UniServe Science

Proceedings of

Research and Development into University Science Teaching and Learning

Workshop

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The University of Sydney

UniServe Science

UniServe Science was established in 1994, under a grant from the then Committee for the Advancement for University Teaching (CAUT), with considerable help from The University of Sydney, to act as a national clearinghouse for the dissemination of information about teaching software in the experimental sciences in Australian universities — specifically in the disciplines of Biochemistry, Biology, Chemistry, Geography, Geology, Physics and Psychology. That grant was for three years. UniServe Science is now fully funded by The University of Sydney and has added Computer Science, Mathematics and Statistics to the client base.

UniServe Science aims to enhance the quality of university science teaching in Australia by collecting, maintaining and disseminating information on up-to-date and innovative teaching materials. UniServe Science publishes regular newsletters which include product reviews and articles on developments related to teaching and learning materials in the earth, life and physical sciences. A database of software packages used in teaching is maintained and is accessible via the UniServe Science web site. Along with software details, the database includes UniServe Science solicited product reviews, usually done by Australian academics. Other activities include: the maintenance of electronic mailing lists for each of the nine disciplines covered; conducting workshops for teaching development; producing software guides and maintaining Australian mirrors for frequently downloaded overseas software.

Papers for the ‘Research and Development into University Science Teaching and Learning’ Workshop have been reviewed to meet the Department of Education, Training and Youth Affairs (DETYA) E1 standard for research publications.

The full papers were peer reviewed by at least two members of a national review panel that was chaired by Associate Professor Ian Johnston, Director, UniServe Science. For those papers deemed to be worthy of refereed publication, authors were provided with feedback from the reviewers and asked to make appropriate changes.

The Workshop was attended by academics from across Australia and the proceedings is distributed nationally and internationally in print and from the Web.

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Pearson Education Australia was a proud sponsor of this UniServe Science workshop. Pearson Education supports UniServe Science's aim to promote the use of technology in science teaching and learning.

Science education research

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Background to this workshop

In today's universities, the job description of academics includes both research and teaching; and while the ideal is that all should be equally interested in both activities, in reality there is a wide spectrum of commitment to either. On the one hand there are those who prefer to spend all their time in research, in pushing forward the frontiers of knowledge in their subject. By and large our university system is tolerant of such people, drawing comfort from the fact that some of the world's most productive scientists have been indifferent teachers. Examples quoted usually include Kepler and Einstein. On the other hand, there are those who are more interested in teaching, in exploring ways to communicate this knowledge to students. Our university system is less comfortable with such people: there seems to be something of the 'those who can, do: those who can't, teach' attitude. Yet increasingly many academics believe that the process by which our subject is codified and passed on to the next generation is a worthwhile field of research in its own right. In science departments in universities throughout the world there have sprung up, in the last decade or so, groups of academics whose main research interest is in the development and practice of their own teaching.

The interesting development is that many of these groups have adopted the philosophy that this kind of educational research is best done, not within traditional Education Faculties, but within science departments and conducted by experienced scientists. The appropriateness of this philosophy is argued on several grounds. Basically they come down to the contention that university education in general, and university science education in particular, must be considered to have their own unique needs and difficulties. We practising scientists have spent a long time learning our subject. We may or may not have found it difficult; we all found it rewarding. Why then do so many of our students find it hard and dull? We can only answer this by thinking deeply about science and pedagogy at the same time. And the payoff is that, by doing so, we can deepen our own understanding of our subject and possibly come up with new methods of passing it on to those who follow us.

This change in attitude of the relation between teaching and research — is it too much of a cliché to call it a 'sea change'? — seemed to begin in the 1980s, largely in physics and largely in the United States. Since then it has spread to other disciplines and countries. In Australia we can now boast a wide range of such work being done at a significant fraction of our universities — as evidenced by the papers in this proceedings. Therefore we at UniServe Science considered it appropriate that the topic of this, our sixth annual national workshop should be 'Research and Development into University Science Teaching and Learning'.

What happened at the workshop

The keynote speakers were Professor Dick Gunstone from the Faculty of Education, Monash University, and Dr Marjan Zadnik from the Physics Department, Curtin University of Technology. Professor Gunstone's address was on the theoretical aspects of how the kind of teaching development that good university teachers carry out can be turned into research outcomes. Dr Zadnik's presentation covered the ways in which he has successfully linked his teaching and research.

As it turned out Professor Gunstone was ill on the day and his paper was presented, most ably, by Ms Susan Feteris from the Department of Physics at Monash University.

The contributed papers, as you can read, cover a wide range, both of subject matter and disciplines — the transferability of mathematical skills, the effect of simulations on learning strategies in chemistry, peer group learning in biochemistry, assessment strategies in physics, the use of constructivist methods in geology, the large scale evaluation of educational resources, and exploration of student and staff perceptions and specific teaching strategies in experimental laboratories.

An innovation this year was the introduction of a ‘Show-and-Tell’ poster session. There were 8 posters contributed, too many to find time in a single day’s workshop for each author to give even a short presentation. In an effort to give each presenter the chance to say something publicly about their poster, we adopted the following procedure. An hour was set aside for formal poster viewing. Each author was asked to give a short, 5–10 minute, talk to whomever wanted to hear; and to repeat this every quarter of an hour. This seemed to be well received and we will follow that procedure in future.

Pearson Education UniServe Science Teaching Award

This was the first time this award was made. The idea had been worked out between us and Susannah Bowen of the publishers, Pearson Education Australia. The award was to be made for teaching that improves student learning outcomes via the innovative and integrated use of information technology. There were 13 entries, and the judging panel, Professor Bob Hewitt (chair), Professor Shirley Alexander (UTS), Dr Roy Lundin (QUT) and Mr Shane Donnelly (Pearson Education Australia) had an extremely difficult job in making the final decision.

The winner was Robert Davidson from Charles Sturt University for his project: *MRI Concepts*: A CD-ROM based teaching tool. You can read a full description on page 17 of these proceedings. Our most sincere congratulations, to Robert, and our thanks to all those who sent in entries. We hope we will have as good a field to choose from this year.

Other issues

An important decision we made this year was that the contributed papers could be peer reviewed. While this might detract a little from the open forum nature of these workshops, everyone is all too aware of the need to produce refereed papers to satisfy the funding criteria that our departments struggle under. Hence we made that decision, in the knowledge that it would delay publication of the proceedings quite a lot — as indeed it has. We will review this decision before next year’s workshop.

Turning teaching development into research outcomes

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Introduction

All research has common features, but research in different fields also has fundamental differences. Significant differences are in the ranges of research methodologies appropriate to be used, and in the nature of appropriate knowledge claims each field seeks to establish. Both of these differences essentially derive from the nature of the questions it is appropriate for the field to seek to answer.

The focus of this paper is on, firstly, the nature of research in education and the ways in which it is similar to and different from research in the scientific disciplines, and, secondly, issues important in conducting educational research in ones' own classroom. An appropriate subtitle would be 'Conducting research of value in the teaching contexts in which you work'.

A brief comment on research

All research involves systematic inquiry, critical investigation. This inquiry is focussed by questions reflecting the motivation for the research. All research aims to develop new understandings/ explanations/relationships, either through the generation of new knowledge or through the reconsideration and collation, and often reinterpretation, of existing knowledge. Research is usually guided by theoretical position(s); research which is atheoretical is almost always fundamentally flawed.

As well as seeking to understand/explain particular phenomena, preferably through some form of causal explanation, research seeks to predict to other situations involving the same phenomena. It is in this predicting that the significance of guiding theor(ies) is most obvious.

Research in education

While all research shares the broad characteristics outlined above, there are clear, systematic and appropriate differences in research conducted in different discipline areas. For example, while much of the systematic inquiry in the sciences has parsimony and universality as fundamental needs, some areas of engineering inquiry are focussed on the development of a contextually specific solution to a specific problem.

There are crucial and necessary differences between research in the sciences and research in education, and particularly educational research concerned with understanding classrooms, teaching and learning. The fundamentally important difference is in the nature of the knowledge claims it is appropriate to seek in these two areas of inquiry. Educational research cannot seek the same forms and levels of parsimony and universality that are so correctly the focus of science; education cannot seek to generate valid knowledge claims that are universal across place and time in the way science seeks to do; education cannot seek to generate mathematically precise relationships in the way that much (but not all) of science seeks to do.

> *At the heart of the inability of educational research to generate universal and precise relationships is the nature of causality*. Conceptions of cause that pervade science and much … teaching and learning of science are often monistic (focus on unity) and absolutist

> (invariant). That is, there is striving to discover the *one* correct explanation of a particular scientific phenomenon, the *one* most elegant procedure for testing an hypothesis, and so on. The veracity and applicability of such explanations or procedures are taken to transcend time, context, and, for some 'universal laws', content. Unlike science itself, however, cause in teaching and learning is unlikely to be unitary and invariant. It is much more likely to be multiple (pluralistic) and content-, context-, and time-dependant (relativistic). For example, most teachers would acknowledge that the success of a particular lesson is influenced by the nature of the content *and* the time of day, *and* the ambient temperature, and so on.
>
> (Baird et al., 1991, p.181; emphasis added)

The essential point here is that although it is sadly not uncommon for educational research to seek singular and universal causality (see examples below), this cannot be done. Causality in educational matters is always multiple and relative. One central reason for this (and *not* the only reason) is that context is a determining variable in situations/phenomena we seek to understand.

Context, rightly, is seen in much scientific research as 'noise', and methodologies are used which seek to eliminate the effects of this 'noise'; in simple terms, 'noise' is a nuisance. This is clearly appropriate for the seeking of knowledge claims that are singular, universal and absolute, and therefore not partially determined by context.

Context, on the other hand, is so central in educational research, and particularly in research concerned with understanding classrooms/teaching/learning, that it needs to be seen in terms of a number of determining variables of central significance to an understanding of the phenomenon being investigated. And one fundamental and inevitable consequence of this is that the notion of 'generalisability' must be seen differently in educational research than it is in scientific research. I return to this issue below.

Context, in the ways it is being used here and when referring to research on classrooms/teaching/learning, clearly embraces a range of matters relating both to individuals and to groups in classrooms. Examples include:

- the motivations of the students and the nature of any 'distracting' possibilities (such as an Olympic Games) that may exist;
- the physical environment and resources being used;
- the extent to which one teacher understands and accommodates/uses the other experiences her/his students are concurrently involved with; and so on.

I see four issues that are part of this broad context that have particular importance for research in science/engineering/technology classrooms at both school and post-school levels:

- the ideas and beliefs students and teachers bring to the teaching/learning of a given topic;
- the content that is to be taught/learned;
- the ways in which the intentions (aims) of a teaching program, approaches to teaching, and assessment are coherent or not coherent; and
- time.

By 'time' I mean that what is understood at one point of time may well not be as valid an interpretation of a situation/phenomenon at a later time. This is not at all specific to science-related classroom contexts. For example, conclusions from research on the ways Australian school students undertook homework in 1955 (pre television) clearly could not be translated unchanged into the totally different broad social situation of 1995. (See also Example B below, in which 'time' is a contextual variable of central significance via a form of feedback mechanism).

There is an extensive literature concerned with parts of the other three aspects of context argued here to be particularly significant for science-related learning and teaching at undergraduate levels (see dot points above):

- the nature of the science concepts held by students when they begin a program, often termed 'alternative conceptions' or sometimes 'misconceptions' (there are many, many studies and reviews here, although the substantial majority are concerned with school rather than undergraduate student understanding; see for example the chapter by Wandersee et al. in Gabel, 1994);
- the nature of ideas and beliefs about learning and teaching brought by undergraduate students to a program, the learning approaches they use and their perceptions of their experiences, both generally (for example the very widely used dichotomy of 'surface' and 'deep' learning and more subtle ways of understanding these approaches; e.g. Biggs, 1993; Marton and Booth, 1997) and in specific science or engineering contexts (e.g. Bliss and Ogborn, 1977; Prosser, Walker and Millar, 1996; Tobias, 1990); and
- the huge impact of assessment on the 'what' and 'how' of student learning (e.g. Ramsden, 1988).

The nature of the content to be learned is certainly recognised as significant context (for example, mechanics and electricity are both very similar – each involves highly abstract concepts and relatively simple mathematical relationships between these concepts – and very different – in the area of mechanics direct observation of phenomena, etc. is clearly possible while in electricity all observation must be indirect via forms of instrumentation). This content variable on learning is less researched as yet. There is also very little yet known about the ideas and beliefs university teachers bring to the teaching/learning of a given topic. Both logic and our own teaching experiences strongly suggest this to be an important variable, both for ideas and beliefs about teaching/learning/roles appropriate for teachers and learners and for ideas and beliefs about content. It needs investigation.

Two examples of failure to recognise context as a variable of significance

Much educational research, both in the past and still some today, is fundamentally flawed because of a failure to recognise the nature of knowledge claims it is appropriate to seek. I now give two examples. Both are flawed because of the consequences of failing to recognise the impact of context as a variable of significance, a failure derived from the vain search for 'precise universality' in educational research.

Example A

Research on laboratory work in science: In the late 1950s-1960s, in school science education, there was a period of quite massive curriculum development (PSSC Physics, CHEM study, BSCS Biology, Web of Life, Harvard Project physics, many Nuffield science programs, etc., etc.). These all gave greater and more integrated emphasis to laboratory work than had previously been the case. Therefore there was a great surge in interest in laboratory work. This included much increased research interest in the impact of laboratory work on school science, particularly the learning of science.

Commonly this research interest was manifested in the pursuit of an answer to the question 'Does laboratory work help the learning of science?'. The methodology then used was, again commonly, to recruit a large number of school science classes where laboratory work had a central place, and a separate large group of classes where laboratory work was of marginal importance or not even used. The same test(s) of science learning were then given to both groups of classes, the results compared by statistical analyses of the two groups as whole entities, and educational judgements then made on the basis of statistical significance (or otherwise) of differences between the two groups.

There is a superficially appealing logic to this methodology, particularly for those of us whose original 'discipline home' is science related. But consider, for example, the two following questions:

- how do we decide what ‘learning science’ is, and how do we measure this? (How do we decide what is to be the form and the detail of the test(s) of learning? If, for example, we decide to include on the test(s) a probe of ability to use a burette it is clear that those who have used a burette, i.e. have done laboratory work, will do better. However, if we decide to include questions requiring rote recall of definitions then those who have spent more time on this, by spending less time on laboratory work, will do better. The essential problem here is that decisions about what mode(s) of learning science are to be assessed is a *value judgement*, and must be so.)
- how do we determine whether or not all the classes in one group are sufficiently similar as to allow one to say they are common in terms of laboratory work or no laboratory work? (Laboratory work is used in a very wide range of ways – the variation within the group of laboratory work classes in such studies was often greater than the variation between the mean form of practice in each group. We also know that the class teacher is the strongest determinant of the ‘what’ and ‘how’ of any classroom, yet this methodology assumes the teacher is not a variable of significance. There was even reason in some cases to ask how we decide what laboratory work is, which group a particular class belongs to? For example, if a teacher takes an experiment and has the class work through this, step by step all together, under her/his direction, then would we call this laboratory work?)

The point I am trying to make is I imagine clear. This methodology does not permit a valid answer to the question to be obtained. The initial question, ‘Does laboratory work help the learning of science?’, seeks to establish a knowledge claim that cannot be made. Issues that are context for this initiating question are causal determining variables for the question, even though the 1960s investigations of this question did not recognise this. (It is significant that this methodology in educational research, which might well be pejoratively described as ‘Brand A versus Brand B’, is directly taken from agricultural research such as comparisons of crop yields with and without a given fertiliser. In that context neither the criterion measure nor the determination of the groups A and B were at all problematic. This taking from agriculture includes the direct use of statistics used to generate considerations of levels of statistical significance of any differences.)

It is true that, given adequate responses to the difficulties of what to include on criterion tests and how to form valid and cohesive groups, this research would have some purpose for education systems such as DETYA or State Education Departments in terms of allowing them to consider if the money being spent on laboratories was worthwhile. However even for this ‘non-classroom’ use of the research a much better approach would be to ask a different question – ‘what sorts of learning result from particular uses of laboratory work?’ – and to then consider the data in terms of what learning was to be valued by the system. For understanding of classrooms, teaching and learning there is nothing of value to be found here. (For an account by one research group of the ways changes came in research on learning science from the days of ‘Brand A versus Brand B’ to the mid 1980s, and why, see Gunstone et al., 1988.)

Example B

Selection into university: This is a conjectural example, perhaps even a somewhat puerile one. There is much thought and energy devoted to selection into first year university courses. People are concerned about the quality of that selection, where quality is usually taken to have a very specific meaning – selection will be seen as of higher quality if performance at first year (or in terms of degree completion) is better. Frequently the adequacy of selection is considered in terms of the correlation between year 12 (selection) performance and performance at first year (or over the undergraduate experience). Real problems arise when one goes to what seems the logical next step – to see the goal of the selection process as having the correlation as near to one as possible. Imagine that this was achieved in year X at your institution, that the relationship between year 12 performance and first year performance was a precise linear one, as shown in Figure 1 (with the indication of year 12 performance as the independent variable being deliberate).

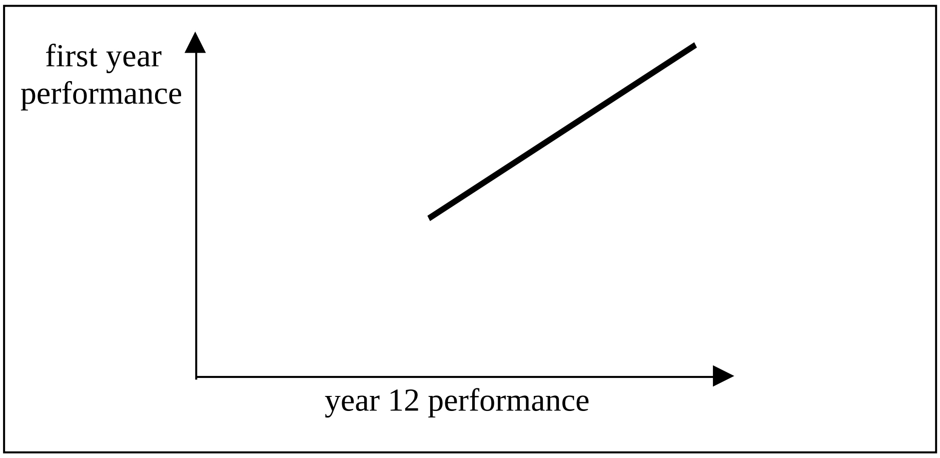

Figure 1. Relationship between year 12 and first year performance desired by many selection processes

And now consider what happens in year X+1, when the next batch of first year students know about the correlation of 1 in year X. Obviously this knowledge will have considerable impact on the ways a proportion of first year undergraduates approach their studies. Some will decide that their performance at year 12 has some predetermining effect on their first year performance and will not approach first year as they would have in other circumstances. Thus the correlation of 1 will evaporate. If it was ever possible to achieve such a correlation, the existence of this relationship in year X would become such a powerful feedback loop into year X+1 that the relationship would no longer exist.

A brief summary of these comments on educational research

Research in education should not attempt to establish causal knowledge claims that are validly independent of place and time – because it cannot do this. Issues that are rightly irrelevant context, 'noise', in scientific research are often relevant causal variables in educational research. And this is even more central in that subset of educational research that is concerned with classrooms/teaching/learning.

Two important consequences of this for those to whom this paper is addressed – academics seeking to turn teaching development into valid research in/of their own classrooms – are the nature of generalisability of knowledge claims and the nature of the questions it is appropriate to seek to generalise about. These are of course significant issues for any teacher at any level of education who seeks to understand aspects of their own classrooms by conducting valid research in these classrooms. There is a substantial recent history of this, widely and appropriately, described as 'teacher as researcher'.

At the heart of the notion of 'teacher as researcher' is an understanding of the nature of research on classrooms/learning/teaching that academic researchers such as me conduct. Academic researchers do (usually) have broader understandings of relevant existing research than a teacher researcher will have (because research is part of the 'core business' of the academic researcher in ways that are rarely the case for teacher researchers). However the academic researcher's understanding of the detailed context of classrooms they are investigating will be much less than the understanding of context held by a teacher researcher. In essence, the knowledge of the academic will be broader than that of the teacher researcher, but will suffer by not being as contextually rich.

Clearly the knowledge of the academic researcher and the teacher researcher are complementary in important ways. It is recognition of this complementarity that has led to the acceptance of teacher research as a legitimate genre of inquiry. And it is the same matter of the need to understand the detail of relevant context in classrooms that has resulted in some science education academics concerned with understanding school science classrooms/learning/teaching returning to school classrooms to explore the validity of their research findings (e.g. Loughran and Northfield, 1996; Northfield and Gunstone, 1985).

I now briefly consider this genre of research, its relevance to teacher researchers working in academic contexts, and address in that context the issues of the nature of questions it is appropriate to ask and the generalisability of knowledge claims that arise.

Teacher as researcher

The notion of ‘teacher as researcher’ has a substantial history and presence in Australia, including in Australian science education. (Two recent issues of the Australasian origin international science education research journal Research in Science Education have been exclusively devoted to teacher research, one in 1999 – Volume 29, Issue 1 – and one in 2000 – Volume 30, Issue 2. The latter issue was exclusively Australian research.) Teacher research became prominent here shortly after the English education academic Stenhouse (1975) first advanced it.

The descriptor ‘teacher as researcher’ denotes explorations by teachers of *their* concerns in the context of their own classrooms, and reflections by teachers on the value to them, as *teachers*, of systematic study of their own contexts. It is not intended to embrace teachers undertaking research degrees in education (where research concerns and approaches are often moderated or changed by the expectations and requirements of research being undertaken for certification).

The essence of what is accepted as ‘teacher as researcher’ inquiry is the combination of:

- the comment just made – ‘explorations by teachers of *their* concerns in the context of their own classrooms, and reflections by teachers on the value to them, as *teachers*, of systematic study of their own contexts’; and
- the comment about research in general made at the start of this paper – ‘all research involves systematic inquiry, critical investigation’.

That is, while the motivations for teacher researcher investigations are frequently quite different from the motivations of an academic researcher, the same demands exist on teacher research as on any other genre. There is fundamental need for data to be valid representations of the situation/phenomenon under investigation, and for the interpretations of the data to be independent of the interpreter.

The nature of research questions; the nature of generalisability

The nature of research questions I argue it is appropriate for teacher researchers to ask is clear from the immediately preceding comments. It *is* appropriate to ask questions that are quite contextually specific, to seek knowledge claims that are quite contextually specific. Other papers given at this workshop are good illustrations of this.

If one is seeking knowledge claims that are at the very least in part contextually specific then the notion of generalisability needs to be seen somewhat differently than in science research. There are two issues here.

The first is how to approach the issue of generalisability in the reporting of a study. This requires being clear and explicit about relevant context in this reporting so as to lead to two approaches: (a) you can also be clear and explicit about the extent to which the study is claimed to be representative of other situations, and (b) readers of the research report will be able to determine what of the research can validly be generalised to the reader’s context.

There is also a wider issue of generalisability in educational research. There are some knowledge claims about classrooms/teaching/learning that I argue are independent of time and place and other aspects of context. These include assertions such as:

- students come to the study of science and technology with ideas and beliefs already formed;
- these ideas and beliefs can impede understanding;
- rote learning will be more prevalent in content areas with a higher proportion of unfamiliar words; and
- students' perceptions of the nature and demands of assessment are a strong determinant of what students learn and how they learn this.

None of these assertions is derived from a single study. Rather each is derived from a considerable number of studies, each of which has been motivated by questions that have been quite contextually specific. The generalisations listed above are, clearly, syntheses across studies.

Where to start and what to do?

The experiences we have had over 20+ years with 'teacher as researcher' in school contexts make clear one fundamental issue – support is crucial for the teacher researcher. This support can be from informed colleagues and/or academic education researchers, and is generally best if both forms of support are involved. In the absence of this support, it is extraordinarily difficult for the teacher researcher to maintain the level of systematic and critical inquiry that is necessary in any form of research. This is because two fundamental aspects of systematic inquiry are not part of the expectations of teachers – knowledge of relevant educational literature and knowledge of educational research methodologies.

Both of these also apply to tertiary teachers of course, and in some contexts are even more problematic. These are contexts where the potential teacher researcher has senior colleagues exerting pressure to not 'waste time' on investigations that are not 'real research'. (There are other aspects of difference in the tertiary context, by comparison with school contexts, that also impact on teacher researchers. These include the common extraordinary difficulty of knowing what experiences one's students are having outside the class in which one teaches them, even other subjects.)

By way of illustration of the need for collegial support for the tertiary teacher researcher, consider the following view from Ramsden (2000) of researching learning in a tertiary classroom.

	Know literature	Improve teaching	Improve own students' learning	Improve learning generally
Collect, read literature	A	B		
Investigate own teaching			C	
Relate discipline knowledge to T&L literature			D	
Communicate results				E

The labelled cells imply a logical sequence, beginning with concern for one's own teaching and leading to the publication of research. At each of the five points A-E support is very likely needed. For A, systematic knowledge of the literature will be clearly valuable (including, but not only, for the articulation of underpinning theory); for B, discussion of the implications of the literature crucial; for C, a colleague to be involved in data collection is often necessary; for D, the same needs as for A; and for E, as for any research report, reaction from an informed colleague will always lead to greater clarity and validity in arguments.

For a small number of tertiary teacher researchers it will be appropriate to seek this support through the formal approach of undertaking a higher degree with this focus (often in education, and with the involvement of colleague(s) from the discipline you teach). Beyond this, and as for school teacher researchers, the obvious sources of collegial support are colleagues in one's department and education academics. The extent to which these are available to you will be very variable of course. However, in general across Australia, both science education research and mathematics education research are, in international terms, very strong. There is a reasonable chance that in your institution there are academics in these areas who are both good researchers and willing collaborators.

The reporting of teacher research is also important to consider. I imagine each of you will be aware of a subset of your discipline professional body concerned with research on the teaching and learning of that discipline (e.g. AIP, RACI), and of other bodies concerned with undergraduate teaching (e.g. Australasian Society for Computers in Learning in Tertiary Education – ASCILITE). There are important possibilities beyond this. There are in this country strong and engaging professional bodies concerned with science education and mathematics education research. These are the Australasian Science Education Research Association – ASERA (http://www.fed.qut.edu.au/projects/asera/) and the Mathematics Education Research Group of Australasia – MERGA (http://www.merga.net.au/). Each runs an annual conference and publishes a journal of international standing. Details are on the Web sites. One of the substantial benefits of engaging with one of these bodies is the generation of a new set of networks to provide collegial support.

The question of 'what to do', in terms of issues to research, is one that will be strongly influenced by the issues of immediate concern to each of us. However there are a number of issues that seem to me to be crying out for investigation by tertiary teacher researchers.

- The notion of independence in undergraduate learning is little understood. There is a substantial literature on metacognition and its development that has yet to find a substantive place in tertiary teaching.
- While we all know the powerful impact on our students of assessment, there is as yet far too little known about the ways in which students perceive assessment tasks, and the ways they relate (or do not relate) these to course aims and teaching approaches, and the ways different discipline areas may have validly different assessment approaches.
- While the surface/deep learning dichotomy has been a powerful tool in focussing thought about learning and teaching, there is emerging evidence that the reality is more complex, and that this more complex reality can be in part discipline specific.
- And that which interests me most, and is clearly the most problematic to investigate – the ways in which teachers' views of learning, teaching, and assessment impact on curriculum and student learning in undergraduate contexts.

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Improving teaching and learning in undergraduate science: Some research and practice

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Abstract: Research has shown that traditional methods of teaching science (lectures, laboratories and problem solving tutorials) are ineffective in promoting conceptual change and are inadequate or unsuitable for many students. Together with a growing number of colleagues around the world, members of the Physics Education Research and Development Group at Curtin University of Technology have attempted to address some of these issues by incorporating, or developing and evaluating, innovative teaching practice in their courses. Teaching innovations, such as the implementation of a 'studio' model, are being researched to examine their effectiveness in changing students' understandings of fundamental concepts. These innovations integrate theory, experiment and problem solving activities in a student-centred 'hands-on' learning environment based on a constructivist epistemology.

This paper discusses some of the reasons for embarking on research into university science teaching and learning. It outlines the guiding principles and then describes some of the current projects and lessons we have learnt, which have led to improvements in student learning.

Rationale for research

Over the past ten years, there has been growing concern internationally over decreasing enrolments in the sciences and the high withdrawal and failure rates amongst first year university science students. In Australia the closure of a number of physics departments or their merger into hybrid schools is evidence of this decline.

The move from the elite, (5% of the 18 year old cohort 30 years ago) to mass (40% of the cohort) education has also resulted in student intake with considerably wider ranges of abilities, preparation and cultural backgrounds. Students are taking longer to finish their degrees. Across Australia only 20% of students finish their degrees in the prescribed number of years. Furthermore, over 65% of first year university students are employed during teaching terms to support themselves and/or their lifestyles.

Additional pressures on academics come from decreasing federal funding, increasing staff costs and staff retiring or being retrenched without being replaced. Many of the surviving physics departments only have about half the number of academics they had 30 years ago and many have lost general staff and technical support.

Increasingly, the Federal Government, universities and employer groups are requiring the incorporation of lifelong and generic learning skills such as communication, teamwork, problem solving, etc. into the ever burgeoning curriculum. The Government is also concerned about the quality of university teaching and is monitoring graduates' university experiences using the Course Experience Questionnaire (CEQ) with the possibility that there will be funding implications (Illing, 2001).

In order to attempt to understand the implication of these changes and deal optimally with them, we decided to carry out research into science education in general and in physics in particular.

Research

As we began to research some of the issues listed above, we quickly realised that there was a large body of science education research available, but much was difficult to interpret due to its size, diversity and unfamiliar jargon. Quite fortuitously a neighbouring building was home to the National Key Centre for Science and Mathematics Education (SMEC) where we met Professor David Treagust, a world authority in the field. About the same time we were also fortunate in meeting and collaborating with Professor Alexandra Radloff, whose background was educational psychology and staff development. Starting with small collaborative projects our mutual interest eventually grew to success in obtaining funding from the Committee for the Advancement of University Teaching (CAUT), the Committee for University Teaching and Staff Development (CUTSD), and the Australian Research Council (ARC) grants.

We started on small projects by identifying problems related to student learning difficulties. Our colleagues provided the educational background and we provided the content expertise. We attended as many conferences, teaching/learning forums and workshops as possible as well as applying for funding from many sources. To make progress, we used the stages of the 'Action Research Cycle' – 1. Develop a plan of action, 2. Carry out the plan, 3. Observe the outcomes, 4. Reflect on the outcomes, and 5. Incorporate the findings into a new plan and then repeating the cycle (see for example Kember and Kelly's (1993) HERDSA Green Guide).

Based on the results of science education research literature, we adopted a constructivist philosophy in our approach to teaching. We believe students 'construct' their knowledge and understanding by incorporating what they see, hear and experience into various 'mental models'. Research has shown that many students have ideas and conceptions which are at variance with scientific or expert conceptions. Such student ideas are termed naive or alternate conceptions or misconceptions. For example, in spite of having instruction in Newtonian mechanics and being able to recite Newton's Laws of Motion and perform algorithmic calculations correctly, many students still strongly hold Aristotelian views. That they do not fully understand mechanics is evidenced by their results in concept tests such as the Force Concept Inventory (Hestenes et al., 1992).

In order to investigate student learning and the effects of innovative teaching, we have adopted mixed qualitative and quantitative research methods depending on the types of questions asked. A brief summary is given in Table 1.

Quantitative…	**Qualitative**…
Draws on scientific research methodology and techniques	Draws on ethnographic methodology and naturalistic inquiry techniques
Controlled variables	Naturalistic inquiry
Population selection	Understanding relationships and motivation
Generalisation/norms or averages	e.g. Case study, focus groups
Deductive reasoning	Interpretative and inductive reasoning
Cause and effect	Personal perspectives and responses

Table 1. Research methodology paradigm spectrum

Current research projects

Physics Studio

studio: *n*. workroom of a photographer, painter, artist, etc. [Ital., L *studium* zeal, *studere* apply oneself, be diligent]

In the context of physics, a studio is a classroom equipped to present courses in which student-centred, interactive, technology-supported classes can replace more traditional forms of physics instruction consisting of didactic lectures with laboratory and/or tutorial sessions. The *studio* metaphor was selected because it conjures a vision of a creative environment in which students are *actively* involved in constructing understanding (Loss and Thornton, 1997). In the Physics Studio, students attend classes with a lecturer and postgraduate teaching assistant, in a single time block of two or three hours per subject, per week. The Curtin Studio is an adaptation of that originally developed and implemented by Professor Jack Wilson at Rensselaer Polytechnic Institute in 1993 (Wilson, 1994).

Physically, the Studio is no more than a room of computers, desks, comfortable chairs and some projection equipment. The physical setting alone does not make a teaching room a 'studio'. At Curtin, the Physics Studio is promoted as:

- a computer-supported learning environment;
- which enables integrated lecture, laboratory and tutorial;
- facilitates a variety of teaching methods and strategies;
- supports communication and collaboration; and
- helps students to model the work of physicists.

The principal agent, however, is the teacher together with his/her philosophical beliefs about knowledge, teaching and learning in physics, and the extent to which he/she models the learning environment on a studio metaphor. Our research is showing that it is possible to create a social constructivist learning environment by making optimal use of situation and facilities and implementing, research-based conceptual change teaching strategies. It is also possible, however, for a teacher to revert to delivering transmissionist-style lectures in the Studio even when using the facilities. Course evaluations in the original Rensselaer Polytechnic Institute Studio (Cooper, 1995; Cummings et al., 1999) have pointed to this as a reason for less than hoped-for student performances.

Current research in the Studio is focussing on how to help students learn effectively in a social constructivist learning environment. Students come to university expecting to be *taught* physics rather than to *learn* it. They continually report favourably on their Studio experiences but because of somewhat objectivist epistemological beliefs, often harbour doubts about their potential to learn the required physics. Students value 'lecturing' because that is how they believe physics should be taught. Teaching physics in a 'constructivist' way requires strategies that scaffold for students metacognitive activities such as goal-setting, taking responsibility for learning, and self-monitoring and evaluating learning. Without this support, some students are unable to make the transition from *being taught* to *learning.*

Interactive multimedia

The Curtin Physics Studio commenced operations in 1997 with the CUPLE (Comprehensive Unified Physics Learning Environment) materials from Rensselaer Polytechnic Institute being used for one semester (Wilson, 1994). What became quickly apparent was just how ineffective most of the computer based materials were in helping students learn. Interactive multimedia (IMM) is promoted as an effective and stimulating medium for learning science; however, students do not always benefit from IMM as intended by software designers. Situated cognition research claims that all learning is situated in context and that all learning activities involve intellectual, affective and physical factors. The emphasis in design and use of IMM should, therefore, be on providing students with enabling experiences in authentic rather than decontextualised situations, and on cultivating learning processes rather than assimilating isolated knowledge items. Enabling experiences and learning processes extend not only to the content of the program but also to the way the computer is used within the learning environment.

Research conducted at Curtin has also shown that the cognitive interaction between student and computer is superficial and of little benefit unless the teacher attends to these issues (Yeo et al., 2000). How they use the program may be as important as the program itself. As well, it is not necessarily big budget IMM programs that are most effective. Programs that maximise student interaction with the physics *content*, *representations* or *ideas,* and not just the interface or tools, promote learning. Even more effective are those that promote meaningful, concurrent student-student interaction (Yeo et al., 1998).

We also realised the important role that electronic communications and peer assisted learning could play in improving student's physics understanding. Since then the more collaborative and peer learning approach described above has been used with the IT infrastructure providing yet another useful tool when required.

Thermal Concept Evaluation

Teaching for conceptual change requires means of evaluating the extent of change. The most efficient method is the use of 'concept inventories', a number of which have been developed by physics education researchers (Hestenes, Wells and Swackhamer, 1992; Thornton and Sokoloff, 1998). Because there was no suitable instrument for the Studio unit on thermodynamics, and because thermal physics is an area rich in students' alternative understandings, we needed to create one. All items were based on results of research dealing with students' understandings about thermal phenomena. The instrument was trialled with almost 500 high school and university students before being refined to its current form (Yeo and Zadnik, 2000). It is now called the Thermal Concept Evaluation and consists of 26 questions set in everyday contexts. The items test students' real beliefs about physical phenomena rather than physics knowledge that they have learned in class but do not necessarily believe. Students choose the answer that they think is most plausible. 'Right' answers exist for most students at different stages of conceptual development in thermodynamics. Year 10 students typically score less than 9 out of 26. Year 11 students, following instruction in introductory thermodynamics, typically score about 16. First year university physics students typically score about 18 before, and 21 following, instruction in thermodynamics. Some students undergo big changes in their understandings while others undergo little or no change.

Other activities

Other activities include collaborative peer learning in lectures (adapted from Mazur, 1997), workshops to improve the competencies of laboratory demonstrators (see http://chemistry.curtin.edu.au/CUTSD/labsci/), and improving science communication skills through student conferences and publishing peer reviewed proceedings (Zadnik and Radloff, 1995).

Conclusions

We believe that research into teaching and learning has led to a number of positive outcomes. Surveys conducted by us, as well as independently, indicate a greater student satisfaction with the Studio learning environment compared with traditional lecture and tutorial instruction. Learning at a deeper level is indicated by comparing students' gain in pre- and post-concept tests. We feel that our research has exposed us to many new ideas and improved our understanding of teaching and student learning, as well as enabling us to obtain research and teaching grants and awards.

The following two quotes best capture some of our conclusions.

> Education is not about filling a bucket but lighting a fire
> (W. B. Yates)

> If students are to learn in a reasonably effective manner, then the teacher must get them to engage in learning activities that will help them learn effectively … It is

> helpful to remember that what the student does is actually more important in determining what is learned than what the teacher does.
>
> (Shuell, 1986, p.429)

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Evaluation of *MRI Concepts* as a teaching and learning resource

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Introduction

The education of medical imaging (MI) students at universities includes the teaching of many imaging modalities including general x-ray, fluoroscopy, conventional angiography, digital subtraction angiography, ultrasound, computer tomography (CT) and the latest modality, magnetic resonance imaging (MRI). Ultrasound and MRI differ from the other modalities as they do not use ionising radiation, x-rays, as their means of producing an image of the patient. Ionising radiation is the focus of the teaching to MI students in the first two years of their three-year undergraduate degree. MRI, which utilises high magnetic fields and radio-waves to acquire images (Stark and Bradley, 1999), is only broached in the third year of the MI degree.

The physics and principles of MRI are vastly different from the other imaging modalities taught at undergraduate level and require additional teaching resources and approaches for student understanding. Medical imaging undergraduate students also need to evaluate magnetic resonance (MR) images to become familiar with MR contrasts of T1, T2 and Proton Density (PD). A further part of the course’s requirements is the ability to evaluate MR image quality. This requires a knowledge of the MR parameters that affect both MR image contrast and quality. This evaluation of MR contrast and quality, in the past, has typically been achieved through students evaluating images in texts, and on occasions, having access to clinical MRI units. Textbooks typically used in MI courses (Hashemi and Bradley, 1997; Westbrook and Kaut, 1998; Bushong, 1996; Woodward and Freimarck, 1995) tend to provide only a few examples of MR image contrast and very few examples of how MR parameters change both MR contrast and quality. Student access to clinical MRI units is difficult to gain. Of the 130 internal and 50 distance education (DE) students at Charles Sturt University (CSU) in 1997, less than 5% have had any substantial time observing an MRI unit in operation (internal CSU survey; 1997 – unpublished).

A project was proposed to assist in overcoming the above difficulties. The project’s goals were to simulate production of clinical quality MR images on a PC environment and allow students to interact with and manipulate MRI factors so as to be able to analyse the changes in the resultant MR images. MR image contrast and quality assessment would be the focus of the use of such a teaching tool. An additional benefit would be that a PC based program would provide equity between internal and DE students, where DE students often only have limited access to library resources.

Previous approaches to MRI undergraduate education

The previous teaching of undergraduate MRI physics and principles involved typical classroom approaches complemented by extensive referencing to texts. Many aspects, such as MR spin factors, T1 recovery, T2 decay, image formation and MRI instrumentation lend themselves well to such approaches. Image characteristics such as MR contrasts of T1, T2 and PD and MR image quality and the parameters that affect these characteristics do not lend themselves to classroom teaching and learning. Classroom approaches, for the teaching of these image characteristics, have been to display MR images, photocopied from texts or copies of clinical images, by overhead projection. Such copies inherently lose quality on copying compared to the original and subtleties of image changes are easily lost.

Although no benchmarks had been established, student knowledge and understanding of MRI, and in particular, MR image contrast and quality, were being hindered by these teaching methods.

Developing a new teaching resource

A variety of authors (Cox, 1997; Dorman, 1997; Dyrli and Kinnaman, 1995) have discussed the advantages in delivery of educational material and student learning through the use of information technology (IT). Silverman (1995) proposes the purpose of education is to foster ‘learning’ which, in contrast to ‘teaching’, is something a person does for himself or herself and Hatcher (1997) states that self directed learning offers a deep level of understanding.

In view of the potential for interactive computer resources to promote self directed learning, it was considered that students’ learning outcomes could be significantly improved by development and use of an IT package incorporating interactivity as well as high quality MR images.

Learning resource project

A Committee for University Teaching and Staff Development (CUTSD) Individual Grant was applied for and gained in 1997 to develop a PC based CD-ROM teaching and learning resource. The project, ‘Interactive Computer Package for the Teaching of Magnetic Resonance Imaging to Medical Imaging Students’, was undertaken for a two-year period.

The initial part of the project was to evaluate software development platforms to meet the needs of the teaching and learning resource. A major fault with available ‘off the shelf’ development packages was the limitation of their image viewing capabilities. MR images are displayed in shades of grey and can have over 1000 different grey scale values within the image. Typical image formats (jpeg, gif, tiff) that were capable of being displayed in these ‘off the shelf’ packages allowed the display of only 256 shades of grey.

A specifically designed viewing and image modification program was considered to provide the best solution to be able to give students the quality of images seen in the clinical environment.

Clinical MR images of the brain were chosen as the basis of the learning resource. MRI has the capability of obtaining images in many anatomical planes such as the axial, coronal and sagittal planes. The axial plane was chosen as undergraduate medical imaging students have more experience with images obtained in this plane through their involvement with CT.

Over 1,100 MR images were obtained from a single volunteer on GE Signa 1.5T MRI units (GE Medical System Australia Pty Ltd, Botany) at the Royal Children’s Hospital, Melbourne and Wagga Medical Imaging, Wagga Wagga. These were obtained using a small change in each of the MRI parameters that control MR image contrast and quality.

The result was the development of the teaching and learning resource, *MRI Concepts*. This CD-ROM based program allows students to access high quality clinical MR images through a PC running *Microsoft Windows 95/98* or *Microsoft NT 4.0*. Figure 1 shows the typical and familiar ‘Windows’ design and features available to the user.

A reference group of clinical MRI users, MRI educators and a third year medical imaging student was established in 1997 to review the development of the software teaching tool and provide feedback to the designer and programmer. The third year student cohort of 1998 was also used as a trial group to evaluate the use of *MRI Concepts*. These students completed survey forms on the useability of the material and their perceptions of the ability to comprehend it.

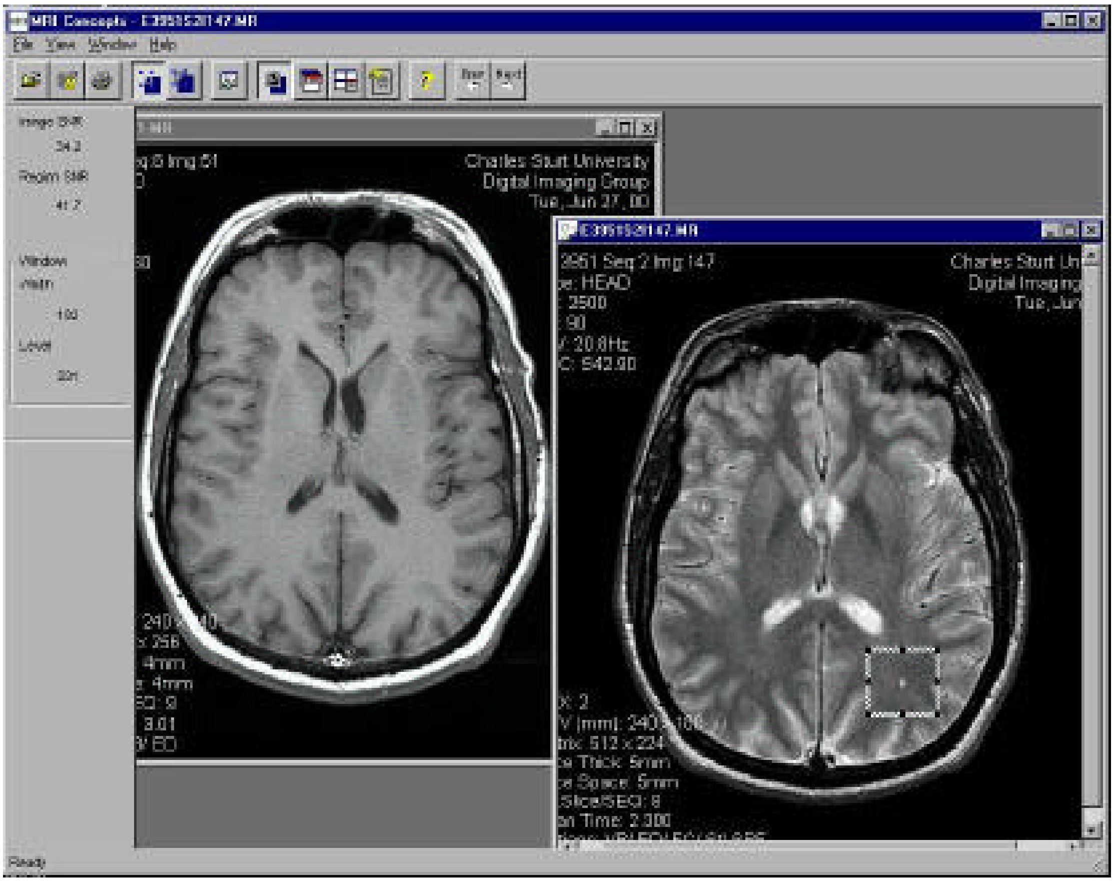

Image SNR
34.2
Region SNR
41.7
Window
Width
100
Level
201

Figure 1. *MRI Concepts*: A *Microsoft Windows* compatible program

Teaching methods

MRI Concepts is used to supplement the teaching of MRI physic and principles. Formal classroom teaching methods are still used to provide students with the majority of the educational content requirements. References to texts and web sites complement the formal material. *MRI Concepts* is provided to each student on a CD-ROM. Tutorial periods are allocated for access to computers. A practical manual aids the students in using the program and a series of tutorial exercises provides a series of tasks to be completed. The tutorial exercises are designed to allow flexibility in outcomes. This encourages students to wander and delve into the program and assess many and varied MR images.

Use of the *MRI Concepts* program also allows learning location independence. Students can access the program at home or outside the allocated tutorial periods. Use of this CD-ROM has allowed convergence of the teaching strategies used for distance education with those used for on-campus students.

Evaluation

The evaluation of the learning effectiveness, when implementing a new teaching strategy or resource, can be difficult. It was decided that the evaluation of learning outcomes should be undertaken to assess improvements of comprehension arising from the use of *MRI Concepts* and associated tutorial exercises. Learning outcomes through the use of *MRI Concepts* and tutorial exercises were identified as:

- identification of a Spin Echo (SE) image sequence in MR imaging;
- identification of MR contrasts of T1, T2 and PD in a MR image;
- identification of parameters that affect MR contrast and image quality;
- analysis of the results of changes in MR image quality when MRI parameters are changed; and
- determination of the changes in Signal to Noise Ratio (SNR) in the MR image when parameters are changed.

The *MRI Concepts* program was used at the same time as formal classroom teaching of the MRI physic and principles, due to timetabling constraints. It was therefore decided that the evaluation of the change in comprehension in each student following the use of the *MRI Concepts* program, could not be undertaken without being confounded with increase in comprehension associated with formal class work.

The most appropriate method to assess student comprehension was to assess different cohorts of students. The 1997 cohort of medical imaging students did not have access to the *MRI Concepts* as the program was still in development. Assessment questions relating to the expected improved learning outcomes were identified in the students' examination answer scripts. The students' responses to these identified questions were marked and the results were recorded. The 1998 and 1999 student cohorts, who used *MRI Concepts* as a part of the subject material, were likewise assessed and their results recorded.

Results

A plot of the 3 student cohorts' results can be seen in Figure 2. This frequency distribution data appears to display differences in results of the 3 cohorts. The mean values and the spread of the results, seen in Table 1, would suggest differences in results between the 3 cohorts. To compare the results, statistical comparisons were undertaken.

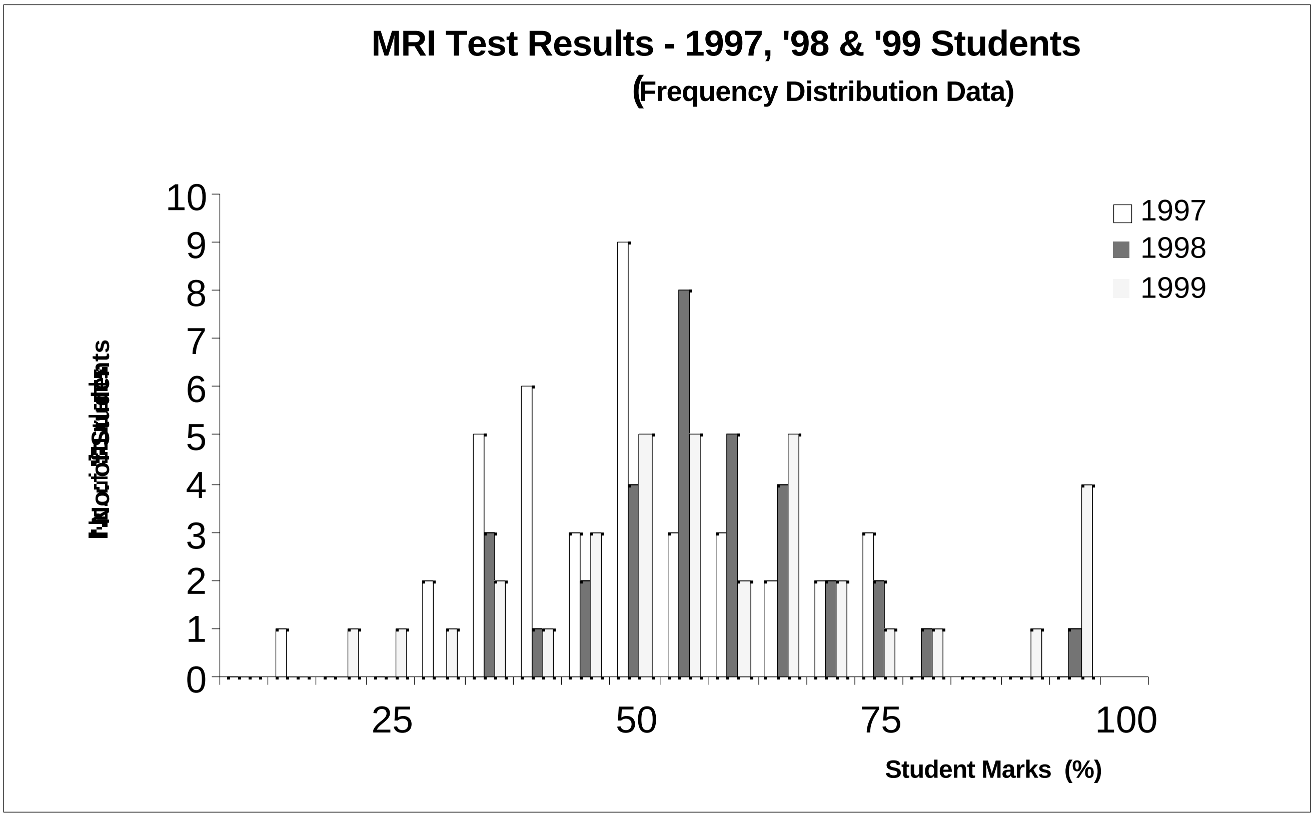

Figure 2. Frequency distribution plot of student results for 1997, 1998 and 1999

t-Test: Two-Sample Assuming Unequal Variances *Comparison of 1998 & 1999 Results to 1997 Results*			
	1997 Results	*1998 Results*	*1999 Results*
Mean	52.1	60.2	61.7
Standard Deviation	14.1	13.0	19.7
Observations	39	33	35
Hypoth. Mean Diff.		0	0
t Stat		-2.5196	-2.3971
P(T<=t) one-tail		0.0070	0.0098

Table 1. Comparison of t-Test statistics of 1998 and 1999 results to 1997 results

The mean mark for the 1998 and 1999 student cohorts were significantly higher than the mean for the 1997 cohort (one-tail t-test, p=0.007 for comparison of 1998 to 1997; p=0.010 for comparison of 1999 to 1997; see Table 1). However, the means for 1998 and 1999 were not significantly different (p=0.694; see Table 2).

t-Test: Two-Sample Assuming Unequal Variances		
	1998 Results	*1999 Results*
Mean	60.2	61.7
Standard Deviation	13.0	19.7
Observations	33	35
Hypoth. Mean Diff.		0
t Stat		-0.3950
P(T<=t) two-tail		0.6943

Table 2. Comparison of t-Test statistics of 1998 results to 1999 results

Discussion

The comparison of student results between various cohorts shows a difference in comprehension of expected learning outcomes that have resulted from the use of *MRI Concepts*. Those students who had access to the *MRI Concepts* program and tutorial exercises showed improved comprehension over those students who did not have access to this teaching resource. Although comparisons of students results could not divulge reasons, such as lower group intellect in the 1997 cohort, student aversion to subject content or teaching methods, the author's observations of the students during use of the CD-ROM package suggest that the improved learning shown results from the use of *MRI Concepts*.

The use of a CD-ROM based program, such as *MRI Concepts*, allows the student to gain a nexus between the learning and the clinical situation. *MRI Concepts* also provides the ability for students to visualise clinical quality MR images. Thus, the interactivity of the program and the ability for students to 'wander' deeper than tutorial material, also allows students to engage in deep-level learning. From the combination of deep-level learning and relevant context of the learning, improved learning outcomes would be expected.

With the integration of *MRI Concepts* and tutorial exercises, learning can progress at the student's own pace. Students can also undertake the learning outside formal classroom times, when they feel their learning experience will be optimised. Students can gain a 'sense of ownership' in their understanding of the material when these factors are allowed. These lead to deep-level learning and a higher level of retained knowledge.

The use of computer programs based on CD-ROMs allows equity of use for both distance and internal students. Teaching practices have differed between internal and DE student cohorts due to physical location differences. Now these practices are beginning to converge. The differences that existed, mainly teaching practices and the ability to provide MR images of the same quality, are disappearing. The medium to visualise MR images is the same, as the quality of those images. *MRI Concepts* provides a teaching and learning resource that any student can access.

Previous teaching practices have been enhanced by the introduction and use of *MRI Concepts*. The teacher's role now is more towards a facilitator of learning rather than the 'fountain of all knowledge'.

Conclusions

MRI Concepts has proved to be a valuable teaching tool for the teaching of MRI to medical imaging students. It has proved a valuable learning resource for students and enhanced learning outcomes for those students. Specifically, the use of *MRI Concepts* and the tutorial exercises improve the level of knowledge of students in the areas of MR image contrast and MR image quality.

The use of the CD-ROM based program has added flexibility in the delivery of the subject content. Students can undertake the tutorial tasks at their own convenience and in a location of their choosing. Students are now not restricted in access to clinical quality images and do not need to be seconded to a clinical MRI unit to gain an understanding of the concepts of MRI parameter changes on MR image contrast and quality.

The *MRI Concepts* program is a teaching and learning tool. Adoption of tutorial exercises to meet specific teaching objectives would allow this program to be used in any institution involved in the teaching of undergraduate medical imaging or introductory postgraduate MRI courses.

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