

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)

Acknowledgements

Marjan Zadnik is very grateful to Professor Ian Johnston, School of Physics, The University of Sydney, and the Director of UniServe Science for being invited to present this paper as a keynote address at the 2001 UniServe Workshop on 'Research and Development into University Science Teaching and Learning'. Thanks also to Anne Fernandez and Kaye Placing for their excellent co-ordination and organisation of the workshop and to Pearson Education Australia for their sponsorship. Thanks also to Dr Robert Loss and Ms Jennifer Bearfoot for reviewing a draft of this paper.

The work reported here would not have been possible without the support, ideas and discussions from the Curtin Physics Education Research Group and in particular, Dr Robert Loss, Professor David Treagust, from the Science and Mathematics Education Centre and Professor Alexandra Radloff, at the Centre for Educational Advancement, Curtin. Financial support in the form of grants and a National Teaching Fellowship is gratefully acknowledged from the Committee for the Advancement of University Teaching (CAUT), the Committee for University Teaching and Staff Development (CUTSD), the Australian Research Council (ARC) and Curtin University of Technology.

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