Collaborative Learning: an Effective and Enjoyable Experience!
A Successful Computer-Facilitated Environment for Tertiary Students

Dr. Robert E. Kemm,
Department of Physiology,
The University of Melbourne,
Victoria, Australia, 3010,
r.kemm@physiology.unimelb.edu.au;

Dr. Helen Kavnoudias,
Department of Physiology,
The University of Melbourne,
Victoria, Australia, 3010,
h.kavnoudias@physiology.unimelb.edu.au;

Debbi Weaver,
Department of Physiology,
The University of Melbourne,
Victoria, Australia, 3010,
d.weaver@physiology.unimelb.edu.au;

Paul Fritze,
Multimedia Education Unit,
The University of Melbourne,
Victoria, Australia, 3010,
p.fritze@meu.unimelb.edu.au;

Nicholas Stone,
Centre for the Study of Higher Education,
The University of Melbourne,
Victoria, Australia, 3010,
n.stone@cshe.unimelb.edu.au;

Dr. Neil Williams,
Department of Physiology,
The University of Melbourne,
Victoria, Australia, 3010,
n.williams@physiology.unimelb.edu.au.

Abstract: We have developed a collaborative learning environment (CLE) as a student-centred approach to lecture replacement, with a special focus on assisting students’ learning of difficult concepts. The majority of the program is structured around cost-efficient web-delivered tutorials incorporating re-usable interactive components. These are supported by several stand-alone computer-based learning tutorials including ones that we developed to allow students to construct their own models of physiological mechanisms, together with computer-facilitated semester-long investigative projects to enhance their communication and critical reasoning skills. Each week for two hours during two semesters, students work in groups of three with an iMac computer. The computer-facilitated tasks are designed to support and extend their three weekly lectures by encouraging peer-learning and peer-teaching. In this article, the successful attributes of this collaborative learning environment are described and evaluated. In addition, relationships between the use of CLE and the students’ approaches to learning are being investigated.
Introduction

Tertiary institutions are moving increasingly towards the delivery of courses using computers to provide students with the opportunities to learn at their own pace, together with a reduction in traditional lectures. There is also a trend to provide asynchronous access to courses via the Internet. There is broad recognition that traditional forms of university course delivery are inappropriate in preparing students for a dynamic workforce in a post-industrialist, knowledge society (Drucker 1995, Lohrey 1995). Where it has been successfully implemented, collaborative learning is recognised as a potent transition factor in supporting the development of higher order cognitive abilities (Johnson & Johnson 1992). Despite this recognition, evidence of direct positive effects on student learning remains largely anecdotal (Meloth 1999). Face-to-face collaborative learning, with academics as facilitators, is an area where campus-based universities have a major advantage in tertiary education. We contend that to provide such collaborative learning opportunities has advantages over relying only on electronic communication in virtual study groups. However, amidst contracting resources and increasingly crowded curricula, there is an understandable reluctance to establish the substantially different and potentially risky conditions of learning necessary for successful collaborative learning (Cooper & Sweet 1999).

We have now evolved a collaborative learning environment (CLE) in which we develop and present computer-facilitated learning as a means of effectively broadening the learning opportunities of science students studying physiology. Since 1993 our efforts in computer-assisted learning have aimed to extend, enhance and replace some of the students’ lecture experiences with multimedia-based tutorials in an environment that encourages peer-learning and peer-teaching. A global aim in our science teaching in physiology is to use the curriculum to develop in our graduates some understanding of the abilities required of them as practicing scientists. Emphasis is given to understanding the experimental, research, theoretical, communication and critical reasoning base of the discipline.

An attribute of key importance to development of our CLE was to bring different experiences to students learning. This diversity was essential to address the wide range of backgrounds of the students entering our courses, such as their achievement levels, approaches to learning and cultural backgrounds. Our approaches included introducing scientific principles and methods for investigating physiology (e.g., simulated experiments), and using a diverse range of computer-aided interactive teaching formats. Importantly, these approaches were not designed to stand alone, rather to integrate with other learning resources such as lectures and printed texts. Students were also encouraged to engage in continuous reflection and evaluation.

Our concept of a collaborative learning environment consists of: a friendly and informal physical workspace that is conducive for group interactions, with an optimum group size of three students per computer; an economical production model that provides a coherent set of weekly web-based problems; supplementary standalone highly-interactive multimedia tutorials dealing with essential concepts; a tutor to guide and assist (not teach); and extension after hours into the virtual classroom of the internet using electronic communications.

Results so far suggest that the introduction of our collaboratively based approaches to course delivery has had a significant positive effect on student learning outcomes. These outcomes include not only traditional examination results, but also more ‘authentic’ (Wiggins 1992) methods of assessment such as observation of group role fulfillment and student audit trails of problem-solving processes.

Background

The Department of Physiology at the University of Melbourne has played a leading role in computer-assisted learning over many years. In 1985 we first tried to improve our practical class teaching of physiology with pilot studies using the Apple II and a computer-oscilloscope for recording from human nerves, accompanied by a computer-aided tutorial relating the theory and practical experience (Delbridge & Kemm, 1985). However, it was not until 1992 when we purchased 64 Mac IICi computers, each with a MacLab physiological recording system, that we really had the computer performance to significantly improve our students’ practical classes and then consider multimedia tutorials as an additional option.

Since 1993 we have been continually successful with our applications for competitive government and University funds to produce standalone multimedia tutorials that aim to help students understand difficult physiological concepts. The Physiology Department has always been a leader in multimedia development at the University of Melbourne and produced the first site-licensed multimedia tutorial sold internationally in 1993. Since then we have been producing and evaluating a series of tutorials that require students to build and test their own models of physiological processes, and the first of these is now being distributed internationally (Weaver et al, 1999). However, although these initiatives have proven to be very effective, production of these highly interactive tutorials was slow and expensive, so they could not be used to provide two semesters of coursework for our science students within the time frame and budget available.
In 1997, the Department introduced fortnightly scheduled 3-hour sessions of computer assisted learning. Initially these CAL sessions were used to revise lecture material. Tutorials were based on HyperCard programs, produced in-house by one of the authors (using Chemistry's 'Tutorial Tools' by Paul Fritze), and a variety of other standalone tutorials obtained nationally and internationally. However, although the in-house tutorials were well received, the standard of external tutorials received a very mixed response.

In 1998, we produced a coherent set of in-house tutorials specifically designed for our students, supplemented by a select few of the best available standalone tutorials. Content was delivered economically on an Intranet for a Web browser, using templates and tools developed in association with Paul Fritze of the University's Multimedia Education Unit. The model for tutorials was that students work on a problem in groups of three with the computer providing questions, feedback and hints as they proceeded with calculations and exploring issues. These 1.5 hr/week CAL sessions were not compulsory and were held in a Science Faculty multimedia computer laboratory remote from the Department. There was no formal assessment of this course component. Attendance fell over each semester, largely because of the many technical problems experienced with the unsatisfactory maintenance of the software and hardware and the remoteness of the laboratory from the support systems within the Department. There was no significant change in student performance.

For the 1999 teaching year the Department of Physiology equipped a refurbished laboratory with 15 iMac computers and a G3 server. Additionally, we introduced group learning of a topic covered in the curriculum, and assessed student participation in the collaborative learning process to encourage attendance. The duration of these computer assisted learning sessions was increased to 2 hours. All this helped staff to provide better support and to emphasise that the CLE was as important as lectures for learning physiology.

In 2000, we are reflecting on all aspects of the Web delivered course and upgrading it where appropriate with new interactive Web components that will allow us to provide more directed feedback to students with different backgrounds and achievement levels (Fritze & Kemm, 2000). We are continuing to develop a few highly interactive multimedia modules dealing with difficult concepts for which students develop their own mechanistic models.

The Current Status of the Evolved Collaborative Learning Environment

The evolution of our collaborative learning environment is the result of adjustments made in response to many surveys and educational experts' observations of how students go about their learning when facilitated by computer programs. The CLE sessions can be regarded as a medium between students who actively construct meaning and skills, using resources of the environment that include discipline content, methods and experiences, such as laboratory work, demonstrations, real-life experience and particularly social interactions.

CLE Sessions and the Physical Environment:

Students attended sessions of 2 hours weekly, with 12 sessions in each of two semesters. This part of the course was first assessed in 1999 and counted for 5% of the course marks (see section on Assessment). Most of the 360 students enrolled for CLE. Attendance was remained high throughout semester in the Department's own facility.

Each collaborative learning environment (CLE) session accommodated 42 students normally working in groups of three on a computer assisted learning (CAL) package presented on an iMac computer. Groups of three were chosen as is claimed to be the optimum group size for interactive computer programs. A G3 Server used AppleShare 6.1 IP to network the 14 students' iMacs and the tutor's iMac. The tables and benches were arranged to encourage groups to talk and argue in a relatively noisy working environment. The tutor's approach further emphasised the friendly and relatively informal learning environment. A wide range of textbooks was provided as student resources. The head CAL tutor and developers were located next door to the laboratory.

Computer Assisted Learning (CAL) Components:

Our overall approach to our CAL development used a constructivist approach and addressed both pedagogical and instructional design issues from the outset, such as using guidelines from the work of Reeves and Harmon (1994) that was designed for the evaluation of completed multimedia. We used a group development model with assistance from education experts, instructional designers, as well as academics and multimedia authors who developed and delivered the material on the Web. We used an iterative process, to adjust tutorials in line with results of formative assessment with students throughout the development.

A true multi-media approach was adopted where students used a combination of paper based work textbook referencing and interactive computer delivered tasks, side by side. The idea was to develop activities that would allow students to build on their own knowledge within their own learning framework, with the computer available as a virtual tutor to help them check their answers, provide a level of tutorial feedback and to
pose further questions to stimulate their interpretations. The problems were initially based on the areas of
difficulties in physiology that staff had previously identified in conventional tutorials.

Students were presented with problems to investigate that required them to examine experimental data,
perform calculations, answer questions and keep written records of their work. A wide variety of tasks were
presented on the Web, occupying about 1.5 hours of each CLE session. Production of sufficient material for 24
weeks required an efficient production method that could be easily modified on reflection after evaluation.

These weekly problems were supplemented by a variety of highly interactive standalone tutorials that
could occupy up to one hour of CAL activities. These included two of our set of highly interactive cell-model
building multimedia tutorials (Weaver et al, 1996; Kemm et al, 1997; Weaver et al, 1999a & 1999b) as well as
externally produced modules. Students were given the opportunity at the end of the session and during the last
session of each semester to test their knowledge with a variety of multiple choice and open-ended questions.

**Semester-long Tasks:**

*In Semester 1:* Students formed extended groups (of six) to investigate one of four problems, such as the
consequences of blood doping on physiological systems. This semester long project was introduced with the
aim of students learning to be perceptive in their reading of short excerpts of scientific writing. They were
required to determine the key phrases in the passage, their relative importance and then to write a concise clear
report on their interpretation of that piece. This project was designed to assist students to develop generic skills
in determining the level of knowledge required and writing abilities to communicate their knowledge more
effectively.

Each group was given a weekly series of tasks, researching the material and progressively developing
their interpretation. 30-minute periods at the end of each CLE session were designated for these assignments.
Students submitted work on the various stages to their own private computer-based discussion forum. They
were provided with weekly feedback on their progressive submissions as a computer checklist, and at the end of
six weeks submitted their report to another group for peer review. The reviewing group was within the same
class and had worked on the same question, therefore were 'expert reviewers'.

We used the learning framework 'TopClass' to allow students to communicate within their group, and
to keep track of their progressive work submissions on a semester long project. Science students study such a
wide range of subjects that it is difficult for them to form cohesive groups to assist their learning (contrasted
with professional courses, eg. dentistry), so that electronic communication is encouraged to reinforce the
exchanges that occur in the weekly CLE sessions.

The key learning issues were to work cohesively as a group and make consensus decisions about
identifying and ranking key concepts, being able to express themselves concisely, unambiguously, accurately
and be able to read another text with some insight as to what is expected... In essence, we aimed to improve
their collective skills in negotiation, communication, reading, and writing and reviewing their science.

*In Semester 2:* We chose to build on the collective skills of collation and consensus writing undertaken in the 1st
semester with a course aimed at providing students with some insight into critically reading their Physiology.
We formally applied reasoning skills to a graded series of reading tasks using the interactive program 'Reason!'..
Although we have reported on this process applied to third year students (van Gelder et al, 1999), the
introduction at this time was only done as a trial. The second year students were not as successful in applying
'Reason!', and some modifications will be needed to allow this less sophisticated group to gain more benefit
from the process.

**Course Assessment:**

**CLE Assessment:** The CLE assessment (5% of total) was aimed at rewarding students who effectively
participated in these sessions. The mark was based on attendance and tutors' records of student participation (by
observation of a group's activities and their submissions, together with individual student's roles in discussion
and record keeping). A student must have attended the majority of sessions be deemed to have participated
effectively in group learning (tutor's observations and computer submissions) to have gained a score of greater
than 3/5 (rated as good in Table 1).

**Examinations:** These are described in a following Section, which discusses attempts to relate the participation
in CLE with examination performance.
Evaluation Strategies

We have a number of evaluation strategies in place and collected data in 1998 and 1999, as part of our overall action research strategy dealing with global learning outcomes from the CLE as well as in students' extension of cell model building skills to new or hypothetical situations. We used a comprehensive set of methods to collate and assess information, in order to gain a broad understanding of student reactions and to obtain a more detailed examination of student learning processes and actions. We obtained human ethics approval for our surveys and to log important student activities in the computer tutorials.

The tutor-facilitators play a key role in the implementation of the program so their impressions of the course are most relevant to understanding student reactions. They made observations and kept records of students' work and participation in the CLE sessions. Formative evaluation continued throughout with regular formal meetings between the main developer and tutors, as well as many informal interactions amongst the students, tutors and the academic developers whose nearby location enabled and encouraged this latter process.

We have found that students cooperate well with questionnaires and interviews if they are fully informed and can see that they are developmental and that timely feedback will assist their own learning. This is unlike their less enthusiastic response to repeated general University circulated questionnaires on teaching quality in each course.

Student Questionnaires

Questionnaires specific to the CLE were used to survey students' attitudes to various aspects of the CAL tutorials and the CLE sessions, in consultation with our educational advisors. These were supplemented by focus group interviews with students.

In addition we investigated students' self-assessment of their approaches to learning. We used a modified study process questionnaire to extend the investigation of deep, achieving and surface learning-approaches (Biggs, 1987) so it included additional learner characteristics. This is discussed in application to one of standalone interactive tutorials (Kemm et al, 1997). Such additional information will be used to further analyse the results reported in this article at a later time.

The student questionnaires were modified each semester from initially determining general reactions to the style and depth of coverage of the tutorials, to focus on particular issues that were relevant to the efficacy of the collaborative learning environment. The study process questionnaire was administered once each year. The last questionnaires had approximately 70 questions designed to reveal students' attitudes and use of the CLE, covering aspects such their pattern of work with the CLE, development of independent learning skills, relevance of the CLE to their learning compared with lectures, and their attitudes to group work. Additionally we had some specific questions about their use of the feedback screens in their learning and about the nature of some tutorials, as part of our interest in learning which tutorial styles worked best and for which students. Most questions required students to rank their responses on a 5-point scale, supplemented by several open-ended questions.

Results

Influences on Assessment:

The aim was to determine whether any part of the CLE assisted students to have a better examination outcome. In all courses, examinations consist of multiple choice questions (MCQ), short answers questions (about 10 min) and essays (about 30 minutes). The written examination questions were set so that one question related to material only covered in lectures, one specifically designed around material obtained in CLE sessions and one question specifically aligned to the semester long CLE project (choice of the four projects undertaken). Multiple choice questions (MCQ), covering the whole syllabus, were no different in their coverage from previous years. Faculty Scores for student's 1st year performance (average of best 75% of subjects) were used to give an idea of the students' previous achievement levels.

Table 1 shows the influence of effective participation in the CLE sessions on the student performance. Student groups were divided into “levels of achievement” based on their previous 1st year academic performance. Subgroups based on CLE participation ratings used scores of 3.5 and 3, a score that should distinguish combined attendance and participation from non-attendance or attendance alone (see course assessment). The data in Table 1 shows a marked polarisation in the mean scores between these subgroups. Thus we are confident that the subgroups did reflect those students who were involved in the material and the learning process, and those who were not. The data suggests that there is an improvement in exam outcome for all groups with good CLE participation, with a greater proportional change for the “lower achieving” students. The examination marks have the CLE component removed and are normalised, so a perfect score is 100%.
Table 1: Influence of collaborative group interactive CLE sessions on the results with each subgroup

Table 2 shows the distribution of examination marks for science students dependent on their participation in the CLE sessions. The data shows a shift to higher grades for those students participating in CLE, again most significantly for the lower achieving students. Of interest is that 55% of the students in this group who attended and participated in CLE passed. By contrast only 35% passed of the group who chose not to participate/attend.

Table 2: Effects of CLE participation on distribution of examination results of science students taking 2nd year Physiology.

Table 3 shows the influence of the CLE participation on the major components of the examination, and the improvement is apparent across both the written and multiple choice components. We had hoped that the semester long written assignment in particular may have enhanced the Science students' performance in the written part of the examination. If this were true then the written part of the exam should have been done better by the group taking CLE, but the MCQ mark might be expected to be independent of CLE participation. The data however show improvement in both the written and multiple choice exam components for those in the high participation group. Accordingly, from the performance data alone, there is no such clear-cut distinction that might indicate the influence of the different components in the CLE. It is suggested that the apparent improvement in learning skills was influenced by the different components of the CLE (e.g. the CAL tutorials).

Table 3: influence of CLE Participation on Components of the Examination

The final observation from the assessment was a marked reduction in the failure-rate to <15% compared with 25% over many previous years. It should be noted that we have not been able to reduce this failure rate in previous modifications of our teaching to assist the students most at risk who, as might be expected, were those students with a poor 1st year performance.
Successful Attributes of the CLE

As will be seen from the data analysis above, it was not possible to attribute changes in learning outcomes to any particular aspect of our CLE. We know from previous experience that many factors can be detrimental, such as the students not realising that concepts and material covered in the CLE are as important as lectures, and that students are intolerant of poor quality material or unreliable hardware or software. We believe that the successful learning outcomes are due to a combination of successful attributes of the CLE, identified by the student surveys and observations, and these are presented in the following sections.

The Physical Environment for the CLE:

The ease of installation and reliability of the iMac computers and the G3 Server has been crucial to the success of the project. They required minimal maintenance since the beginning of 1999. Also, attention to software protection and automatic overnight reinstatement of any student modifications of the desktop eliminated significant problems that we had in teaching in an open-access laboratory in previous years.

Our surveys showed that 74% of students preferred to work in groups, showing a minority of students still liked to work alone. At the beginning of the 1st semester, more high achieving students preferred to work alone but many changed their minds, having experienced the benefits of group work. There may also be cultural differences in these preferences. Focus group interviews confirmed these results and the major advantage seen from group work were the interactions and discussions, which were confirmed by the noise levels in the classes.

The scheduling of sessions for group-work was crucial for collaboration, since our experience of other courses with open-access computer laboratory sessions shows that most students tend to work alone, a few in pairs and rarely in larger groups. We believe this is a critical issue to encourage collaborative learning, especially in Science where the diversity of courses that students undertake make it difficult for them to find collaborators with similar timetables.

The CLE sessions induced a 'sense of belonging' to a community within a course where the students come from quite disparate backgrounds, generating more of the interactions that exist in our more selective professional courses. There was identification within each session of 40, rather than just being an anonymous student amongst the class of 350. The open discussions and studying together also reinforced a common approach to scientific investigation and enhanced their appreciation of the philosophical approaches to learning.

The modern, pleasant and comfortable surroundings were found to encourage lively interaction, the main features being the open layout, lighting, carpets and comfortable seating. Furthermore, its location within the Department and easy access to support staff and academics next door showed the commitment of the Department to assisting the students. This sense of personalised support was reinforced by having a tutor look after each class and by providing easy email access by students to staff specialists. Lastly reference should be given to hugely successful paisley 60s style couch in the adjoining corridor, where many successful physiology and non-physiology related communication skills were reinforced.

Web Delivered CAL Components:

It is not possible to relate the learning outcomes to any specific CAL components. There is insufficient space to describe all the characteristics of the computer-assisted web components that worked well with our students in the CLE sessions, but the highlights are as follows, including some representative screen shots:

Weekly tasks not only had a Web-delivered component, but also were accompanied by a paper task sheet indicating the scope of the task for the session. This gave the students some take-away material that could be used in later study/reflection. In addition students were required to keep a record book and make notes, and do calculations as they progressed, so further reinforcing their learning and providing their own records.

The developed Web-authoring tools were essential for producing the core of the material for the 24-weeks of CLE sessions in a cost-effective manner. A single important feature over stand-alone programs is that both material and tasks could be updated relatively easily to incorporate new knowledge, or change emphasis in tasks with changes in the staff presenting lectures. The Interactive Web Objects were controlled by scripts that were readily modified by standard text editors and we used Dreamweaver to manage the website. This meant that ‘authoring’ of the web pages did not require a programmer, but an academic with some skills in word processing and HTML could be employed instead. This allowed the focus to be on appropriate pedagogy and relevant physiological content. The collaboration between the Multimedia Education Unit and the Physiology Department was essential to both bodies, providing Physiology with a suite of Web based tools while allowing the authors the feedback to develop and test them using pedagogical requirements firmly grounded in the context of the real course.
Students indicated that the diversity of tasks and web-presentations were stimulating and very helpful for their learning. These included calculations with relevant human data, interactive graphing of relationships, open-ended answers to questions, sorting sequences of processes, building models of cellular functions. Fig. 1 shows a screen showing one of a sequence of tasks requiring investigation about cell communication. This requires association of modes of cell communication with a diagram as a simple revision task.

Figure 1: Set of Tasks listed, one of which is shown requiring matching of mechanisms to diagrams.

A popular format (Fig. 2) was the sorting of sequences of events in a physiological process, which students found challenging and rewarding and generated much discussion as they explored many of the possible solutions. As developers, we did not predict this preference. This emphasised that continuous evaluation of what is working is essential, since academics often misjudge what students will find useful and challenging.

Our students have a poor understanding of the significance of the shape of graphs, so we use a free form drawing tool (Fig. 3) to allow them to represent changes that they might expect in important relationships. Here they have drawn the straight line as the change they expect in the supplied curve.

Students used the textual feedback on what was appropriate or inappropriate about their responses and found this to be very helpful in their learning. The feedback was designed to progressively reinforce students' development of an appropriate framework for their solutions to problems - such as their own summaries with the key features of negative feedback control by hormones (see insets in all Figures).

While the students found the content challenging, the computer-aided tutorials gave them a better idea than lectures of the level of understanding required to understand physiological mechanisms.

Students developed appropriate learning strategies: such as exploring mechanisms using interactive programs, reinforcing lecture material by more study, and by reflection of the material and by redoing components of the CAL.
Standalone Interactive Multimedia Components:

Students found the interactive model-building standalone tutorials to be challenging and very helpful for understanding some difficult concepts. However, their approaches to using these tutorials is being researched separately and is too extensive to fully report here. Previous investigations, (Kemm et al, 1997), showed that students were unable to construct hypothetical cells from their experience of constructing a cell to secrete stomach acid. A revision tutorial that shows the principles in the operation of membrane transporters was then developed to allow students to think out their solutions (Fig. 4) and apply this knowledge to new cell models, such as for the operation of cells in the proximal tubule of kidney (Fig. 5). We are currently investigating this transfer of model building skills in a controlled study to see if we can increase the number of students who think out solutions rather than simply use trial and error. We use audit trails to investigate the actual steps students take in arriving at their model solutions. In later modules, more emphasis has been given to placing the cell modelling tasks in context with overall requirements of the tissues in which they are found.

![Figure 4: Animated tool to show transporter operations.](image)

![Figure 5: Student’s partially constructed model of a cell.](image)

Another approach to model building is to develop neural circuits underlying the operation of physiological control systems. Students found our first version of a tutorial on the control of blood pressure very difficult. Our analysis of audit trails and questionnaires showed that we needed to separate their learning of how the elements of the model worked, using a simple ‘playground’ (Fig. 6) that also allowed them to develop a negative feedback neural circuit. They were then better able to deal with the complex neural feedback pathway involved in the regulation of blood pressure when moving from a lying to standing position.

Semester-long Tasks:

Students undertook the semester long task of writing about a topical issue with enthusiasm. There was lively discussion, although they were quite frustrated by some features of the TopClass Framework which meant it proved less than optimal for their purposes. There was considerable variation in the standards of both the final submissions and the quality of peer reviews, but students generally produced good work. Not many were...
able to identify all of the requirements, such as: the key issues in their problem, the relative importance of various factors, and to produce concise and unambiguous writing about the problem. In 2000 we have introduced a new means of for students to develop their submissions, receive feedback and to track their efforts using more effective interactive Web tools (OCCA described in Fritze & Kemm, 2000).

**Discussion:**

**Learning Outcomes:**

It is extraordinarily difficult to use traditional quantitative methods to show differences in learning outcomes attributable to a particular curriculum intervention by using traditional statistical methods (Reeves, 1993). Even if there are reasonable control groups, large numbers are often necessary to overcome the many confounding factors influencing the students in studying in a course, although there have been occasional successes such as (Reeves et al., 1997).

In our study, we were fortunate to have a self-selected control group who did not participate effectively in the CLE. Although less than ideal, we were not permitted to design an experiment in which some students are not offered this learning opportunity. Nevertheless, the self-selected group did represent a broad coverage of student achievement and there was no difference in sub-groupings based on prior achievements (first year Faculty Score). The significant results show that effective CLE participation was associated with an improvement in learning outcomes of some groups of students when compared with performance in another subject in the same year.

These improvements were observed in students across the achievement scale with students always doing better if they attended and took CLE. A significant outcome was a marked reduction in the failure-rate to <15% compared with an average of 25% over many previous years. It is of consequence that while CLE enhanced the outcome of the Physiology students most likely to fail (45% ± 2 to 52% ± 2) the same improvement was not evident in their Biochemistry mark, a closely related subject (51% ± 2 and 51% ± 2). This preliminary information gives further support to the notion that the CLE has enhanced learning in Physiology in this low achieving group. It is of note that we have not been able to reduce this failure rate in previous modifications of our teaching to assist the students most at risk. Perhaps the more diverse learning strategies provided these students with new and additional ways to understand and communicate physiology.

It was not possible to identify the improved learning with any particular aspect of the CLE. We believe that it is the combination of computer and human facilitated learning environment within which students work together and discuss the subject on a regular basis that has contributed to a general improvement in learning skills and attitudes.

**Important Characteristics of our Collaborative Learning Environment:**

The important characteristics that we believed supported our successful implementation were:

- The choice of an appropriate and flexible set of delivery tools that allowed development of an appropriate pedagogy for students to learn effectively from their tasks. It was important not to allow development to be held up by awaiting the 'latest' version of any delivery tool, but to work our way around it to ensure that one could deliver an appropriate task on time, even if resorting to a greater dependence on written tasks. Our productivity exceeded that in our prior multimedia developments.
- Using the computer's interactivity to focus on concepts not easily covered in lectures, with the CAL not designed to replace all lectures or students' use of textbooks and other resources.
- A generation of a pleasant and friendly learning space was crucial to encouraging students to openly discuss issues and to discover the power of peer-learning and peer-teaching, with supportive staff.
- Choice of reliable software and hardware (eg our experience with iMacs, compared with previous years, meant staff could concentrate on learning issues and not solving technical problems).
- Students needed to recognise that learning in CLE sessions was as important as attending and learning from lectures. Assessment was an important signal that encouraged students to attend, but it must be make it so competitive that students no longer wish to collaborate. We found that allocating 5% for participation in CLE sessions did encourage the CAL to be taken more seriously than previous years, but increasing this will bring on more issues of equity and accuracy of assessment methods.
- The proximity of the developers to the CLE laboratory provided opportunities for them to obtain a deeper understanding to the cultural and individual characteristics of the learning experiences.
- Students openly showed their enjoyment of the learning environment and there was always lively discussion of physiology (and not extraneous social matters). This also encouraged both the tutors' and the developers' interest in further improving the collaborative learning experience in line with the students' survey results and informal feedback. The use of scheduled classes was imperative to allow students to establish and maintain working relationships with their group.
Conclusions and Future Directions

We have found that there is significant value in using scheduled face-to-face on-campus collaborative learning, to complement student's individual self-paced asynchronous learning, that is facilitated by computer tutorials and resources. Continuing investigation of our collaborative learning environment has the potential to build on existing initial successes and to provide some credible evidence and advice to support the management of such positive educational change. Additional evaluation of what works and why with each of our computer tutorials, and with which students, will allow us to make more use of adaptive feedback with new embedded Web objects (Fritze & Kemm, 2000). Thus we could provide more appropriate learning challenges to students who have different approaches to learning and have different achievement levels.

While our results appear promising, in order to maximise the benefit of this innovation there is a need to investigate empirically which factors provide the most positive influences. This could allow the development of a transferable framework for establishing even more successful collaborative learning environments. In particular, we need to learn more about where to allocate human and other resources in order to have optimal effect on student achievement (Thomas, Sammons & Mortimore 1995). In addition to existing teaching processes, this would entail a carefully planned action research project that will provide some more precise and actionable indicators of key factors. More specifically, it would help to create more educative links between instruction, learning and assessment essential for the development of ‘deeper’ and more durable learning abilities by students (Boud 1994, Loacker, Cromwell, & O’Brien 1986). Such data would be a valuable contribution to other academic staff taking up the challenge of introducing more progressive teaching approaches that foster greater levels of self-directed and higher order learning such as collaborative problem solving and active reflection and metacognitive analysis (Slavin 1990, Mezirow 1994). It would also provide a local infrastructure and an adaptable generic model for generating useful ongoing measures to inform quality assurance and continuous improvement processes.

Overall, we will continue to use an iterative approach to the development of collaborative learning tasks that address effective pedagogy in a campus-based computer-facilitated learning environment. We will use a pragmatic mix of available tools (such as commercial products that support emerging standards for delivery of interactive multimedia) and locally developed solutions that address our own needs. In particular, our aim is to provide a more inclusive curriculum with learning opportunities for the wide range of abilities and learning styles of our students.

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