A computer-assisted learning (CAL) package, NeuroLab, developed for use by first-year university students undertaking professional programs in the health area, is described and evaluated. NeuroLab is a simulation of a laboratory, in which students are able to impale neurons to measure resting membrane potentials and subsequently undertake experiments including measuring resting membrane potentials, determining threshold potentials, measuring refractory periods, and examining effects on membrane potential through altering the membrane permeability to sodium and potassium ions. Students find the package to be a worthwhile learning experience, with 81% reporting the package increased their understanding of neuron function, and 78% expressing a desire for more CAL packages. Exposure to the package resulted in significantly higher mean scores in a multiple-choice question test on measuring neuron membrane potentials compared with those who were not exposed (mean scores out of 4 of 2.42 and 2.02, respectively, \( P \leq 0.001 \)).

**Key words:** neuron; membrane potential; action potential; threshold; refractory period; membrane permeability

One of the difficulties for students of bioscience is that, due to the complexity of body systems, real-life experiments do not always turn out as expected. There is evidence that the use of models can be more effective than the use of real objects in helping beginning tertiary students understand complex concepts (17). Computer-assisted learning (CAL) packages are an appropriate option for physiology instruction, as they are amenable to modeling complex systems and elucidating complex concepts and are usually considered a valuable learning tool by students (1). Not unexpectedly, many computer simulations have been developed and are available in the public domain for use in teaching about the function of neurons and the action potential in particular.

In many instances, these can be accessed via the Web. Some of these are concerned with the original experiments of Hodgkin and Huxley on the squid giant axon (5, 8), and these and others allow manipulations of ion conductances (4) or ion concentrations (5) as well as current and voltage clamp experiments to examine effects on membrane potential, current flows, and the shape of the action potential wave (7, 18). The emphasis with these simulations is on the neurophysics of responses of neurons to differing physiological conditions. Little attention is given to providing realistic simulations of a physiological laboratory.

Simulations on the Web, which seem to be intended more for beginning students, sometimes fail to convey a sense of reality. In some simulations (10), the only activity undertaken by the user is the clicking of the mouse. With each click the next part of the operation or experiment is performed. The continual clicking detracts from the perception of reality.
Other simulations are distributed on CDs accompanying textbooks (11, 12). These mainly take the form of a tutorial in which the content is presented in a descriptive way, and again through simple mouse clicking the user observes phenomena displayed in front of them on the computer screen. There is no genuine attempt to allow self-discovery of facts and concepts by the user, and, apart from having to guess true or false or answer some multiple-choice questions (MCQs), there is little decision making being demanded of the user.

Descriptions of simulations in the literature reveal genuine attempts to simulate the laboratory situation of extracellular recordings from neurons (15) as well as intracellular impalement of neurons (2). However, with these and others (3), some of which are specifically directed at medical students (6, 9), the depth to which the information is analyzed goes far beyond what is presented in the present simulation.

Although all of the simulations reported above are valuable resources within the context in which they are delivered, they are either too advanced or are presented in an inappropriate way for the target audience for which the present simulation is intended, that is, beginning university students undertaking degrees in professional health courses. The majority of these students will not specialize in physiology and may not have a primary interest in physiology.

The aims of this report are to 1) describe a CAL package (NeuroLab) for use in the teaching of introductory neurophysiology, 2) assess student satisfaction in using NeuroLab, and 3) assess whether student learning is facilitated by NeuroLab.

NEUROLAB

NeuroLab has been developed at the Faculty of Health, University of Newcastle in Australia, to concentrate on the structure and function of neurons. At the heart of NeuroLab are several simulations of experiments on the basic functions of neurons. Classical laboratory exercises utilizing external recordings of nerve impulses, as is commonly performed on frog sciatic nerve preparations, sometimes mislead students about what it is they are observing. Because in lectures and in textbooks students are taught about intracellular recording of a single action potential, they sometimes wrongly believe that they are observing the activity of just one axon when the intensity of stimulation applied to the sciatic nerve is increased and the amplitude of the compound action potential increases. Students, who wrongly believe that they are observing intracellular events, interpret this to mean that the amplitude of a single action potential can increase with increasing intensity of the stimulus. It is explicit in NeuroLab that students are carrying out intracellular impalements of neurons so that these misconceptions do not arise.

To engage students’ interest and active participation in NeuroLab, we paid close attention to the graphic and instructional design to create a realistic simulation of an electrophysiology laboratory. For example, when students use the microelectrode to impale the neuron, the electrode can break, pass right through the neuron, or become clogged at the tip or slip out of the cell. Only in ~50% of attempts do they get a “good” impalement. These various scenarios, as well as the need to manipulate the cathode ray oscilloscope and the stimulator in a knowledgeable way, generate a strong sense of realism throughout and, in turn, encourage high-level interactivity between the student and the software. As students work through NeuroLab, they receive immediate and highly specific feedback from within the package about how to use the equipment and on the results they obtain. The feedback is delivered by way of audio, textbox information, and animations.

NeuroLab has been placed on a server in the University with student access through a computer laboratory that contains 20 computers fitted with sound cards and adapters that allow two students to work at one terminal if necessary. A CD of NeuroLab (Experiments With Neurons) has also been created and is available through Pearson Education (Sydney, Australia). Extensive audio instruction and feedback are provided to the user through headphones. Headphones also allow many students to work in the laboratory without distracting one another. For the past five years, a one-hour session has been scheduled into the course for groups of about 30 students at a time (total of ~600 students). Each station is independent of the others, so students can proceed through NeuroLab at their own pace. NeuroLab remains available on the...
server after the scheduled sessions to allow students ready access to the software on their own time. Student use of NeuroLab outside of scheduled sessions was not tracked.

NeuroLab is introduced by “Professor Neuron,” an animated cartoon character, who explains what the students will be required to do when using the package and who acts as a tutor to help them when they are having difficulties (Figs. 1 and 2).

NeuroLab uses the metaphor of a book and is divided into seven chapters (Table 1). Students are able to browse any chapter in any order.

In the exercises and simulated experiments described in Table 1, the data that one student obtains will differ from those of other students and so require independent interpretation and evaluation of their validity. After the students have considered the acceptability of the data or determined the appropriateness of results obtained, they then receive personalized advice and instruction on their decision making through specific feedback provided by NeuroLab.

METHODS OF CAL PACKAGE EVALUATION

Two methods were used to assess NeuroLab. The first involved student feedback about the software, and the second compared student examination scores.

Student Feedback

In a period of three academic years, a total of 1,541 students used NeuroLab. The students were enrolled in a variety of courses, including Biomedical Sciences, Nursing, Nutrition and Dietetics, Occupational Therapy, Physical Education, and Speech Pathology. Of these, about 1,044 (68%) returned completed questionnaires about the course including specific questions about NeuroLab. The questions were worded as statements with a five-category Likert response scale (strongly agree, agree, neutral, disagree, strongly disagree). The statements were:

Screen capture of introduction to the package. “Professor Neuron” is shown here addressing the student. Audio as well as text displays are used throughout.
I found using this package a satisfying learning experience.

I found using this package increased my understanding of neuron function.

I would like more of these computer-assisted learning packages.

The student responses to these statements are presented as percentages in RESULTS, Table 1, with 95% confidence intervals shown in the abstract.

**Student Examination Scores**

The students used in this study come from several university degree programs, which have widely different entry requirements and, presumably, students with a wide range of abilities. Students from each program attend weekly tutorials in groups of about 25. Tutorials are unstructured and are intended as sessions in which students can seek help on what is covered in lectures. All students attend the same mass lectures in Human Bioscience 1. For the lectures on the nervous system, students were given quite detailed explanations on methods of investigating the electrical properties of neurons and, in particular, the way in which resting membrane potentials and action potentials are measured. Included in these explanations were descriptions of the equipment used (cathode ray oscilloscope, KCl-filled glass microelectrodes, electrical stimulator, etc.). They were also directed to relevant diagrams in their textbook. In addition, students were shown a video in lectures of a stylized neuron being used to measure resting membrane potentials and action potentials.

Student tutorial groups were allocated to receive either the one NeuroLab session including the usual tutorials (CAL) or the usual tutorials without the
NeuroLab session (non-CAL). One month after the CAL session, both groups (CAL and non-CAL) were assessed using 12 CMQs (two of which were true/false questions). Seven questions related to neuron membrane potentials and ion flows, one question to the structure of the neuron, and four questions to the use of equipment used in measuring and recording membrane potentials (see Appendix 1). The test was not compulsory, and students were not given advance notice of this assessment. They undertook the test at the end of a lecture. About one-half of the students at the lecture stayed behind to do the test. Students were asked to mark on their answer sheets the degree program that they were doing and whether or not they had done the NeuroLab session. After the test and before final assessment, those who had not received the CAL session were scheduled for their session. Statistical significance of the test score differences, within each enrollment category, between CAL and non-CAL students was tested using Student’s t-test (Table 3, RESULTS). Differences in overall scores and question topic scores between those who had undertaken the CAL package and those who had not were tested using analysis of variance, adjusting for program enrollment (Table 4, RESULTS).

RESULTS
Student Feedback
Overall, NeuroLab has been very well received by the students. The majority found it to be a satisfying learning experience and, perhaps even more importantly, believed that it had increased their level of understanding of neuron function (Table 2). Indicative of their interest in the package is that most students believed that more CAL packages should be developed and made available to them (Table 2).
When the performances of students from the same program enrollment group were compared, it was found that, in each case, the means for the CAL students were higher than those for the non-CAL students (Table 3).

After adjustment for program enrollment, CAL students performed better overall than non-CAL students (Table 4). However, when the test was broken down into sections of questions on similar topics, the analysis showed that CAL students performed significantly better than non-CAL students on questions concerning labeling of neurons as well as on questions relating to the use of equipment and measuring of neuron membrane potentials, but they did not perform significantly better than non-CAL students on questions about neuron membrane potentials and ion flows (Table 4).

**DISCUSSION**

Using the CAL package (NeuroLab) seems to enhance student understanding of the way in which neuron membrane potentials are recorded and measured. CAL student performance on MCQs relating to the use of equipment and methods of measuring neuron membrane potentials was significantly better than the performance of non-CAL students (Table 4). This result may reflect the realism of the NeuroLab simulation and the fact that students find NeuroLab to be user-friendly and would like more of these CAL packages (Table 2).

In terms of increasing understanding of physiological concepts the results were less clear. Although students believed that their understanding of neuron function had improved (Table 2), this has not been borne out in an analysis of student performance on MCQs concerning neuron membrane potentials and ion flows. Although the mean result of the CAL students for these questions was slightly higher than that of the non-CAL students, this difference was not statistically significant (Table 4). Only one question in the MCQ test related specifically to neuron structure. CAL students performed much better than the non-CAL students on this question.

<table>
<thead>
<tr>
<th>Program</th>
<th>CAL n</th>
<th>Mean Score ± SD</th>
<th>Non-CAL n</th>
<th>Mean Score ± SD</th>
<th>P Value (Student’s t-test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nursing</td>
<td>45</td>
<td>6.76 ± 1.92</td>
<td>51</td>
<td>5.92 ± 1.59</td>
<td>0.04</td>
</tr>
<tr>
<td>Biomedical Science</td>
<td>13</td>
<td>8.92 ± 1.98</td>
<td>16</td>
<td>8.50 ± 2.48</td>
<td>0.62</td>
</tr>
<tr>
<td>Speech Pathology</td>
<td>4</td>
<td>9.00 ± 0.82</td>
<td>21</td>
<td>6.57 ± 2.01</td>
<td>0.03</td>
</tr>
<tr>
<td>Unknown</td>
<td>5</td>
<td>5.40 ± 1.67</td>
<td>3</td>
<td>6.00 ± 1.00</td>
<td>0.60</td>
</tr>
<tr>
<td>Occupational Therapy</td>
<td>30</td>
<td>7.03 ± 1.36</td>
<td>2</td>
<td>5.50 ± 2.12</td>
<td>0.18</td>
</tr>
<tr>
<td>Nutrition and Dietetics</td>
<td>19</td>
<td>7.57 ± 1.80</td>
<td>43</td>
<td>6.58 ± 2.06</td>
<td></td>
</tr>
<tr>
<td>Physical Education</td>
<td>38</td>
<td>6.00 ± 1.88</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical Radiation Science</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
question (Table 4). This may reflect the additional practice that CAL students obtained in labeling diagrams of neurons in NeuroLab. Because the students who undertook the test (Tables 3 and 4) volunteered, there may be a selection bias in our results. The potential for bias is mitigated to some extent because the test was not advertised; approximately the same proportion of CAL and non-CAL students undertook the tests, and the differences were consistent across enrollment programs.

As well as influences on student learning, NeuroLab provides an opportunity for all students to participate in all aspects of the experiments. This is not always the case in conventional laboratory classes, where students often work in groups with only one or two being active participants. Furthermore, the degree and level of assistance is improved. It is difficult for academic staff to provide much personalized assistance for anything more than a few minutes at a time in a conventional laboratory class of 30 or more students. In NeuroLab, assistance is regular and personalized.

Students have to become very intellectually involved to work through the package successfully. Throughout, each student is called upon to respond to questions, to label diagrams, to undertake arithmetic calculations, and to collect and interpret data in an experimental situation. The computer simulations of these experiments provide models of the real thing—models that can be manipulated and experimented on to yield appropriate information. The complexity of interaction of body systems can be avoided. As Michael (13) has commented, “One of the things that makes learning physiology difficult is the fact that everything ultimately is connected to everything else. Disturbances to one part of one system will give rise to consequences that involve many organs or organ systems.” It is not always clear to the student why an experiment has “gone wrong.” There is evidence in other fields of tertiary study that the use of models can be more effective than the use of real objects in helping beginning students understand complex concepts (17). Although our models incorporate realistic data, they do not present what might appear to be conflicting or confusing information to the user.

NeuroLab has been developed using the authoring system, Asymetrix Toolbook. Through the use of the programming language supporting the authoring software, immediate audio and textbox feedback is provided to each student on how to use the equipment and on the results they obtain as they work through the package. This individualized feedback helps put students’ results in context. It assists them to develop mental models of neuron function, thereby making neurophysiology more meaningful and significant to them (13, 14). The specificity and immediacy of the feedback helps correct misunderstandings. From observation of students in the computer laboratory, there is no doubt that students find this aspect of the package very valuable to their learning. This result is consistent with other research on the effects of feedback in computer-assisted instruction (1).

There are also financial benefits. To set up just one electrophysiology laboratory is very expensive. Furthermore, only one experimenter at a time can use the equipment. To cater for large numbers of students is virtually impossible. The use of a computer simulation obviates these difficulties and offers

<table>
<thead>
<tr>
<th>Question Topic</th>
<th>No. of Questions</th>
<th>CAL (n = 116)</th>
<th>Non-CAL (n = 174)</th>
<th>F Test</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neuron membrane Potentials and ion flows</td>
<td>7</td>
<td>4.21</td>
<td>4.11</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>Labeling the neuron</td>
<td>1</td>
<td>0.56</td>
<td>0.28</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Use of equipment and measurement</td>
<td>4</td>
<td>2.42</td>
<td>2.02</td>
<td></td>
<td>0.0009</td>
</tr>
<tr>
<td>All questions</td>
<td>12</td>
<td>7.19</td>
<td>6.49</td>
<td></td>
<td>0.0012</td>
</tr>
</tbody>
</table>

Values of CAL and non-CAL are means.
large numbers of students at the University of Newcastle an opportunity to undertake these sorts of experiments.

CONCLUSION

NeuroLab is interactive. It makes extensive use of multimedia, including animations, audio, graphics, pictures, and text to engage students. It has been developed with the nonspecialist physiology student in mind. Students make discoveries for themselves and receive specific and extensive feedback on their data collection, their interpretations, and their decision making throughout the package. The instructional design, the feedback provided, and the quality of the graphic design have been well received, capturing the students’ interest to the point of wanting more such learning tools. These factors enhance understanding of measurement methods employed in neurophysiology and facilitate a discovery approach to the learning of physiology.

APPENDIX 1

Q1. A nerve fiber, when stimulated, produces either a complete action potential or no action potential at all.
   A. True
   B. False

Q2. The strength of the stimulus determines the size of the action potential produced by a nerve fiber.
   A. True
   B. False

Q3. Opening of sodium channels in the membrane of a neuron results in
   A. depolarization
   B. repolarization
   C. hyperpolarization
   D. increased negative charge inside the membrane
   E. reestablishing the resting potential

Q4. The all-or-none principle states that
   A. all stimuli will produce identical action potentials
   B. all stimuli great enough to bring the membrane to threshold will produce identical action potentials
   C. the greater the magnitude of the stimulus, the greater the intensity of the action potential
   D. all sensory stimuli activate action potentials and no motor stimuli activate action potentials
   E. all motor stimuli activate action potentials and no sensory stimuli activate action potentials

Q5. Which segment of the graph (Fig. 3), representing a neuron action potential, best corresponds to the time when the Na⁺ gates are open?
   A. 1
   B. 2
   C. 3
   D. 4
   E. 1 and 4

Q6. Suppose that a neuron is stimulated by a stimulus that is of just sufficient strength to generate an action potential. When a second, identical stimulus is introduced some time after the first stimulus, it will produce an action potential only if the
   A. neuron is myelinated
   B. second stimulus is applied outside the neuron refractory period
   C. neuron is a motor neuron
   D. second stimulus is much greater than the first
   E. sodium gates are still open

Q7. When sodium ions move into the neuron during an action potential,
   A. they flood in through nonspecific protein channels
   B. they flood in through specific protein channels
   C. they can enter only through sodium or potassium channels
   D. they dissolve in the membrane and quickly move to the inside
   E. three sodium ions move in for every two potassium ions that move out

FIG. 3. A neuron action potential.
Q8. In the diagram (Fig. 4) the number 3 is pointing to
A. a Schwann cell nucleus  
B. the neuron cell nucleus  
C. a mitochondrion of the neuron  
D. a collateral sprout of the axon  
E. none of the above

Q9. A cathode ray oscilloscope (CRO) is an item of equipment that can be used in electrophysiological laboratories
A. to rectify the oscillating AC current  
B. to stimulate neurons  
C. to produce action potentials in neurons  
D. to display electrical responses from biological tissues  
E. for none of the above

Q10. A common way to measure membrane potentials of neurons in the laboratory
A. involves the use of a glass microelectrode to impale the cell  
B. is to stimulate the cell and observe the response  
C. is to undertake a chemical analysis of the inside of the cell compared with the outside  
D. involves removal of the outer membrane of the cell to expose the internal contents  
E. involves aspirating the contents of the cell with a glass microelectrode

Q11. If the gain on a CRO was set on 10 mV/division and there was a deflection of the beam of the CRO of 7.3 divisions from the baseline position, this would indicate
A. that there was electrical interference disrupting the function of the CRO  
B. the starting position of the CRO needed to be adjusted  
C. a voltage of 7.3 mV was being displayed  
D. a voltage of 13.7 (i.e., 10 \div 7.3) was being displayed  
E. a voltage of 73 mV was being displayed

Q12. When the sweep speed of the beam of the cathode ray oscilloscope (CRO) is changed from 1 s division to 1 ms/division
A. the beam moves 1,000 times slower across the screen  
B. the beam moves 1,000 times faster across the screen  
C. only electrical events that take a brief period of time can be displayed  
D. only electrical events that take a long period of time can be displayed  
E. only electrical events that are triggered by a stimulator can be displayed

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Submitted 9 December 2002; accepted in final form 5 June 2003

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