experiences with *SimNerv*, because this is the program which has been in use longest and for which we have a recent detailed students' evaluation.

When we introduced *SimNerv/MacFrog* into the regular physiology course we didn't have time to write the instructions in advance. We used the instructions and protocol forms which were left from previous courses with the animal preparations. With no difficulties, the students followed the same instructions and did exactly the same experiments as previous students did with the real nerve - and with even better success. This illustrates how closely this simulation resembles the real lab, something that was confirmed by many other groups ("This simulation allows the students to experience virtually everything that they would see in the real nerve"). Indeed, there are several institutes where I know that the teachers originally wanted to use *SimNerv* as an introduction to the real experiments but who then decided that "this follow activity may be unnecessary" (quotations from a report by D. Wilson, Miami University, Oxford, Ohio).

However, over the course of time, we noticed that we were in fact doing a better job with the virtual than with the real preparations. We realised - admittedly only from our new experience from the virtual labs - that it was an illusion that students were doing their own experiments in the animal lab. They always strictly followed the instructions and, whenever some settings had to be changed, they would ask the tutors whether the settings were correct before they continued with the experiments. The reason for this is obvious. The students were afraid that wrong settings might destroy the preparation, and that as a consequence they might not get the certificate or might have to kill another animal (which we, by the way, would never have allowed).

So we were unexpectedly confronted with surprisingly active students in the virtual labs which, step-by-step, led us to modify the instructions. Specifically, tasks have been included for which we do not explain the experiment in detail but let the students investigate. Some of these experiments would have been very difficult to carry out in the real lab but are of particularly high didactic value. For example, in the real nerve experiment it is almost impossible to block the nerve conduction or even to change the positions of stimulating and recording electrodes without unpredictable changes in the whole situation. This can easily be done in the virtual lab. So we ask the students to induce mono- and biphasic or inverted action potentials, or to find out which electrode is connected to the positive and negative stimulator output or the inverting and non-inverting input of the differential amplifier, respectively. By the time the students have succeeded in answering this question through their own experimentation they have understood a lot about the generation and recording of compound action potentials, and, as a more general aspect, should have seen that the experimental settings can interfere profoundly with the outcome of an experiment.

As another example, in *SimHeart* we encourage the students to examine heart activity at its limits, in addition to the standard experiments. We let them induce and compare cardiac arrests in the systole and the diastole, or ask them to apply glycosides to an already pre-activated heart to see not only the positive effects of therapeutic substances but also their potential toxicity. We believe that the students can learn a lot from such extreme situations of heart contractions which, in the real lab, are mostly avoided because you never can be sure that the preparation recovers.

Hence, experimentation in the virtual labs is more rich, and students are more active. It is my impression and that of other tutors that teaching has become not worse but more effective. There are no students who are frustrated due to preparations or instruments that sometimes fail. They are not confused by instruments that have extra controls which they should not touch. Requests for help from tutors are less numerous and the students' own initiative is clearly improved. Last but not least, experimentation and learning do not suffer from the negative emotions of using killed animals.

Of course, there are still teachers who definitely want to have 'animal experiments' in student physiology or biology courses. Our programs seem to be dangerous to their concepts. This would partly explain the curious criticisms, especially from German colleagues, that the programs are "worse than television", "toys", or "tamagotchies". Such comments (R. Klinke, H. Wiese in Uni-Spiegel 2/2001), however, are the exception. Most reports in German newspapers and journals, especially those with the highest reputation, praise our programs and emphasise, for example, that "the authors, undoubtedly, did excellent work" (Frankfurter Allgemeine Zeitung, FAZ, 22.07.98), or, more recently, that these programs "are more instructive than classical experiments" (Zeitpunkte 1, 2001) and "have set international standards for high quality teaching software" (Die Zeit, 28.12.00).

These positive reviews of our programs were recently confirmed by an evaluation of *SimNerv* with a detailed questionnaire that was anonymously answered by 155 medical students in our regular physiology course. Questions about user-friendliness revealed that there were no difficulties associated with the use of the virtual devices. The students felt that *SimNerv* helped to increase their understanding of nerve physiology, and most assumed that they may even have learned more than in the real experiment. As the *SimNerv* experiment was held towards the end of the course when the students had already done most of the other experiments, we also asked them to compare *SimNerv* with other training experiments, and this again gave excellent positive results (>80%). This is even more remarkable considering that nerve physiology usually does not belong to medical students' favourite topics and that *SimNerv* had to compete with clinically very important exercises (EEG, ECG, blood plasma analysis etc.) performed in very well equipped labs.

The students were also asked whether they consider multimedia simulations as valid alternatives to real experiments. This question was asked prior to using *SimNerv*, revealing a principally positive opinion on computer simulations. When the students were asked again following the *SimNerv* experiment there was an additional, statistically highly significant shift toward still more positive values. It is therefore no surprise that the students showed an interest in the development and use of further simulation programs.

Current situation and plans: the *cLabs* concept

Our present work continues with an advanced series of virtual computer labs, called *cLabs*, which expands the *Virtual Physiology* concept in several respects.

Firstly, the cLabs programs will further facilitate students' own experimentation and therefore also include more simple animations and simulations to prepare step-by-step for the experiments in the more complex virtual labs. For one of our programs, *cLabs-Neuron*, part of these applets are already running on our homepage www.cLabs.de. For the other program, *cLabs-SkinSenses*, they will soon be available, and we are going to develop similar resources for the *Virtual Physiology* series too.

The *cLabs* series also includes experiments which, like *SimPatch*, are too difficult to be physically carried out in student coursework but which can be realised *in silico*. This is the case for *cLabs-Neuron*, which provides virtual labs for ion-channel recordings and current/voltage clamp experiments, as well as for *cLabs-SkinSenses* which simulates single-fibre recordings from mechano- and thermosensitive afferents from the skin.

Moreover, our principal approach with the use of mathematical simulations, including random components, fits perfectly with the idea of an advanced 'Virtual University' because it allows control of individual experiments by the students themselves as well as by the tutors - and also via the internet. For example, whenever a user opens one of our virtual labs he/she will find his/her personal preparations. However, what for the user will appear as principally unpredictable variability is mathematically clearly defined. This makes it possible to develop a control software for immediate check of individual results. Here we see the most promising solutions for highly effective teaching software for the future.

This was, unfortunately, not the opinion of some unknown referees. In a major initiative, the German Ministry of Education and Science (BMBF) spent about US$100 million for the development of new teaching software, but refused any support for us although we are still the only German group with teaching software of international reputation, at least as far we are aware within the fields of biology and medicine.

We have been continuing our efforts and have made good progress with some support from 'transMIT', Giessen. We have already presented parts of the *cLabs*-programs with great success at international conferences, including the teaching exhibition of the 2001 Neuroscience Meeting in San Diego. The dates of upcoming exhibitions are given on our homepage www.cLabs.de. To speed up the progress and to realise our plans with the integrated control software we would be happy to explore potential co-operation. We are confident that these programs, even more than the *Virtual Physiology* series, will find hundreds of interested institutes with many thousands of users all over the world.

Biography

Hans Albert Braun is head of the Neurodynamics Group at the Institute of Physiology at the University of Marburg in Germany. He trained as an electronic engineer at the Technical University in Karlsruhe, where he obtained a degree in 'Electrobiology'. In a supplementary study of 'Human Biology' he obtained his PhD at the Medical Faculty of the University of Marburg. His research involves experiments and models of neuronal encoding and neuromodulatory processes in peripheral sensory receptors and hypothalamic neurones, including computer modeling studies of affective disorders. The aim is the understanding of neuronal systems dynamics at different levels and to elucidate their common functional principles. With the background of these experiences, the Neurodynamics Group has developed teaching software with virtual computer laboratories for practice-oriented learning, including the award winning teaching software *SimNerv*. Hans A. Braun is a member of several scientific societies and has been honoured with the fellowship of the Biophysics Division of the American Physical Society.

Hans A. Braun, PhD

Institute of Physiology
University of Marburg
Deutschhausstr. 2
D-35037 Marburg
Germany

tel: +49 6421 286 2307
fax: +49 6421 286 6967
e-mail: braun@mailer.uni-marburg.de