Here we describe an evaluation of the effectiveness, compared with a traditional laboratory, of an interactive computer-assisted learning (CAL) program, which simulates a series of experiments performed using isolated, everted sacs of rat small intestine. The program is aimed at undergraduate students of physiology and is designed to offer an alternative student-centered learning approach to the traditional laboratory-based practical class. The evaluative study compared two groups of second-year undergraduate students studying a module on epithelial transport: one group worked independently using the CAL program and associated learning materials, and the other group followed a conventional practical class approach, working in the laboratory under supervision. Knowledge gain of each group was measured by means of a test consisting of a range of question types (e.g., short-answer factual, calculation, interpretation) given to students before and after the module. Student attitude to both approaches was assessed by questionnaire, and the resource requirements were also compared. It was found that the knowledge gain of both groups of students was the same, that students had a positive attitude toward using CAL programs of this type, and that the cost of the conventional laboratory-based approach was five times greater. The potential for integrating CAL programs into the undergraduate curriculum is discussed.

Key words: computer-assisted learning; intestinal transport; teaching undergraduate students; evaluation

The increased availability of microcomputers for teaching undergraduate students in recent years has led to the development of a range of computer-assisted learning (CAL) materials in biomedical sciences. A number of these simulate laboratory-based experiments (1–7; 9–16; 19–21) and may be used either to support or, for some students, offer an alternative approach to conventional teaching methods. In this paper we describe how a CAL program, designed specifically to teach by investigation the principles of nutrient transport in the small intestine, was implemented and evaluated in an undergraduate course. A detailed description of the content of the CAL program has been published (7).

PEDAGOGICAL PROBLEM

Undergraduate (BSc Honors Physiology) students (University of Sheffield, UK) undertake, as part of their second-year studies, a module on epithelial transport in the small intestine, that is, the study of how substances are transported across cells and tissues. This module is typically taught using conventional laboratory-based methods, where students perform experiments on isolated tissue samples under the supervision of a laboratory technician. However, this method can be time-consuming and resource-intensive, with each experiment requiring the use of live animals. To address these limitations, a CAL program was developed to simulate these experiments, allowing students to work at their own pace and receive instant feedback on their results.

The CAL program was developed to teach the principles of nutrient transport in the small intestine, focusing on the mechanisms by which nutrients are absorbed. Students use the program to perform experiments on isolated tissue samples, and they receive immediate feedback on their results. This allows them to learn at their own pace and receive immediate feedback on their understanding.

The program was evaluated to determine its effectiveness compared with the traditional laboratory-based approach. Two groups of students were compared: one group worked independently using the CAL program and associated learning materials, while the other group followed a conventional practical class approach, working in the laboratory under supervision. Knowledge gain of each group was measured by means of a test consisting of a range of question types (e.g., short-answer factual, calculation, interpretation) given to students before and after the module. Student attitude to both approaches was assessed by questionnaire, and the resource requirements were also compared. It was found that the knowledge gain of both groups of students was the same, that students had a positive attitude toward using CAL programs of this type, and that the cost of the conventional laboratory-based approach was five times greater.

The potential for integrating CAL programs into the undergraduate curriculum is discussed, highlighting the benefits of this approach for teaching complex and resource-intensive topics in a more flexible and efficient manner.
transport. This comprises conventional lectures, seminars, and a practical component that involves a laboratory-based project to study the transport of amino acids (typified by glycine and methionine) and hexoses (typified by galactose) by use of the isolated, everted intestinal sac of the rat as the vehicle for experimental investigation. In the laboratory, students work in small groups under close supervision by lecturing staff and follow a tutor-designed schedule. They carry out a number of experiments to measure fluid and glycine transport (using $^{14}$C-labeled glycine) and then use the preparation to investigate the dependence of the transport mechanism on Na$^+$ by substituting NaCl in the mucosal fluid with KCl or tris(hydroxymethyl)aminomethane chloride. In addition, the concept of a mutual interaction between the amino acid and hexose carriers is addressed both experimentally and by providing students with data from experiments, which they then have to analyze. Students are normally assessed by a laboratory report completed in their own time, which forms part of the module assessment.

The project occupies, in total, 35 hours of student time. The majority of the unit is laboratory based, although a small number of lectures and tutorials are included. The laboratory work requires close supervision by academic staff and support from a technician.

Two factors stimulated a demand for an alternative approach. First, the department is under considerable pressure to increase student numbers with no comparable increase in resources and to reduce staff-student contact time. Second, an increasing number of students have expressed unease at the use of animals simply to teach known facts or principles. This is particularly true of those students who have no intention of pursuing a career in research (often as many as 50% of students on this degree course).

AIMS AND LEARNING OBJECTIVES

To facilitate the development of the software and printed support materials, the academic staff involved in teaching this module were asked to define the learning objectives.

Aims

Aims were to teach by investigation:

- the transport of hexoses and amino acids by the small intestine;
- the principles of a method for investigating transport;
- the effects of a number of factors that influence transport.

Learning Outcomes

On completion the student will be able to:

- list the criteria for active transport;
- define the parameters used to measure intestinal transport and assess their limitations;
- appreciate the basis of experiments to investigate absorption of nutrients, the Na$^+$ dependence of the transport system, the mutual interaction between the hexose and amino acid transport systems;
- describe the advantages and limitations of this technique;
- appreciate the basis of the indirect methods used for collection of kinetic data;
- collect and analyze the data from these experiments;
- effectively present these data in a clear and understandable format;
- discuss the significance of this analysis in explaining the interaction of transport processes.

Generic practical/laboratory and tissue-handling skills were specifically not included as major objectives, because it was considered that these were adequately covered in other areas of the course.
COMPUTER SOLUTION

A CAL program (Intestinal Absorption: Sheffield BioScience Programs, 1992) was developed specifically to offer an alternative, student-centered approach to teaching this module. The program, which is written in Turbo C++ (Borland) to run on any IBM-compatible personal computer with CGA, EGA, VGA, or Hercules graphics cards, was designed to promote learning by investigation and to simulate as many as possible of the student-centered tasks demanded by the conventional approach. Thus students are expected to simulate designing and carrying out experiments, collecting raw data, and using those data to calculate a variety of transport parameters. They must analyze the raw data, present the data in an understandable form, and interpret the results. These tasks are not different from those expected of the laboratory-based project.

The CAL program makes use of an easy-to-use windows-like menu from which a number of options may be selected. The INTRODUCTION uses a combination of text and high-resolution color graphics (including some animation) to describe the principles of Na+-dependent, carrier-mediated transport in the small intestine. A METHODS section also uses text and graphics to describe the preparation of the everted intestinal sac and the methods used to investigate transport. The EXPERIMENTS section offers the student the choice of a range of investigative experiments: direct measurement of the transport of fluid and that of glycine, methionine, and galactose; investigation of the Na+ dependence of the transport systems for all three nutrients; a series of experiments to study the basis of the interaction of the hexose and amino acid transport systems.

A student workbook was developed to accompany the software. It comprised all the descriptive text from the program with integrated student assignments and data sheets for completion by the student. The workbook directs students through a schedule of tasks designed to address the learning objectives. Students are required to answer questions relating to the text, solve problems, perform calculations, draw graphs, and offer explanations of results obtained to encourage and ensure interpretation of data.

EVALUATION

Before deciding whether to use the CAL program to replace the traditional teaching method, we implemented and evaluated the new program with one cohort of second-year BSc (Honors) Physiology students in the Department of Biomedical Science, University of Sheffield. Fourteen students were divided into two groups, and each group then followed a different learning experience.

One group (control, n = 8: 3 males; 5 females) followed the traditional approach, which had been developed by academic staff in the department and used for several years. Students worked in the laboratory under close supervision and followed a tutor-prepared work schedule. A lecturer was always present to answer questions, demonstrate procedures, and solve technical problems. An introductory lecture (2 hours) covered the theoretical background and introduced students to the methods of measuring transport that they would be using in the laboratory. This session also included a video, which showed how to prepare the intestinal sac and worked through the experimental protocol and method of data collection. In the laboratory the students were taught how to prepare everted sacs of rat small intestine, and then they carried out experiments to measure fluid and nutrient transport. Some compulsory tutorial sessions (4 hours) were arranged to explain how the raw data they had collected are used to calculate transport parameters. Staff were also available for a further 4 hours of optional tutorials, and most students in this group made use of these sessions. Thus, for this group, staff-student contact involved 35 hours of time, including laboratory supervision (25 hours), tutorial (8 hours: 4 compulsory, 4 hours optional), and lecture (2 hours to introduce the unit). Students in this group took a minimum of 15 hours to complete and collect data from only three experiments. Data from other experiments were then provided in the form of results sheets, which they were expected to analyze in their own time.
The second group (test, n = 6: 3 males; 3 females) were provided with the CAL program and a student-centered workbook designed to accompany the software. They had the same introductory lecture and video as the control group, but then they worked independently of staff contact. They were required to organize their own work schedule and to book university computer facilities. Staff-student contact for these students was 6 hours, which comprised tutorial (4 hours optional) and lecture (2 hours introductory). Students were given complete control over how much time they spent on the task and when and how they worked. Their progress was not monitored, although they were asked to estimate the time they spent using the CAL program and working through the assignments in the workbook. This varied from 8 to 25 hours (mean 15.6 hours). They too were given the opportunity to attend optional tutorials (4 hours), although only one student from the test group made use of these.

Assessment of Knowledge Gain

All students were given a written test before starting the unit to assess a baseline level of knowledge. This comprised 50 questions (primarily short-answer) and included questions of several types. Some required descriptive answers, some were problem-solving exercises, and others required data manipulation, calculation, and interpretation. After completing the unit, students were retested (the same test was used but the students did not know that this was to be the case).

The test results (converted to % scores) for each student are shown in Table 1. All students showed a significant increase in knowledge after their respective learning experiences. The mean pretest and posttest scores for both groups were comparable. There was no statistically significant difference in the mean knowledge gain between groups.

Survey of Student Attitudes to CAL

Student attitudes were surveyed by a questionnaire consisting of 30 questions. One of these (Q30) was an open question asking for comments on the pedagogical approach followed, i.e., using the CAL program or attending the laboratory sessions. Three questions (Q1–3) requested information about previous experience with computers. In the test group, two of the six owned a computer of their own, whereas in the control group, one of eight owned a computer (Q1). All students had reasonable access to a computer (Q2), and all had used computer simulations before in the course (Q3).

The remainder of the questions (Table 2) were designed to elicit specific responses and asked students to rank their agreement or disagreement with certain statements [using a five-point Likert scale: strongly agree (+2) to strongly disagree (-2)]. Within the questionnaire, questions designed to elicit similar information were phrased both as negative and positive statements to check for inconsistencies in the way the questions were answered. Students were asked to complete the questionnaire.

Table 1

<table>
<thead>
<tr>
<th>Student No.</th>
<th>Control Group (Lab)</th>
<th>Test Group (CAL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretest, %</td>
<td>Posttest, %</td>
</tr>
<tr>
<td>1</td>
<td>12</td>
<td>81</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>67</td>
</tr>
<tr>
<td>3</td>
<td>22</td>
<td>71</td>
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<td>4</td>
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<tr>
<td>5</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>16</td>
<td>62</td>
</tr>
<tr>
<td>7</td>
<td>14</td>
<td>47</td>
</tr>
<tr>
<td>8</td>
<td>28</td>
<td>71</td>
</tr>
<tr>
<td>Mean</td>
<td>16.4</td>
<td>67</td>
</tr>
</tbody>
</table>

The control group performed a series of traditional, closely supervised, laboratory-based experiments to study intestinal transport of nutrients. The test group worked independently, using a computer-assisted learning (CAL) program covering the same subject area. Students were presented with a written (unseen) exam (consisting of 50 primarily short-answer questions) before and again after their respective learning experiences. Scores are the % marks achieved before (pretest) and after (posttest) the learning experiences. Results show that the 2 groups of students were comparable in their baseline knowledge of this subject area (pretest). Knowledge of all students improved after the respective learning experiences. There was no statistically significant difference in the mean knowledge gain between groups.
represent the score (sum of the individual student scores for questions Q+Q29) of each group. Nos. in the positive column (+) indicate agreement with one of the statements, this would give a positive score of +8 (4

2. Do you have reasonable access to a computer?
3. Have you ever used a computer simulation program in your course?
4. Computer simulations of animal experiments are difficult to use
5. Practical laboratory experiments, using live tissue, are the only successful method available to reinforce the theory
6. The use of animal tissue, such as rat intestine, to demonstrate known facts, poses no moral dilemma.
7. Computer simulation programs cannot adequately replace laboratory practical experiments when teaching physiology.
8. The use of computer simulations of animal experiments will enable the lecturer to spend more time with students.
9. Computers are pieces of complex machinery and should be avoided if possible.
10. Hands-on experience with live animal tissue is essential for all students of biology.

All students completed the questionnaire before and after their respective learning experiences: test group working independently using the CAL program (n = 6) and control group working under lab supervision (n = 8). Responses were coded using key (below); nos. represent the score (sum of the individual student scores for questions Q5-Q29) of each group. Nos. in the positive column (+) indicate agreement with the statement; nos. in the negative column (−) indicate disagreement with it. For example, if 4 of 6 students in the test group strongly agreed with one of the statements, this would give a positive score of +8 (4 × +2); if the remaining 2 students disagreed with the statement, this would give a negative score of −2 (2 × −1). Note that certain statements are phrased in both negative and positive ways, e.g., Q7 and Q28, to test for inconsistencies in the way students answer the questions.

Key: Strongly agree +2; Agree +1; Undecided 0; Disagree −1; Strongly disagree −2.

D I S C U S S I O N

Undergraduate laboratory experiments do not exploit animals unnecessarily.

There is no place for computer simulations of animal experiments in undergraduate biology courses.

Students who need laboratory skills for their future careers can only learn them through experiments on animals.

Students need to receive special training to use a computer simulation of an animal experiment.

Computer simulations of animal experiments will enable the lecturer to spend more time with students.

Computers are pieces of complex machinery and should be avoided if possible.

Hands-on experience with live animal tissue is essential for all students of biology.

Practical laboratory experiments, using live tissue, are the only successful method available to reinforce the theory.

The use of computer simulations of animal experiments is difficult to use.

The use of computer simulations of animal experiments will enable the lecturer to spend more time with students.

Computers are pieces of complex machinery and should be avoided if possible.

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before they were assigned to groups and then again after their respective learning experiences.

The analysis of the responses from each individual showed that particularly the test group (median score +11.5; Fig. 1), but also the control group (median score +1.0; Fig. 2), had a positive attitude toward using computer simulations before they undertook the session. All students had had previous experience in using similar computer simulation programs in other modules of the course. The postsession questionnaire analysis showed a statistically significant increase (Mann-Whitney U test, $P < 0.05$) in positive attitude in the test group (median +18.0), whereas in the control group (median +1.5) there was little change. All students in the test group showed an increase in positive attitude after using the program, indicating that they found it a useful learning aid. The attitude of the control group, none of whom had used the CAL program (although they were given the option to do so in their own time), remained unchanged.

### FIG. 1

Attitudes of individual students in the control group toward use of a computer-assisted learning (CAL) program as an alternative to a laboratory practical. These students performed the "wet" laboratory practicals. Scores are the sum of responses to questions 4-29 in the questionnaire (Table 2), which they completed before (pretest, stippled bars) and after (posttest, open bars) their learning experience. Differences in how the questions were phrased have been taken into account; thus if a student agreed with Q7 (a negative statement with respect to using CAL), the response was coded as negative, whereas if he or she agreed with Q28 (a positive statement with respect to using CAL), the response was coded positively. Thus a positive attitude score indicates that a student had a favorable attitude to working independently, using the CAL program as an alternative to performing a laboratory practical. Results show that the control group contained students with differing views (some positive to, and some negative to using CAL) before the study and that their attitudes were generally unaltered after they had completed the laboratory practical sessions.
Attitudes of individual students in the test group toward use of the CAL program as an alternative to a laboratory practical session. These students worked independently, using a CAL program (Intestinal Absorption). Scores are the sum of the responses to questions 4–29 in the questionnaire (Table 2), which they completed before (pretest, stippled bars) and after (posttest, open bars) their learning experience. Differences in how the questions were phrased have been taken into account; thus if a student agreed with Q7 (a negative statement with respect to using CAL), the response was coded as negative, whereas if he or she agreed with Q28 (a positive statement with respect to using CAL), the response was coded positively. Thus a positive attitude score indicates that a student had a favorable attitude toward working independently, using the CAL program as an alternative to performing a laboratory practical. Results show that the majority of students in the test group had a favorable attitude toward using computer simulations that was enhanced in all but one instance after use of the CAL program (Intestinal Absorption).

The questions/statements are shown in Table 2. A number of the questions (Q5–7, Q10, Q12, Q16, Q17, Q19–29) are related to the students’ attitudes to, and issues surrounding, the use of CAL as an alternative to performing laboratory practicals using animals. The majority of the test group (CAL) believed that there was a place for non-animal-based teaching in physiology and that using animal tissue did pose a moral dilemma. Some even thought that animal experiments in undergraduate education should cease. The majority of the control group (laboratory class), on the other hand, thought that the use of animals was essential in undergraduate physiology teaching, although it did still pose a moral dilemma. In both cases these attitudes were strengthened after students had completed their respective classes. Possible reasons for this might be: 1) there is the feeling that a computer simulation did not convey a sense of reality (Q23); 2) students need the opportunity to develop essential laboratory skills (Q25, Q29); or 3) there is a need for the same opportunity for staff-student contact as in the practical class (Q14). Both groups appreciated the high cost of animal experiments (Q26). The responses to Q16 and Q28 were interesting. The test group thought that the computer program could be...
Students found the program easy to use and believed they did not require special training (Q4, Q13). Both groups had found the computer simulations they had used elsewhere in the course interesting, and this perception was enhanced in the test group after use of the specific program on Intestinal Absorption (Q15). Students from both groups appreciated the control over their learning that using a CAL program gave them (Q18). It was also revealing that both groups of students thought that practical classes generally gave variable, inconclusive data whereas the computer simulation allowed them to obtain accurate results (Q19, Q21). It was also thought by both groups that too much time was spent learning how to use equipment in practical classes (Q20).

The test group also thought (Q8, Q11) that using CAL would provide additional time for lecturing staff to spend with students or prepare lessons. (Interestingly, the control group did not think so.)

One question on the questionnaire gave students the opportunity to comment on the sessions that they had taken part in. Some of the major comments are summarized below:

**Test group (CAL):**
- enjoyable, interesting (most students); boring, only gave results (one student);
- more effective if students worked in groups, which facilitated a more disciplined approach;
- good support material would have benefited from a demonstration of the experiment; found tutorial support useful;
- good results, effective learning aid;
- didn’t teach laboratory skills.

**Control group (laboratory):**
- enjoyable;
- liked communication between staff and students;
- lab sessions provided useful experience (e.g., tissue handling skills) for projects in final year;
- poor results; impressed by quality of CAL material and printed support materials;
- would be useful to have both approaches;
- lack of opportunity to develop computer skills.

**Resource Analysis**

The study also attempted to compare the resources required by each approach (Table 3). This took into account the cost of consumables (e.g., reagents, animals, disposable apparatus); staff [academic staff time costed at £40 ($60) per hour, technician time costed at £10 ($15) per hour, demonstrator (postgraduate student) time costed at £10 ($15) per hour, glasswashing time costed at £5 ($7.50) per hour) required for the two approaches. Capital cost of equipment for both groups was ignored. The analysis revealed that the laboratory class was approximately five times more expensive than the computer-based approach and cost £1,372 ($2,058) more.

A brief summary of these results has been previously reported (8).

<table>
<thead>
<tr>
<th>Comparison of resources required by 2 approaches to learning intestinal transport unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CAL &amp; ($)</strong></td>
<td><strong>LAB &amp; ($)</strong></td>
</tr>
<tr>
<td>Lecturers’ time (£40 per hour)</td>
<td>80 (120)</td>
</tr>
<tr>
<td>Introduction, 2 hours</td>
<td>100 (160)</td>
</tr>
<tr>
<td>Tutorials</td>
<td>160 (240)</td>
</tr>
<tr>
<td>Laboratory Supervision, 25 hours</td>
<td>1,000 (1,500)</td>
</tr>
<tr>
<td>Technician Time (6 hours @ £10 per hour)</td>
<td>60 (90)</td>
</tr>
<tr>
<td>Demonstrators’ Time (3 hours @ £10 per hour)</td>
<td>30 (45)</td>
</tr>
<tr>
<td>Glasswashers’ Time (9 hours @ £5 per hour)</td>
<td>25 (37.5)</td>
</tr>
<tr>
<td>Laboratory Consumables e.g., animals, chemicals</td>
<td>237 (355.5)</td>
</tr>
<tr>
<td>Software</td>
<td>120 (180)</td>
</tr>
<tr>
<td>Total</td>
<td>360 (540)</td>
</tr>
</tbody>
</table>

Resources required by the 2 learning experiences were calculated as shown. Those required by the control group (Lab) were approximately five times greater than those for the test group (CAL).
CONCLUSION

In physiology and pharmacology courses, practical classes using animals or animal tissues form a major component of the curriculum. For some students, particularly those intending to pursue a career in research, skills developed during these sessions (both generic laboratory skills and those specific to this particular practical, investigating intestinal transport) are essential. For many others, these skills are not essential. This traditional laboratory practical class is staff intensive and has a high recurrent cost. In addition, students are clearly concerned about using animals to demonstrate known facts or principles, although they accept that some experience of using animals and/or animal tissue is essential if they are to pursue a career in research. Several studies have demonstrated that CAL may be effective in replacing (1, 2, 6, 13, 14) or enhancing (18) traditional laboratory classes in undergraduate biomedical science courses, and it is clear that replacing a proportion of traditional practical classes with computer simulations would not disadvantage students and might indeed improve learning.

The CAL program described is highly interactive and, together with the accompanying printed support materials, was designed to cover the major objectives of the unit of study. It was successfully implemented, and student feedback on its ease of use and level of interaction was very positive. The evaluation demonstrated that the students who used the computer simulation achieved the same level of knowledge as those working in the laboratory and that primary learning objectives were equally well achieved by both approaches. Student attitudes towards using the CAL program were positive and supportive of an approach that maintained some practical work in the laboratory and a more flexible, student-centered program of study supported by tutorials. Other evaluations of the effectiveness of such programs have also demonstrated that students using computer simulations of specific practicals perform equally well in their assessments (3, 5, 10, 13, 14, 17).

A comparison of the resource implications of the two approaches demonstrated that the laboratory session was almost five times more expensive in terms of staff time (academic and technical) and consumables (the cost of the CAL program was included but could then be omitted in subsequent years). No attempt was made to estimate the cost of purchasing or maintaining equipment or the use of specialized laboratory accommodation, although indications are that these costs too would be lower for the CAL program. As a direct result of this study, the unit of the curriculum on intestinal transport will be modified, and in future all students will spend one week in the laboratory when they will perform one experiment to measure fluid transport. They will then all work independently with the CAL program over the next three weeks.

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REFERENCES

Teachers and their students may find the following articles from *News in Physiological Sciences* useful when exploring the physiology of intestinal absorption:


