Teaching Technology Using Educational Robotics

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Introduction

The interest in mathematics, science and technology based courses at both pre-university and tertiary levels have been steadily declining over the past number of years. This is particularly felt in regional areas such as Rockhampton, Queensland (Chiou 2004). To overcome this problem, different strategies have been employed to regain popularity in these areas of studies. Many schemes have been undertaken to implement these strategies. One of more successful and promising strategies attempted by Central Queensland University (CQU) is the utilisation of robotics as an educational tool. However, its implementation cannot be haphazard lest the interest in robotics will quickly diminish as its novelty wears off. Hence, long term planning is required in order to maximise the potential of educational robotics. At the same time, educational robotics should be implemented with great caution as not to cause a reverse effect where it may inadvertently detract students from traditionally based mathematics and science subjects. This paper describes such a project carried out at CQU.

Project Mindstorms

While the practice of using robots as an educational tool to introduce, teach and promote technologically based subjects is a recent development (Druin and Hendler 2000), the concept itself dates back to the early 1980s. From the year 2002 to 2004, the Educational Robotics and Research Group at Central Queensland University have been involved in Project Mindstorms. Named after Papert's (1999) seminal work and also Lego's (2004) line of robot construction kits, the project's main objective is to promote mathematics, science, engineering and technology to pre-university and tertiary level students in regional Central Queensland. Originally, there were two basic goals. The primary goal is to ultimately establish enough interest in students to allow them to enrol in these technologically based courses at tertiary level upon graduating high school. The secondary goal is to design a comprehensive educational robotics curriculum for pre-university level that would provide continuity into mainstream technology courses at tertiary levels. Through succeeding investigation however, it is revealed the project has enough collective expertise and resources to actually develop an advanced curriculum for first-year and second-year university studies.

The schedule of the project was initially carried out in two phases. Phase I was fundamentally to introduce educational robotics in the region. Phase II was the development of a more formal and more comprehensive educational curriculum at pre-university level. In this phase, the project also organised and ran an annual robotics competition. Phase III was integrated into Project Mindstorms at a later date to develop an advance robotic curriculum.

Phase I

The project's earlier activities in 2002 include that of promoting educational robotics to the public, schools, running workshops and summer schools. That is, to make the project's presence and purpose known to audiences spanning from primary school to pre-university level students. These involve school visitations and running demonstration during national and state sponsored science fairs, such as the National Science Week and Central Queensland Multicultural Fair. Longer workshops that ran from three days to weeklong sessions were carried out at summer schools. Most notably are the Siemens Science School Experience and the Women in Mathematics, Science and Technology summer school robotics workshop held annually at Central Queensland University. Every opportunity is taken to send a team of instructors to schools to provide professional development to teachers who were keen in starting robotics classes of their own.

Phase II

Subsequent follow up (in 2003 and 2004) from Phase I was the development and implementation of a curriculum that would provide guidance in the delivery and teaching of a year-long comprehensive robotics course at pre-university level. The objective of this phase is to gradually incorporate mainstream mathematics, science and technology topics into the robotics curriculum. This is carried out in order to maintain the interest of the students without losing sight of the primary objective. The major challenge in the development of this curriculum is to provide a syllabus that would not require skills or knowledge beyond that of what a science school teacher currently knows.

In addition, an extracurricular activity, the annual Central Queensland Junior Robotics Competition (Bell 2004), was organised during Phase II of the project and facilitated by CQU. The competition is to provide a platform to showcase the collective involvement of the community, schools, teachers, students and the university in the area of educational robotics. The competition features the Robocup Junior Australia event that is organised and run at the international, national and state levels (O'Connor 2004). To cater to all students from different age groups and grades, the competition provides three major categories to students to participate. These categories are: robo soccer, dance robots and rescue robot challenges.

Phase III

In mid-2004, a review of the project's resources and expertise revealed that it has the infrastructure in further developing an advanced curriculum in educational robotics. This curriculum is based on the pre-university syllabus, but with advance concepts. The purpose of this curriculum is once again, to allow a subtle introduction of mainstream science and maths subjects without losing the interest of the students. The syllabus is also developed to be challenging enough to motivate students to want to enrol in other currently available university courses to further their understanding and skills required for more complex studies of robotics other related areas.

The Curriculum

The curriculum can be divided into two major syllabuses, Phase II and Phase III. The former is developed for pre-university level while the later syllabus caters to tertiary first and second year level.

Phase II Educational Robotics Syllabus – Pre-University Level

Phase II's syllabus consist of four modules, where each module is to be delivered in a standard 10 to 12-week school term. Hence, the complete Phase II syllabus can be covered in a four-term year. The modules are an introduction to robotics design followed by three technology-based modules. These three modules are data logging, engineering and applied computing (Table 1). However, as mathematics is inherent in all four modules, it was decided that a whole module allocated to it would be unnecessary at this level to teach robotics. In delivering the sequence of the modules, it is of utmost importance that the first module, introduction to robotics, be delivered first. Teaching and introducing the topic of robotics early on in the curriculum ensures that strong motivation is established to provide sustainable interest for the rest of the modules (Beer, Chilel and Drushel 1999; Chiou 2002a). However, the remaining technology-based modules can be taught in any order at the instructor's discretion.

Table 1. A summary of the syllabus used for educational robotics at pre-university level

Module 1: Introduction to Robotics Design	**Topics:** 1. What are robots? 2. The hardware, 3. The software, 4. Types of robots, 4. Autonomous robots, 5. Mobile robots, 6. Static robots, 7. Articulated joints, 8. Introduction to RoboLab, 9. Programming methodology, and 10. Putting all this together. **Challenge:** Design, construct and program a simple robot to pick and remove as many objects as possible from a predefined area. The robot must be able to detect these objects and avoid obstacles.
Module 2: Scientific Datalogging	**Topics:** 1. What is datalogging? 2. How to interpret data? 3. Simple statistical analysis, 4. Types of sensors, 5. Light sensors, 6. Temperature sensors, 7. Data logging, 8. Putting all this together. **Challenge:** Design, construct and program a simple electro-mechanical device that can read barcodes. Upon reading the correct barcode, the device should activate a door to release a piece of 'treasure' (i.e., Lego block, etc.).
Module 3: Engineering	**Topics:** 1. What is engineering? 2. Electronics, 3. Mechanical engineering, 4. Structures and reinforcement, 5. Gears, trains, racks, 6. Motors, 7. Articulated joints, and 8. Putting all this together. **Challenge:** Design, construct and program a simple robot arm with two articulated joints to simulate a pick-and-relocate movement.
Module 4: Applied Computing	**Topics:** 1. What is computing and programming? 2. Program structure, 3. Variables, 4. Procedures/Functions, 5. Conditional statements, 6. Loop control, 7. Concurrent and multi-tasking, and 8. Putting all this together. **Challenge:** Design, construct and program a simple wheeled autonomous robot that is capable of finding [simulated] food and feeding itself.

Table 2. A summary of the PBL-based syllabus used for teaching robotics at a tertiary level.

Module 1: Robotics Design	**Challenge:** Design, construct and program an autonomous wheeled motor vehicle capable of performing self-directed parking. Its function should also include the ability to navigate itself to the allocated parking slot prior to attempting the parking exercise.
Module 2: Scientific Datalogging	**Challenge:** Design, construct and program an autonomous explorer-type vehicle that can navigate over an undefined terrain (e.g., simulated Mars surface), collect rock samples and perform multiple datalogging functions. It should be able to identify and avoid coming in contact with [simulated] dangerous spots.
Module 3: Mechatronics/ Engineering	**Challenge:** Design, construct and program a factory assembly line to simulate the sorting and packaging of different sized parcels. Students must use vision/image processing and some pneumatic systems.
Module 4: Applied Computing	**Challenge:** Design, construct and program a device that can perform a repetitive task that is normally considered mundane by human operators. Students are encouraged to propose their own challenge and use any combination of skills acquired from the other modules. For example, a cash register, poker-slot machine, a dot-matrix printer, an Enigma cipher device and text-to-Morsecode-to-text transceiver.
Module 5: Intelligent Systems	**Challenge:** Design, construct and program a team of two robots that can play against another team in any reasonably challenging sports. Most popular category is soccer playing robots. The emphasis is for students to implement intelligent function in each robot. The topics expected to be investigated by the students are fuzzy logic, neural networks, genetic algorithm, evolutionary algorithm and swarm intelligence.

Fundamentally, the technology based modules correspond approximately to the areas of science, mechatronics and computing science respectively—core areas that can be commonly found in subjects relating to mathematics and science. Even though the development of these modules focuses on respective areas of science or mathematics, the emphasis of individual topics and experiments is deliberately set in the context of robotics (Jones, Flynn and Seiger 1999). Assessment at the end of each module is based on a set of robo-challenges. Robo-challenges are modelled after problem-based learning (PBL) teaching methodologies. Working in groups of three or four, students are given two weeks at the end of each term to solve a problem. Students then design and build a working prototype of the proposed solution.

Phase III Educational Robotics Syllabus – Tertiary Level

The more advance curriculum in Phase III provides continuity for students to seamlessly progress from high school into tertiary studies in the field of robotics. There are five modules at this level. The first four modules are advanced versions of the curriculum found in Phase II. The fifth module, introduces intelligent system concepts (Table 2). Each of the five modules can be delivered in a standard 12 to 13 week university term. However, unlike Phase II, the tertiary curriculum would require formal assessment to test the students' knowledge and level of understanding at the end of each module. The assessment material would be in the form of projects to be carried out by the students and assessed throughout the end of each module (Chiou 2002b). The method of delivery of each module is fully based on the PBL model. After an introduction at the beginning of the respective modules, the students are given a challenge. The students are to perform their own research and learning throughout the duration of the course (with guidance from the instructor) to produce the most optimal solution in tackling the given challenge. The challenge is designed in such a way that most of the required topics relating to the specific module will be inadvertently investigated by the student.

The Tools

The hardware and software equipment used in each phase of the project's activities are robot building kits and flowchart—based programming software to control the robot.

The Hardware: Mindstorms Robotics Invention System

The Mindstorms Robotics Invention System (RIS) manufactured by Lego in Denmark was developed and released in the late 1990s. The contents of the kit are an assortment of approximately 700 pieces of building blocks, gears, wheels, tyres, pins, racks, brackets, electric motors, sensors, microswitches, electrical cables and other parts necessary to build a fully functional educational robot. At the heart of the RIS set is the RCX, a programmable 'smart brick' package in a similar look-a-like design to Lego's familiar building blocks. The RCX has an embedded Hitachi H8 microcontroller (Polpeta and Frohlich 2003) capable of accepting a combination of three different types of sensors such as light, temperature, rotational, and sonar sensors. The microcontroller has three further output ports capable of controlling a combination of electrical motors, actuators, lighting, solenoids and pneumatic systems. The functionality of the RCX can be further extended with add-on peripheral hardware. This can include a realtime video camera system and adaptors that allow specialised sensors to be attached to the RCX, thus extending its usefulness beyond that of an educational tool to that of a fully functional prototyping tool.

The development of the RCX is partly based on the *Handyboard*, a palm sized microcontroller developed by Martin (2001) at the Massachusetts Institute of Technology, USA. The concept behind the Handyboard can itself be further traced to Papert's (1994) seminal work on using cutting edge electronic devices to teach children technology (Martin 1994). Therefore, from the onset of RIS's original proof-of-concept, the motivation behind its development has a foundation in proven educational technology and theory. In addition to selecting an established educational product, other reasons for selecting the Lego's RIS includes: re-useability, affordability, product recognition, availability and user support (Chiou 2004; LUGNET 2004).

The Software: RoboLab

The programs for the robots are written on a *Windows* or *MacOS* based computer that are later uploaded wirelessly to specific robots via an infrared transceiver linked to the computer. This transceiver is part of the RIS kit. The programming software used is RoboLab, developed by Tufts

University, USA (2003). RoboLab has in-built functionality: programming language and datalogging capabilities. The programming language is based on a flowchart programming approach. It can be customised to cater to different student level, hence its intended users can range from primary school pupils to professional roboticists. The programming functions include if-then statements, loop management, linear variables, abstract variables, concurrency, multitasking and real-time communication protocol with the RCX. In addition, it is capable of realtime vision and image processing.


Figure 1. Lego Mindstorms Robotics Invention System.

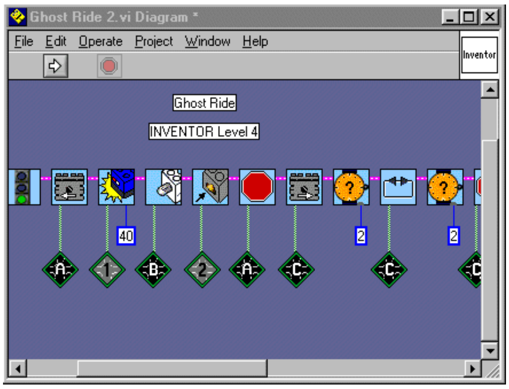

Figure 2. RoboLab programming screen.

Based on LabVIEW (Cyr 2002; National Instruments 2004), RoboLab in conjunction with the RCX can be used as a sophisticated datalogging device. Many of the experiments in the curriculum include using the RCX with appropriate sensors to measure temperature, light, pH levels, humidity, lux level, barometric air pressure, voltage and linear acceleration. Data gathered in these experiments can be downloaded to RoboLab for further assessment using its full range of built-in statistical and analysis tools.

Preliminary Evaluation and Results

As Project Mindstorms was initially carried out as a promotional and not a research activity, no formal method of evaluation was ever conducted at Phase I. However, records were kept of details of participants. These records indicate that as a result of the first 18-month period of the project, approximately 1,500 students and 120 school teachers from 36 schools in the region participated in one or more of the workshops ran by the project team. Surveys and anecdotal feedback gathered at these workshops indicated a very high level of interest in educational robotics.

In 2004, Phase II was carried out at a selected school located in Rockhampton. This involved an instructor from the project team conducting a 3-hour lesson every week. 16 students (12 males and 4 females) from year 10, 11 and 12 attended the class. In addition, two schoolteachers from the school attended these lessons as observers and also part of their professional development. Even though a larger number of teachers and students showed interest in attending these classes, they were however limited to the hardware resources available at the school. The selection of students and participation of the schoolteachers were left at the discretion of the school's management. The students worked in teams of 4, totalling four teams. The school is now up to Module 3 of the pre-university syllabus and is expected to complete Module 4 in the final school term of 2004. At the beginning of the year, only one year 12 male student showed an interest in continuing on in any technology-based courses at tertiary level. At the end of Module 2, an initial survey and feedback showed that 5 males (not including the original year 12 male) and 3 females showed great interest in continuing in a technology based course; 3 male students will seriously consider a technology based course; and the remaining 3 male and 1 female student still retain their preferences for non-technology based courses, but their interest in technology-based courses have significantly increased in comparison to the beginning of the term. These results however, are tentative and only a final enrolment at Phase III would give a more accurate indication of the level of success for this project. Nevertheless, the preliminary survey does offer a glimpse that educational robotics can help build interest in technology based courses. In addition, continued feedback gathered from the current group of students continues to show progressive interest in educational robotics and the likelihood the students will continue their involvement in robotics by enrolling in one of the existing technology based courses at tertiary level.

Summary

To make certain that robots can be used successfully as part of a strategy to halt declining numbers in students enrolling in mathematics and science based courses, a formal approach has to be undertaken. This is to ensure that interest does not quickly diminish as the novelty in robotics wears off. To accomplish this objective, Project Mindstorms at Central Queensland University have set out to introduce robots as an educational technology in three separate phases, where each phase builds on the foundation of the previous one. In this way, any project that is modelled after this basic framework can expect to have reasonable results, as preliminary feedback indicates, in regaining the popularity of mathematics and science based courses.

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What factors contribute to students' confidence in chemistry laboratory sessions and does preparation in a virtual laboratory help?

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Introduction

Many undergraduate students studying chemistry subjects at Charles Sturt University (CSU) do so by Distance Education (DE). CSU has been offering subjects in chemistry in distance mode for more than 20 years. One of the greatest problems that confronts us, and others (Hollingworth and McLoughlin 2001; Kennepohl and Last 2000) in providing DE subjects is how to adequately address the teaching of a laboratory component. The practical work for CSU DE chemistry subjects is completed at intensive three or four day residential schools. Thus, DE students have only a few days to face the challenges that are spread out over many weeks for on-campus students. Providing a quality laboratory experience for these students within that short period and within the constraints of our resources is the subject of ongoing review at CSU. Problems associated with high stress and information overload for the laboratory component in DE had been noted anecdotally and in the literature (e.g., Loonat 1996). Adequately preparing DE students for residential school is a difficult task.

One strategy we have adopted to help prepare DE students has been the provision on CD-ROM of a 3D virtual laboratory, which is an accurate representation of the teaching laboratories. In a paper at last year's UniServe Symposium (Dalgarno, Bishop and Bedgood 2003), we hypothesised that as a pre-laboratory familiarisation tool, the virtual laboratory would include the following potential benefits:

- *students would feel more relaxed and comfortable in the laboratory;*
- *less laboratory time would be wasted looking for items of apparatus;*
- *students would be more likely to assemble and use apparatus in the correct way leading to more meaningful experimental results; and*
- *students could devote more of their attention to the chemistry concepts involved in the experiments because they would already be familiar with the procedural aspects of the task (p. 91).*

This paper presents the results of a qualitative and quantitative study of the laboratory experience of DE students in first year chemistry subjects which provides initial tests of these hypotheses, as well as expanding our understanding of factors involved with the student experience of laboratory.

About the Virtual Laboratory

The virtual chemistry laboratory provided to students on CD-ROM is an accurate 3D model of the Charles Sturt University Wagga Wagga undergraduate teaching laboratory. The initial version of the virtual laboratory has been designed to enable DE chemistry students to become familiar with the laboratory prior to their residential school. Though the virtual laboratory does not yet allow students to conduct experiments, it provides an environment where students can freely explore, collect and assemble items of apparatus, and find out information about laboratory procedures and apparatus (Figure 1). The virtual laboratory has been developed using the Virtual Reality Modelling Language (VRML) (Carson, Puk and Carey 1999) as well as using additional enhancements to VRML provided by the Blaxxun Contact VRML Browser (Blaxxun Technologies 2004). Blaxxun Contact runs within a web browser such as Internet Explorer, but can be run full-screen so that the web browser toolbars are not visible.

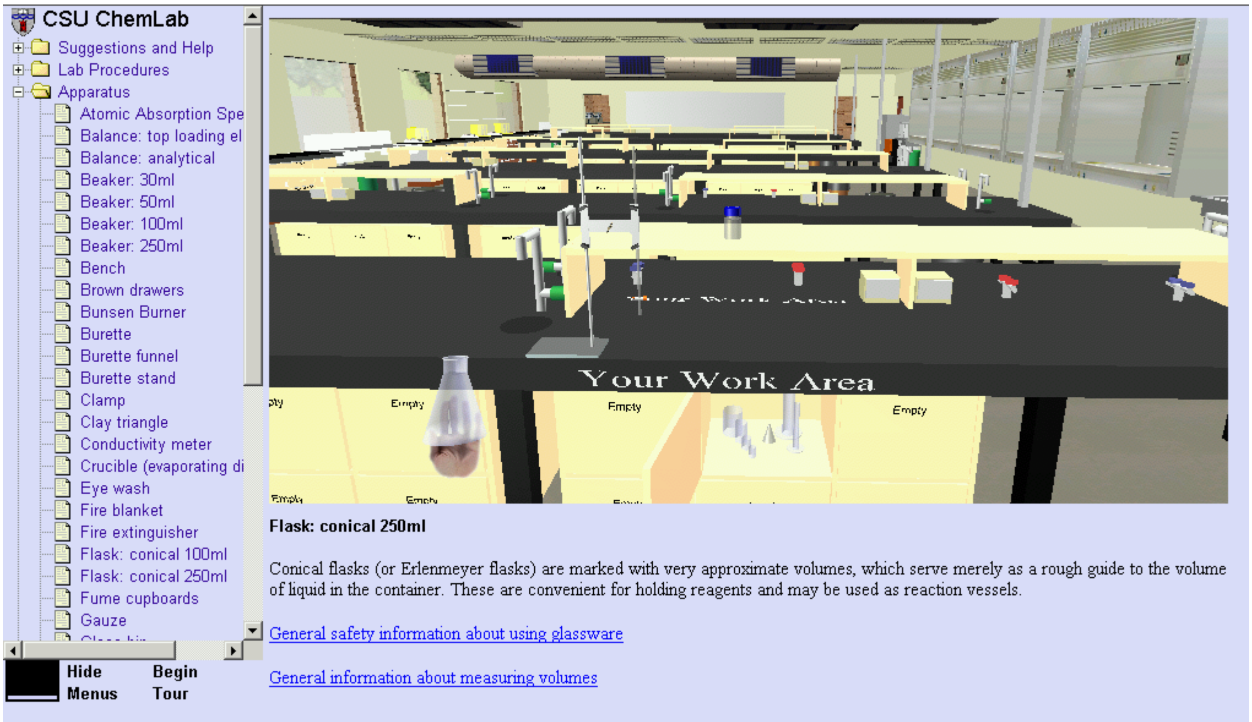

Figure 1. The Virtual Chemistry Laboratory

The Potential of a 3D Virtual Chemistry Laboratory

Dalgarno (2002) carried out an analysis of the potential of 3D learning environments in the context of contemporary theories of learning. Specifically, Dalgarno classifies the potential applications of 3D learning environments according to Moshman's (1982) interpretations of constructivism, endogenous, exogenous and dialectical constructivism. The current version of the virtual chemistry laboratory is primarily an example of a 'place simulation', that allows elements of 'skill practice', each of which were classified by Dalgarno as applications of 3D learning environments consistent with Moshman's endogenous interpretation of constructivism. Additionally, the embedded information about laboratory procedures and apparatus provide an example of what Dalgarno terms a 'situated instructional resource' which was found to be consistent with Moshman's exogenous interpretation of constructivism.

There are various non-3D examples of simulated chemistry laboratories, designed to familiarise students with laboratory procedures before entering the laboratory (see, for example Carter 1997), however, none has the level of fidelity provided by a realistic 3D environment. There has also been extensive use of 3D molecular animations in chemistry (see, for example Tasker 1998) but without the level of interactivity provided by a navigable 3D environment.

Results and Discussion

All students who attended a residential school in the two first year chemistry subjects were asked to complete a questionnaire. Of the 42 students from Chemistry 1A and 28 from Chemistry Fundamentals who attended the residential schools, 55 completed the questionnaire. Additionally 16 students agreed to be interviewed about their experience before and during the first laboratory session at the residential school. Although these 16 students were not randomly selected, they included equal numbers of students from each subject and equal numbers of students who did and did not use the virtual laboratory. Students were asked about issues such as:

- Feelings of confidence and anxiety;

- Difficulties in locating, identifying, and using apparatus;
- Prior laboratory experience;
- Ability to focus on underlying chemical concepts during the practical;
- Effect of laboratory partner on confidence; and
- Pre-prac activities contributing to confidence.

The questionnaire was laid out in parts so that only students who had chosen to use the virtual laboratory answered the main set of questions about the effect of the virtual laboratory.

In relation to questions about feelings of confidence and anxiety before the first laboratory session: 23 indicated that they did not feel confident that they would be able to successfully complete the laboratory sessions, compared to 20 who did feel confident, with 12 undecided; and 43 students indicated that they felt anxious about the laboratory sessions compared with 10 who did not and 2 undecided. As expected, a strong negative correlation was found between confidence and anxiety. Males were more likely to indicate that they felt confident than female students. Using a Likert scale where 7 = very strongly agree, males averaged 4.87 to females 3.54; the difference was significant (T-test, p=0.001). Burdge and Daubenmire (2001, p. 296) report that research suggests that women are still significantly less self-confident than men in introductory college science classes.

When the responses of those who had used the virtual laboratory were compared to the responses of those who had not, there was no significant difference in relation to level of agreement to statements such as, ‘Before the laboratory sessions commenced, I felt confident that I would be able to successfully complete them’. Statistical comparison of the responses of the two groups suggests that using the virtual laboratory prior to the residential school did not have a significant effect on students’ levels of confidence or anxiety, nor did it have a significant effect on the indicated ease with which students were able to identify, locate, choose, assemble or operate items of apparatus. More than half of all students indicated that they did not have difficulty identifying, locating, choosing, assembling and operating items of apparatus. However, there was a significant minority who indicated that they did experience difficulties with apparatus. There were differences between male and female responses to questions about difficulty in assembling (T-test, p=0.042, which is significant) and operating (T-test, p=0.088, significant only at the 90% level) items of apparatus. Male students were more confident in these tasks. Hazel and Baillie (1998, p. 37) suggest that women’s lack of technical background and behavioural tendency to ‘tinker’ less, may be a problem in their science learning.

Understandably, the level of prior laboratory experience influenced student comfort in the practical classes. Students were grouped into three levels of prior experience: recent relevant experience—considered to include laboratory experience (in 1999 or since) in year 11 or 12, TAFE, University, or work; some experience—including any experience not in the first group, e.g., year 10-12, TAFE, University[1] or work experience since 1994; and no experience. Participants with recent, relevant laboratory experience were significantly less likely to indicate that they found it difficult to assemble items of apparatus than participants with ‘some experience’ (ANOVA, p=0.047).

Overall, students felt that a positive relationship with one’s laboratory partner contributes to confidence. This was consistent with our expectations, and further supported by interview data. The opportunities to share the workload and discuss with a partner what steps to undertake can improve confidence. When asked whether they were able to concentrate on the underlying chemistry concepts while performing the experiments, 43.6% of all respondents felt that they were able to, 29.1% indicated that they were not able to, while the remainder were undecided. This is consistent with previous focus groups, in which a number of first year chemistry students discussed developing their understanding later when reviewing and reflecting upon their laboratory experience in relation to theory. Interviews in this study also revealed that a lack of mathematical grounding can detract from students’ confidence: they feel that it undermines their ability to progress in chemistry. While

[1]Students categorised as having ‘recent relevant experience’ may have had that recent experience in a laboratory at CSU.

we have known this for some time, we were surprised at the percentage of students who mentioned it and the apparent magnitude of the influence.

Students were asked to rank ten pre-laboratory activities in order of their importance in contributing to their confidence in the first laboratory session. These results are summarized below in Table 1. The preparative activities that students considered most important were pre-reading of the laboratory manual, prior study, pre-lab exercises and pre-reading of the text book. Interviews revealed that students who felt they had a fair grasp of the theory prior to residential school were more confident of success.

Table 1. Student rankings of pre-laboratory activities in order of their importance (respondents were instructed to rank any activities that they had not completed as last; i.e. as unimportant)

Ranked activity	Mean	S D	Ranked activity	Mean	S D
Pre-reading lab manual	2.47	1.33	Prior work experience	6.09	2.95
Prior study	3.15	2.00	e- or online- resources provided with text	7.26	1.61
Pre-lab exercises	3.64	1.93	Online resources from lecturer	7.45	1.57
Pre-reading textbook	4.23	1.65	Using virtual lab	7.46	2.46
Lectures/tutorials prior to laboratory	4.72	3.05	Reading online subject forum postings	8.13	1.63

A significant difference was noted in the perceived importance of pre-reading the textbook for students of different levels of relevant experience. Students with recent, relevant laboratory experience ranked this 4.78 out of the 10, ranking it of significantly less importance compared to those with some experience, who ranked it 3.33 (ANOVA followed by Post Hoc Tukey's HSD test, p=0.026). Students with no prior experience ranked this factor 3.75.

Several online and electronic resources were available for student preparation: online and CD resources provided with the textbook, online resources posted by lecturers, the forum (asynchronous, electronic discussion forum provided for each CSU subject), and the virtual laboratory. These resources were all low ranking in their contributions to student confidence, and some differences between groups were evident. For example, older students (> 35 years) ranked forum discussions higher than other student age groups. This suggests that older students may get more out of discussions on the forum than the younger age group (ANOVA followed by Tukey's HSD test, p=0.062, which is significant at the 90% level). Hollingworth and McLoughlin (2001) also suggest that willingness to participate in forum discussions relates to maturity.

Males, on average, ranked online resources that came with the text as 7.92, whereas females ranked it 6.88. The difference was significant (T-test, p=0.048). Males were also more likely to use the virtual laboratory in preparation for the residential school: 40% of males compared to 24% of females chose to use it. The very low ranking of the virtual laboratory reflects the fact that only 29.1% of students used it and students were asked to rank activities they had not completed last. Students who used the virtual laboratory rated its importance in contributing to their confidence in laboratory session sixth out of 10 activities, behind pre-reading of the laboratory manual, prior study, pre-reading of the text book, pre-lab exercises and residential school lectures and tutorials, but ahead of prior work experience and use of online resources.

Contribution of the virtual laboratory

Sixteen students (29.1%) chose to use the virtual laboratory in preparation for the residential school. Only these students responded to a section of the survey that had statements about the value and effect of the virtual laboratory. Those who had chosen to use the virtual laboratory comprised 50% of the younger age group, 28% of the middle age group and 19% of the older age group. Twenty-four percent of the respondents with highly relevant laboratory experience used the virtual lab, compared with 40% of the 'some experience' group and 27% of respondents with no relevant experience. As previously noted, 40% of male respondents used the virtual lab compared with 24% of female respondents.

Users of the virtual laboratory were generally positive about the value of it in contributing to their confidence and reducing their anxiety about practical work. On average, they found that the virtual laboratory helped them to identify and locate items of apparatus, and to work out which items to use, but not to improve their ability to assemble items and operate items of apparatus. Males (5.40/7.00) were significantly more likely than females (4.33) to indicate that the virtual lab helped them to identify named items of apparatus in the laboratory (T-test, p=0.030).

The age groups of users of the virtual laboratory responded differently to the suggestion that use of the virtual laboratory helped them to select appropriate items of apparatus during the lab session. Students in the younger age group averaged 3.83, middle age group 3.25 and older age group averaged 5.00 (Likert scale where 7 = very strongly agree). A Post Hoc Tukey's test indicated that the difference between the middle age group and the older age group was significant at the 90% level (p=0.054), suggesting that students aged >35 were less likely to learn the utility of items of apparatus from the virtual lab. Further analysis is required to determine if prior experience correlates with age or whether there were interactions between age and prior experience in the degree to which participants thought the virtual lab helped them.

Consistent with the findings about confidence in the whole group, male users of the virtual laboratory (5.0/7.0) were significantly more inclined than females (3.9) to agree with the statement 'the virtual lab made me feel more confident' (T-test, p=0.030). Male students were also more likely than females to indicate that they found the use of the virtual laboratory enjoyable (T-test, p=0.079, which is significant at the 90% level) and to consider the virtual lab valuable as preparation for the lab sessions (T-test, p=0.089, which again is significant only at the 90% level). A preference to prepare by using the virtual lab rather than by reading a laboratory manual was significantly more frequently expressed by male students than females (T-test, p=0.040). Differences were also found for this preference based on level of prior experience: students with recent, relevant experience averaged 4.71, while those with some experience averaged 3.00, and the 'no experience' group averaged 5.00. Interestingly, 9 out of the 16 students who used the virtual laboratory agreed that a video tour of the laboratory would be more valuable than the virtual laboratory as preparation for the laboratory sessions, with 5 undecided and 2 disagreeing. This was surprising because it was anticipated that the ability to carry out simulated tasks in the virtual laboratory would make it more effective than a video as a preparatory tool. Loonat (1996), however, did find 'far-reaching' benefits to the use of a 35 minute pre-lab video with DE chemistry groups.

When asked whether they would recommend that future students use the virtual lab prior to their first laboratory session, 69% of users of the virtual laboratory agreed. It was interesting to find how the level of prior experience influenced the responses to this question: recent, relevant experience averaged 5.14 and those with no experience averaged 5.33, while students with some experience averaged 3.67. Overall, there was also strong support for the statement 'If the virtual lab allowed me to carry out virtual experiments, it would be useful as a resource to prepare for laboratory sessions.' However, this support must be qualified by the fact that the students can only imagine what such virtual experiments may include.

Conclusions

This study, based on the self reporting of students, allowed the development of the following conclusions about the value of preparation in a virtual laboratory.

The levels of confidence and anxiety were found to vary broadly across the cohort. Statistical comparison of those who used the virtual laboratory with those who did not suggests that it had minimal effect on student confidence in their first practical session in the subject, particularly for those with no prior laboratory experience. Nevertheless, students who used the virtual laboratory were generally positive about the value of the virtual laboratory in contributing to their confidence and reducing their anxiety about practical work. Many of these students indicated that the virtual laboratory helped them to *locate* items of apparatus, and *to work out which* items to use, which we expect would have improved their confidence. Responses of users indicated, however, that, in its current form, the virtual laboratory provides no improvement in student ability to *assemble* and *operate* items of apparatus. Extensions of the current software are now underway, including the addition of a virtual experiment that includes assembly and operation of the apparatus; we expect this addition will improve student skills in this area.

Younger students appear to perceive more benefits from the virtual laboratory, and are more likely to use it. Older students may not derive as much benefit from virtual laboratory environments constructed like this one; these students report valuing personal interaction more than younger students, and so may benefit less from such isolated resources. One way to address this issue is to allow for multiple students to explore the virtual laboratory together, to view 'avatars' representing other students – we have now begun investigation of such mechanisms. Older students also rate the virtual lab as less effective in developing skills in selecting apparatus for an experiment; it is hoped addition of the virtual experiment noted above will address this issue.

The fact that there was such diverse ranking of important items for student preparation suggests that students utilise a wide range of approaches in their study and preparation for the laboratory. Provision of this resource caters to the particular learning preferences of a minority of students. As such, we consider the virtual laboratory as one of the suite of options available to students, in catering to the range of learning preferences among them. Despite mixed impressions of the virtual laboratory, a large majority of students recommend the use of the virtual laboratory before attending residential school.

These results are likely to be of interest to lecturers in chemistry and other laboratory disciplines, whether teaching on campus or at a distance. A better understanding of the student laboratory experience is essential if we are to ensure that students obtain the maximum possible benefit from their laboratory sessions.

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Ignoring the web?: Use of learning resources by psychology and biology students

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Does educational technology help?

Are our first-year students in science ignoring the Web? No, indeed they are not. Their use of web-based lecture notes, for example, approaches the frequency of use of the course textbook in the courses that we surveyed. However, students' reception of the range of educational technology components of these courses varies significantly. We researched the impact of educational technology on students' learning at an aggregate level to find out whether it is necessarily helping those university science students who use it more frequently to learn more effectively, all else being equal. We found that the simple answer is no, at least not for the students whom we studied, who are in large classes in first-year biology and psychology at The University of New South Wales (UNSW is one of Australia's more research-intensive universities). In and of itself, educational technology does not appear to boost the performance of these students across the board, a result foreshadowed decades ago on the introduction of television and video into classrooms (Clark 1983). There is no premium in marks that is predominantly attributable to use of a specific mix of print and online educational resources. What we can say is that the students who receive high marks have entered university with a higher UAI admissions score than their classmates with lower marks.

The apparent lack of correlation between resource use and marks does not prove that educational technology lacks value. Indeed, it suggests that students are finding numerous ways to navigate through the print and online educational resources that we provide. A given set of resource use strategies can produce high marks for some students while the same strategy will not yield high marks for other students of equivalent ability, as gauged by their UAI. In view of this result, one can ask, what exactly is going on in our classes in relation to these new resources—CD-ROMs, online notes, interactive exercises, etc.?

Questions about the educational impact of educational technology—and its frequency of use by students—are rising in importance as lecturers are being urged to make more and more of their material available to students online. For example, half of the lecturers at our university now have an online component in at least one of their courses, specifically via the platform, *WebCT*. Academics are preparing online collections of lecture notes, quizzes, interactive discussion forums, course calendars, submission of assessments, and reading material. Textbook publishers have added CD-ROMs and web sites containing up-to-date supplementary materials. The question remains, though, to what extent is creation of this additional online and multi-media material enhancing students' learning as reflected by their overall mark for a class? According to our study, a textbook web site, for example, does not boost final marks, nor do the students whom we studied seem to employ this resource frequently.

Our study

We addressed these issues by surveying two large (600+ students), first-year classes in science, one in Psychology and one in Biology at UNSW. Our analysis was designed to identify the strategies of resource use that most strongly correlated with higher marks after taking into account other significant factors, such as a student's UAI, their gender, or their linguistic background (NESB versus native English speaker). The analysis revealed, though, that UAI far outweighed all other factors in both courses as an influence on students' final marks. This result should, for now, be seen as limited in relevance to large, first-year classes in science, where the learning of large amounts of content often seems to be stressed, and a significant portion of assessment is via a multiple-choice exam.

Details on the methods and results of this study can be found in two publications, Huon, Adam, Spehar, and Rifkin (2003) and Huon, Spehar, Adam and Rifkin (2004). In this conference paper, rather than reiterating the range of correlations found in the study, we would like to frame questions stimulated by our research, ones that require further examination and discussion based on our findings.

Questions for Discussion

1. Our study's results indicate that students use more frequently the resources that provide information that is assessed, and they tend to avoid resources that cater to free discussion and unguided exploration, such as a textbook's supplementary web site. To what extent can online resources for large, first-year classes in science help to foster an environment of 'deep learning' in place of what appears to be instrumental, 'surface learning'?

2. Does the array of resources that are currently available—textbooks, CD-ROMs, web sites, online quizzes, online discussion forums, etc.—permit students with a wider array of learning styles, learning preferences, and learning goals (i.e., achieving, satisfying modest goals, or merely struggling through) to learn science in an effective and engaging way?

More broadly, what can be learned about successful strategies for using educational resources, and other aspects of life at university, from studying students who 'out-perform' their UAI and those who 'under-perform' their UAI?

Is the growth of the Internet and of online components of university courses trapping lecturers between a 'rock'—student expectations—and a 'hard place'—institutional initiatives to adopt educational technology more widely? How can this tension stifle and how can it creatively enhance advances in teaching and learning?

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AUTC Physics Project: Learning outcomes and curriculum development

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Abstract: *The Australian Universities Teaching Committee is funding a project to investigate the learning outcomes and curriculum development in physics at Australian universities. The project aims to map current practices and future directions in the broad areas of curriculum relating to service/multidisciplinary teaching and majors, employer satisfaction and industry involvement, and student satisfaction. A questionnaire has been administered with 85% return to date from the 34 physics departments or groups in Australian universities. In this paper we present the study design and initial results which include consideration of challenges faced by departments with respect to teaching and learning, departmental strengths and the development of new courses.*

Introduction

Concern has been expressed nationally and internationally about the strategic directions taken by physics departments to ensure a healthy future for the discipline of physics. This concern encompasses many elements including the role of physics departments in nurturing highly capable graduates destined to play major roles in research and industry and providing the essential practical and quantitative underpinning to many disciplines including those of engineering and the biosciences. These concerns have motivated major studies in undergraduate physics in both the USA (AAPT 2003) and the UK (IOP 2001), which provide some comparative materials for this study.

In 2003, the Australian Universities Teaching Committee (AUTC) provided a project brief for an investigation of learning outcomes and curriculum development in physics in Australian Universities (AUTC web site 2003). The majority of the successful project team belongs to an existing network, the Physics Education Group of the Australian Institute of Physics, (AIP-PEG), with expertise in the teaching and learning of physics in Australian universities. The project team comprises a Steering Committee with working party leaders who have responsibilities for specific tasks, a wider group of working party members, and a group of expert advisors. Representing 13 universities, the project team provides excellent coverage for obtaining an accurate and representative picture of the teaching and learning of physics in Australian universities. In this paper we present the study design, initial results from the questionnaire and main features emerging from the study so far.

In the first phase of the project, we identified key areas and designed a questionnaire. In the second phase the questionnaire was administered in universities teaching physics, and further data is to be obtained by in-depth interviews and focus groups. In the third phase, we will develop criteria and identify good and innovative practices. The final phase is to complete the analysis and present a report, due in December 2004.

Aims of the project

The project brief was to evaluate how undergraduate physics teaching and learning is responding to a number of substantial changes, in particular: the new requirements of multidisciplinary areas; the increasing role of the new technologies and of globalisation; the nature of the student body and of student expectations; graduate employment destinations and the requirements of employers; the relationships between Physics and Engineering, and Physics and Biological Sciences; and the role of academic physicists in preparing teachers for physics in schools. As tangible outcomes which will benefit all stakeholders, we aim to identify, evaluate and communicate good practices in Australian undergraduate physics education.

Methodology

There are 34 Australian universities with a group of academics teaching physics. For convenience we refer to such a group as a 'department' even though several groups do not carry this title. All such groups in the 34 universities have agreed to participate in the project and each has nominated a contact person. Privacy arrangements require that institutions and individuals are not identified except when a department agrees to have a good-practice example show-cased.

We are using the 7 key areas listed below as a map for our data collection and analysis.

1. Overview of Teaching and Learning in the context of each department's environment
2. Teaching and Learning practices for physics majors, service and multidisciplinary teaching.
3. Student satisfaction, expectations and attitudes.
4. Relations with industry and employers, and graduate employability.
5. Staff development and successful Teaching and Learning practices.
6. Trends in student numbers and strategies for staffing in the face of declining budgets
7. School teacher education and in-service.

Table 1: A summary of the data collection methods and the key areas that are addressed

	Key areas						
Data collection method	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Questionnaire	×	×		×	×		×
DEST data						×	
CEQ data			×				
Head of department interview	×	×		×	×		
Teaching programs interview	×	×	×	×	×	×	
Focus group with first year students		×	×		×		
Focus group with third year students		×	×		×		
Focus group with postgraduate students		×	×	×	×		
Interviews with graduates			×	×	×		
Interviews with employers				×			

Table 1 summarises the data collection methods and how they address the key areas. The questionnaire has been designed and distributed to each of the 34 departments, requesting responses by the department Head or a designated representative. The questionnaire design was based on the recognition that each department has a unique teaching and learning situation, including its institutional structure, degree programs, and student cohorts, so that the local context will often affect how a question is interpreted. For this reason the questionnaire is almost entirely free-form. It focuses on the current situation and those changes in the past 5 years which impact on the present, with opportunity to comment on future directions. The data from the questionnaire is being used to provide an overview of the teaching and learning across all Australian universities, and to identify trends, themes, and successful practices. Data analysis and interpretation occurs as data are gathered, at times influencing further research questions.

In August-September 2004 we will conduct in-depth studies at nine selected institutions, comprising an interview with the department's head, an interview with the person responsible for academic programs in the department, and focus groups with first year, third year, and postgraduate students. Interviews with graduates in the work force and employers are also planned.

Two external sources of data will be considered. The Department of Science Education and Training (DEST) in Australia maintains enrolment statistics for Australian universities, and it is hoped that these may be used to show trends in student numbers. However there are recognised difficulties in using such data, as reported by the Australian Council of Deans of Science (Dobson 2003). The Course Experience Questionnaire (CEQ) is administered to university graduates within six months of their graduation, and may be used to study trends and comparisons for key area 3. There are concerns about CEQ's relatively low return rate and the inclusion of astronomy and materials science with physics in the 'Physical Sciences' category.

Analysis and results

In this paper we present preliminary results giving an overview of the teaching and learning of physics, some features that recur across institutions and some aspects of the broader context for teaching and learning. The data from 29 questionnaires that have been returned (to July) are analysed using categories generated from the free form responses. If a response to a question has multiple comments then it is placed in more than one category. The categories are then synthesised into three themes: changes in human resources; infrastructure and resources; and teaching profile. The latter can be subdivided into changes in student numbers, changes in offerings of subjects, courses or degree programs and changes in teaching quality.

Overview

We now present the initial analysis of some questions for key area 1, overview of teaching and learning at a departmental level, and related questions from other key areas. The reported features vary greatly between departments, and within one department there are often multiple causes for changes in teaching profile. Six institutions reported that they do not offer a physics major; the remaining 23 have physics to third year. Five departments indicated that the focus of their physics major was theoretical physics. The remainder have some combination of experimental, applied and specialist research areas or a broad range of areas. In the analysis below, the frequency of each comment and its theme is indicated in brackets.

What challenges has your department faced in physics teaching and learning in the last 3-5 years?

The dominant comments were:

- declining staff numbers and downsizing departments (18: human resources);
- laboratory and IT facilities and staff downgraded (12: infrastructure and resources);
- attracting students, drop in student numbers (11: teaching profile: changes in student numbers); and
- loss of (or conflicts with) service teaching (11: teaching profile: changes in offerings)

How has your department responded to the challenges mentioned above?

The most frequent comments were:

- restructuring of curricula and/or labs (11: teaching profile: changes in teaching quality)
- introduction of new technology e.g., *WebCT* (10: teaching profile: changes in teaching quality); and

- introduction of new majors or degrees e.g., photonics, nanotechnology (9: teaching profile: changes in offerings).

What directions will the teaching and learning in your department take in the near future?
The most frequent comments were:

- more new majors or courses (15: teaching profile: changes in offerings);
- more online delivery of subjects (12: teaching profile: changes in teaching quality); and
- more service and/or multidisciplinary teaching (8: teaching profile: changes in offerings)

What are the strengths of the teaching and learning in your department?
The most frequent comments were:

- dedicated experienced staff (13: human resources);
- high quality research area specialisation (12: teaching profile: changes in teaching quality); and
- staff-student interactions (11: teaching profile: changes in teaching quality).

These responses help form an overview of these 29 departments. The challenges are dominated by human resources and by changes in the teaching profile generally resulting from loss of service teaching. Departments have responded to the challenges predominantly by introducing new subjects/degrees or rationalising existing ones and changing teaching quality by exploring different ways of teaching and learning physics. Four departments commented on the conflict between teaching and research, but for other departments, the teaching-research nexus has generated new teaching opportunities.

Future directions are dominated by the introduction of new subjects or degrees. There were six comments regarding sharing of service teaching and four comments about sharing of subjects with other institutions. We note diverging strategies such as small-group interactive learning for in-depth learning (3 comments) versus reduction of contact time with students for staffing or budgetary reasons (3 comments). Dedicated and experienced staff and the quality of teaching are viewed as strengths by approximately half the responding departments. However increased efforts to recruit students were mentioned only twice and attempts to improve retention only once. While such an absence may not be significant in free-form responses, the low response indicates that it is rarely considered in the sweep of teaching and learning issues.

Recurrent features

There is a complex interplay between the categories and themes across all questions. The following features in the theme of teaching profile emerge from questions in key areas 1 (overview), 2 (teaching offered) and 5 (staff and teaching development).

Use of undergraduate research/project work either in teaching laboratories or with research groups
The coupling of research expertise of a department with the teaching and learning is being explored in various ways with undergraduate research projects being a popular option.

The importance of laboratory work
Two-thirds of the responding departments had over 30% of students' contact time in physics spent in laboratory in year 1, and over half of the departments had registered over 30% time in laboratory in year 3. In response to a question asking how the physics education community could work cooperatively, five institutions requested assistance with experimental work.

Use of Information Technology and web based teaching and learning resources
Online teaching and learning resources specifically mentioned are e-learning using *WebCT*, *Blackboard*, online testing and assessment, online tutorials, online-computer labs, and mixed media lectures. Suggestions of ways in which the physics education community could help departments

included a database of physics resources, online subjects, online showcase of Physics in Australia and updated videos.

Changes in assessment practices
Departments are exploring alternative means of assessment with less focus on final exams. The assessment of undergraduate research/project is interesting in that it can be coupled with generic skills. Eleven comments were made that physics majors from their programs were characterised by generic scientific skills, raising interest in how these skills are evaluated and assessed.

Broader Context for Teaching and Learning

Several features arising from the questionnaire deserve special mention.

Students' preparation for undergraduate physics is a concern
This issue was explored by asking '*Please make any general comments regarding student backgrounds entering physics …*'. In response, 15 departments indicated that students were less prepared in mathematics, 9 that students were less prepared in physics, 2 that students have better background in physics and 4 that students were poor at understanding/applying physics concepts.

Industry and employer partners are participating in a variety of ways
Advisory committees (8 departments), required industry experience (7 departments), curriculum design (5 departments) and assessment (3 departments) are the common inputs from external partners. Only one department indicated that industry ties constitute a strength of their teaching and learning, although four departments said that teaching by outside experts is a strength. Nine departments have indicated that new degrees have been introduced in response to changing perceptions of employment opportunities. Four institutions say that they obtain formal (built-in) feedback from employers, while seven say that they have informal feedback.

Service teaching continues as a major factor in teaching effort and funding
Eight departments report that more than 50% of their departmental income is from service and multidisciplinary teaching, while seven report figures between 20 to 50%. Service teaching for engineering has been reduced substantially (14 departments). Six departments have service teaching branching into new areas. Five departments specifically refer to losses in service teaching resulting in reduced funding and loss of staff. Six departments indicate that client departments have increased input into curriculum development. Only two departments report that service teaching is poorly supported; others indicate good support or the same level of support as mainstream subjects.

Specialist and double degree programs are increasingly popular
About half the departments indicate that such programs are successful although five say that student numbers are small. Areas being developed include nanoscience, photonics, biophysics, medical physics, meteorology, energy studies, sports mechanics and security technology.

Support for teaching and learning development
In a majority of departments, good support is provided for curriculum enhancement and teaching and learning issues. In 16 departments, this is through resources, financial support, encouragement, promotion, awards and study leave. Five departments indicate that no special support is provided, two that such activities are poorly supported and one has an embargo on course redevelopment.

Mechanisms for training new staff
Nineteen departments mention university generic teaching courses, seven mention mentoring by senior staff and six have departmental training courses. Three departments say there is a requirement for a certificate in higher education teaching and two that staff are expected to learn as they go.

Discussion and Implications

The number of bachelors degrees awarded in physics in the US declined steadily in the 1990s (AAPT 2003). In Australia the number of third year physics students reached an all-time peak in 1993 and steadily declined until 2001, although a strong rise occurred in 2002 (Jennings, de laeter and Putt 2003). In the UK, numbers of graduates in physics have held steady, though the number of departments offering physics has decreased (IOP 2001). The UK and Australia are following contrasting paths in order to meet the challenge of enduring and flourishing in a difficult and increasingly competitive environment. In the UK, some physics departments have expanded dramatically, focussing largely on the 'core business' of teaching physics to physics majors. By contrast, results so far in our study indicate that service teaching and new multidisciplinary degrees, such as nanotechnology, are vital ingredients of the physics teaching being carried out in Australian universities. This study supports the notion that reliance on service teaching places smaller physics departments in Australia at risk when, for example, faculties of engineering revise their undergraduate courses. There is evidence in our preliminary results that physics departments are exploring new areas for service teaching and new degree programs. This is happening in parallel with, or as a result of declining staff numbers and reduced teaching in tradition areas, such as service teaching to engineers. These findings confirm the impressions gained through discussions with physics academics in Australian universities. On one hand we note the exploration of more new alliances to introduce new subjects and degrees, and on the other hand improving teaching quality, e.g., by introducing research projects and online delivery. There is a recognition by departments that shared resources should be beneficial, yet on the other hand the sharing to date has been informal and diffuse, without much recognisable gain from specifically funded projects.

The US study identified that no single element guarantees a thriving physics department, and found that the common elements for success were: a) a well-developed curriculum and strongly supportive student-staff interactions; b) the support of a large fraction of the department in developing the undergraduate curriculum; c) strong and sustained leadership identifying strategies suited to their local environment (AAPT 2003). Hence this overview of teaching and learning is important in establishing the nature of the local environment. This will be essential for identifying and effectively sharing good practices as the project progress to exploring in depth the successful approaches taken in various local situations.

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