Evaluation of a research based teaching development in first year physics

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Abstract: The School of Physics at The University of Sydney has developed workshop tutorials for first year physics in accord with findings in physics education research. The students work in cooperative groups at a variety of tasks including hands-on activities and discussion questions. The tutorials are self-paced and focus on understanding, with tutors acting as facilitators. A CUTSD funded project to develop a workshop manual is now nearing completion, and the workshops are already being used at other Australian universities.

Formative evaluation, such as the use of minute papers and a feedback box, has helped to improve the workshops. The students provide a 'snap-shot' of a particular workshop by filling in a minute paper, which allows that workshop to be revised and improved. Summative evaluation of the workshops has been provided by Likert scale surveys and focus groups. The surveys have been administered to large numbers of students and provide a broad overview of the workshops. The focus groups, run by the Institute of Teaching and Learning at The University of Sydney, provide in-depth information from a small number of students. The information from the focus groups and the surveys has enabled the expansion of the project both within and beyond The University of Sydney.

The teaching development – Workshop Tutorials

Workshop Tutorials have been developed at The University of Sydney in response to changing student needs and expectations and poor attendance at traditional tutorials. The workshops were developed over several years by Manjula Sharma and colleagues in the School of Physics and are based on findings from physics education research, and ongoing informal evaluation of the workshops.

The workshops are a student centred learning environment, rather than a traditional teacher centred problem solving tutorial. The students sit in cooperative groups of three or four students, each group at their own table. The students are encouraged to work collaboratively on each problem, discussing each question and arriving at a plan of attack before beginning. This is an important aspect of the cooperative grouping – often when students are put into groups for problem solving activities they work as individuals, only comparing solutions at the end. When this happens the students are missing out on an opportunity for developing communication and teamwork skills. Tutors in the workshop tutorials encourage students to solve problems as a group, rather than as individuals, and try to interact with an entire group, rather than a single student when questions arise. Group problem solving has been shown to be of value not only to the weaker students in a group, but also to the stronger students. Weaker students benefit from peer tutoring while stronger students benefit from being forced to articulate their knowledge, often clarifying it in the process (Heller et al., 1992). In general, students involved in interactive learning schemes consistently out-perform those in the more traditional teacher oriented systems (Heller, Keith and Anderson, 1992; Hake, 1998; Thornton and Sokoloff, 1998). Students working in groups also tend towards 'deep learning' more than students working alone (Ramsden, 1992). This is because by discussing problems, particularly conceptual or qualitative problems, they are forced to discuss their own assumptions and question their understanding of the subject. Students explaining their own understanding to another student are likely to try to make links to their previous knowledge, making analogies to help explain a new concept in terms of familiar ideas. This helps them to relate the new knowledge or understanding to their existing knowledge and experience, giving them a more coherent, and less fractured, understanding of the topic. The tasks, in particular the qualitative questions described below, are particularly designed to encourage students to draw on their experience and previous knowledge, as well as knowledge from other subjects and courses, to help them construct a 'big picture' and coherent understanding of the physics they are learning. The use of context rich questions which relate to other studies, such as engineering or biology, help to do this by making them link ideas in physics to what they are learning in other classes.

First year students often experience difficulties in making the transition from high school to university. They move from an environment where they sit in small classes and they know the other members of the class and the teacher. When they come to university they are often in large classes where they know no-one, and, according to a 1995 report by McInnis and James, well over a quarter worked in isolation from their peers and were not interested in extra-curricular activities. Working in a small group in the workshop tutorials means that from almost the very beginning, they know at least two or three other people in the same class, and can discuss problems in physics with those people. This can be very reassuring to students who otherwise find the transition difficult.

The students are presented with three types of problem to work on in each tutorial; conceptual/qualitative problems, hands-on activities requiring an observation and explanation and quantitative questions requiring calculation.

The qualitative questions aim to address student's conceptual understanding of physics and encourage discussion within the group. These questions explore concepts which students find difficult. Some of the questions are based on misconceptions identified in physics education research, for example student conceptions of simultaneity in relativity (Scherr, Shaffer and Vokos, 2001) and difficulties with Newton's laws (Hestenes, Wells and Swackhamer, 1992). Some questions have also been based on student misconceptions which have appeared on previous examinations, for example 'x-rays have momentum, therefore x-rays have mass and are particles'. The questions are particularly designed to challenge students existing ideas, and encourage discussion within the groups. Tutors are encouraged to use Socratic dialogue when discussing these questions with students, drawing out their ideas rather than simply telling them the answer.

The hands-on activities have been carefully chosen to illustrate particular concepts of physics, and encourage students to discuss the concepts while answering questions from the worksheet. The activities are usually simple in nature and may have been seen by students as lecture demonstrations. The workshop tutorials give students an opportunity to explore the activities in their own time and on their own terms. Students at a concrete operational stage of development need to see physical phenomena directly while they manipulate the equipment themselves so that they can progress on to the abstract operational stage, which characterizes experts in the subject (Laurillard, 1992). Even students who are comfortable with dealing with abstract ideas enjoy the opportunity to see applications and real-life examples of the physics they are learning. The personal interaction with the apparatus rather than passive observation is important in learning. In addition, many of the activities involve simple apparatus such as detergent, kitchen scales, smoke detectors and other household items, allowing students to revisit the activities at home in their own time, and explain the activity to family or friends thus further reinforcing their understanding. Using familiar objects, which students may not have considered from a 'physics viewpoint' helps them to link their previous knowledge of how things work to what they are learning in physics, and encourages them to consider physics around them and at home, not just in the laboratory and tutorial room. This helps them to compartmentalize their knowledge less, and form a more coherent view of the world.

The quantitative questions are generally context rich, with a context appropriate to the course, for example there are questions on blood flow through the circulatory system in the fluids workshops for the biological and environmental physics students, and fuel flow through injection systems for engineering and applied physics students. This helps give relevance to the physics, particularly for non-physics majors. As described above, helping them to relate the theoretical knowledge learned in lectures in everyday experience and knowledge of other subjects.

Evaluation

Evaluation plays an important role in any teaching development. Even prior to introducing a teaching development, evaluation of existing teaching and learning may identify problems or needs which are not being addressed, showing the need for a new initiative. Obviously it is important to know what the problems are before implementing new teaching strategies to address the problems. This gives a basis for comparison, so that the level of success of the new teaching development can be assessed.

When a teaching development is first introduced it is important to have formative evaluation of the development, to allow it to evolve. This is true whether it is an original innovation, or an 'imported' innovation being used in a new setting.

Formative assessment is often very informal, for example anecdotal reports of teaching staff and students' comments. This is very important in the initial design and testing phase of a teaching development. Formal evaluations, such as minute papers and student-staff meetings, help with the testing and evolution of a teaching development.

One weakness of informal evaluation, such as anecdotal evidence, is that a few complaints about a particular aspect of a development can have a very large effect on the development – the squeaky wheel getting the oil. For example, there are always a few vocal students who do not like group work, and are very clear about it. This can give the impression that cooperative grouping is not popular with students. However surveys to large numbers of students reveals that most students (the silent majority) in fact enjoy that aspect of the workshop tutorials. Hence it may be important to have some formal, formative evaluation of a new development, rather than relying on a small amount of informal feedback.

Summative evaluation, such as large scale surveys of students and focus groups, may be important for extending the teaching development. For example, results of early evaluation of the Workshop Tutorials led to a CUTSD grant to fund 'The Workshop Tutorial Project' (Wilson, Sharma and Millar, 2001). The grant enabled the further evaluation and development of the workshop tutorials, enabling the spread of the workshops beyond The University of Sydney. For a description of the early evaluation process leading up to the grant application see Sharma et al. (2001). A summary of the different forms of evaluation used is shown in Table 1 below.

	USyd regular, advanced, fundamentals technological	USyd CCHS bridging course	UNSW optometry	UWS engineering	ACU environment al science	USyd primary education
minute papers		yes, *n* = 110	yes, *n* = 43	yes, *n* = 33	yes, *n* = 18	yes, *n* = 127
surveys	yes, *n* = 415				yes, *n* = 21	yes, *n* = 108
focus groups	yes, *n* = 29					yes, *n* = 3

Table 1. Summary of forms of evaluation used for the Workshop Tutorials. USyd – The University of Sydney, CCHS – Cumberland Campus Health Sciences, UNSW – The University of New South Wales, UWS – University of Western Sydney, ACU – Australian Catholic University. *n* indicates the number of students contributing to each evaluation.

Formative evaluation of the Workshop Tutorials

Four main methods of formative evaluation of the Workshop Tutorials have been used – these are a feedback box for tutors and students in the tutorial room, tutor meetings reviewing the tutorials, minute papers and focus groups.

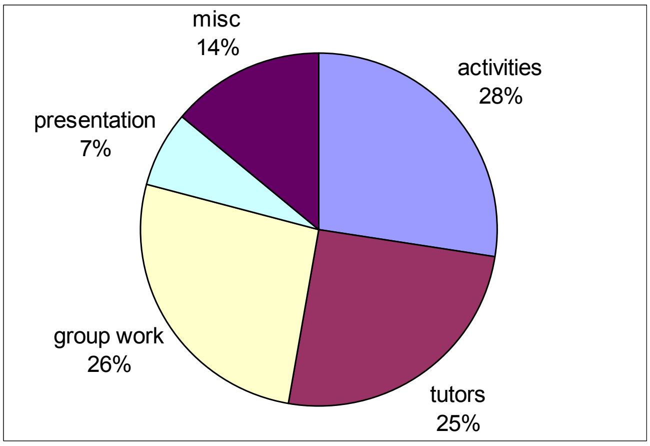
The feedback box and tutor meetings provided informal feedback, allowing immediate action to be taken on minor problems, for example errors in worksheets or broken equipment.

Minute papers and focus groups provided more formal feedback. Minute papers are short surveys consisting of three open questions, plus space for comments. These literally take only a minute to fill in, and are not a major imposition on students who may already be over-surveyed. The questions typically used on the minute papers were:

- What helped you to learn in this tutorial?
- What hindered you from learning? and
- What is one thing which is still unclear?

The minute papers were used with engineering students at University of Western Sydney, environmental science students at the Australian Catholic University, optometry students at The University of New South Wales and an array of different students at The University of Sydney, see Table 1 for details.

For all groups but one (optometry at UNSW), the most common answers to 'What helped you to learn in this tutorial?' were the activities and the group work. This indicates that students find working in a small group a valuable learning experience, a result reinforced by comments in the focus groups, described later. Many students also made comments on the hands-on activities, not only stating that they enjoyed them, but that they helped them to learn. One student responded to the question 'What helped you to learn in this tutorial?' with '*being able to do things myself, instead of just watching the lecturer do it*'. The figure below summarises the answers to the question 'What helped you to learn in this tutorial?'.



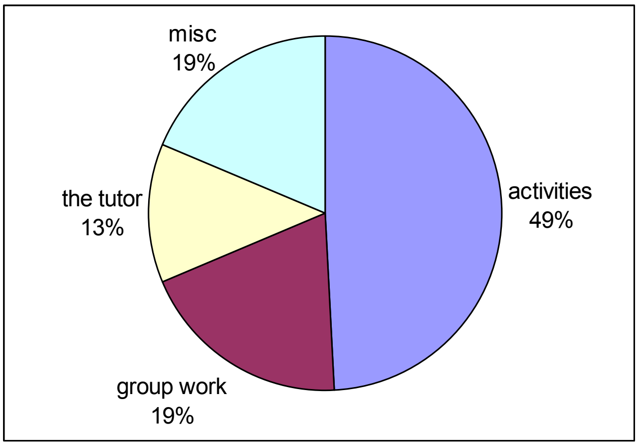


Figure 1. Results of minute papers. The chart on the left shows the responses by 127 primary education students at The University of Sydney to the question '*What helped you to learn in this tutorial?*'. In addition to the normal workshop tutorials as described in the text, the education students were required to give brief presentations at the end of each workshop. The chart on the right shows the responses from 110 bridging course students at the Cumberland Health Sciences campus of The University of Sydney to this same question.

The third question on the minute papers, 'What is one thing which is still unclear?', provided impetus to cover particular concepts again where a large number of students gave the same response. For example, in a bridging course, interference of light was identified as a particular difficulty and was addressed again, in more detail, in a later lecture. This had the added value of reassuring students that their time was not being wasted providing feedback which they would not see used.

In addition to the cognitive domain, students also indicated improvements in attitude due to the workshops. In the 'any other comments' space, a primary education student wrote '*I am really enjoying our interactive tutorials. Physics is becoming less of a chore and more of an interest*'.

Student focus groups were run by Tai Peseta of the Institute of Teaching and Learning at The University of Sydney. Tai was not connected with the tutorials or the Workshop Tutorial Project in any way, so that no bias would affect the results, and the students would feel free to give their opinions. The focus groups provide detailed information on the experiences in the workshops of a small number of students, in contrast to the 'snap-shot' view from a large number of students, as provided by the minute papers.

The focus groups provided some formative feedback on the organisation of the workshops, for example a need to increase the staff:student ratio for some sessions and timing problems with presentation of material in lectures and workshops. It also provided feedback on some minor changes to the tutorials during the semester, for example the introduction of large sheets of 'scribble paper' (butcher's paper) for groups to sketch diagrams, etc. The focus groups also provided valuable summative evaluation, as described below.

Summative evaluation of the Workshop Tutorials

The focus groups have been a useful form of summative evaluation for the workshops. In general the comments made by the students were very positive. They felt that the questions were at a suitable level, they enjoyed working in groups and also felt that they learned well that way. Student comments include: '*Qualitative questions are good – allows people to discuss their thinking processes*', '*Like group discussion – helps you to understand the concepts in different ways if each person in the group has a different way of arriving at a/the solution*'.

There is much interest in, and concern about, the 'first year experience' and the transition between high school and university. Many students feel lonely and alienated by the sheer size of the lecture classes in many first year courses. By ensuring that each student knows at least two or three others in their course, the workshops help to overcome some of these transition issues. It emerged from the focus groups that social networks outside of the workshops have formed from those initial groupings.

Another aim of the workshop tutorials is to teach generic skills, in line with the University's policy on graduate attributes. These skills include communication skills, the ability to work in a team, and 'life long learning' skills. One engineering student commented that '*the tutorials seem to be about learning how to learn*'.

The focus groups provided detailed information from a small number of students. To get a broader view of the students' experience of the workshops a survey was given to a large number of students at The University of Sydney, and the environmental physics students at the Australian Catholic University. The surveys were designed with the assistance of the Institute of Teaching and Learning to look at student learning, rather than just student enjoyment of the workshops. The survey used a five point Likert scale from Strongly Disagree to Strongly Agree. Again the results were largely positive with students indicating that they enjoyed the tutorials and that they found them a valuable learning experience. In particular they felt that the hands-on activities were a valuable learning experience, allowing them to apply knowledge they had learnt in lectures to real-life situations.

Use of evaluation to extend the project

The early evaluation of the workshops led to their expansion within the School of Physics from small remedial classes to a one hour per week component of all main stream physics courses in the school. A collaboration was then set up across The University of Sydney, the University of Western Sydney, the Australian Catholic University, University of Technology, Sydney and The University of New South Wales. This collaboration was successful in applying for a CUTSD grant to fund the Workshop Tutorial Project. The early evaluation which led to the grant is described in Sharma et al. (2001) and Sharma, Millar and Seth (1999). Without this initial evaluation phase the workshops would not have evolved, nor expanded, into their current form.

The collaboration across universities allowed the implementation of workshops for a broader range of students in a variety of settings, for example bridging courses. This gave the opportunity to evaluate the success of the workshops in these settings, and hence the portability and adaptability of the teaching development. The workshops were found to be easily transferable, with positive evaluation results in all settings. This is particularly encouraging, as many teaching developments are not easily transferable. McDermott's 'Tutorials in Introductory Physics' (McDermott and

Shaffer, 2002) have been extremely successful at the University of Washington, but are difficult to implement successfully without high levels of tutor training, and excellent tutor resources. Many other innovations, such as studio physics (Cummings et al., 1999), have been found too expensive for many Australian universities to run. In contrast, the workshop tutorials are relatively inexpensive and easily transferable. They have been successfully run with tutor:student ratios as low as 1 to 6 and as high as 1 to 30. The equipment used is generally inexpensive and easily obtainable, or consists of standard lecture demonstration items. This ease of implementation has allowed the implementation of workshop tutorials into several physics courses at The University of New South Wales and the Australian Catholic University, with other universities trialling the material including two universities from outside the initial collaboration.

Conclusion

Evaluation is necessary to judge whether a teaching development is worth pursuing or continuing. Any new development should be tested to see whether or not it actually does work, or work better than what was done previously. The success of teaching and learning grants is often measured by implementation into different courses and at other institutions. This is a challenging outcome which we have achieved within the two years of funding. Evaluation has been vital in achieving this outcome. Ongoing evaluation is necessary so that a teaching development can continue to evolve to meet the changing needs of students. Without ongoing evaluation the teaching development cannot adapt, and quickly becomes stale and out of date, ongoing evaluation is necessary for a teaching development to be sustained, and outlast the person or group who introduced the development.

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