This handbook is for all tertiary physics educators. Creative ways of engaging students in effective learning, drawn from physics departments across Australia, are readily accessible in this one resource.

*"As academics we do not share our teaching achievements as well as we communicate our research. This booklet provides a wonderful opportunity for physics teachers to explore new approaches to teaching in their discipline. If an idea appeals to you, I encourage you to contact the authors, get more details and then try it out in your teaching. I congratulate the AUTC Physics Project Team on this initiative. Try something new: your students will benefit."*

**Professor Adrian Lee**
Pro-Vice-Chancellor (Education and Quality Improvement)
University of New South Wales

*"These snapshots contain some great ideas for engaging students in physics. I can't help but compare my study of physics at university. Despite the pressures on physics in universities, the examples produced here are a testament to the commitment of physics academics to their discipline and to student learning. There is so much more capacity to provide an interesting physics education today."*

**Dr Elizabeth McDonald**
The Carrick Institute for Learning and Teaching in Higher Education

*"This is an important collection of outlines of a rich range of current good teaching practices from Australian undergraduate physics - it deserves to provoke valuable discussions about physics teaching and learning around the country."*

**Professor Richard Gunstone**
Centre for Science, Mathematics and Technology Education
Monash University

*"This booklet should prove inspirational to anyone starting out teaching physics at our universities. Not only does it show them how they might teach their own courses, but it inducts them into a nationwide community of physics teachers only too willing to share experiences and expertise with one another."*

**A/Professor Ian Johnston**
Editor, IUPAP International Commission on Physics Education newsletter

# SNAPSHOTS

## Good Learning and Teaching in Physics

in Australian Universities

A resource booklet from the project
*Learning Outcomes and Curriculum Development in Physics*
funded by
The Carrick Institute for Learning and Teaching in Higher Education

December 2005

The Carrick Institute for Learning and Teaching in Higher Education

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**SNAPSHOTS - Good Learning and Teaching in Physics**

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funded by the AUTC and the Carrick Institute



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www.physics.usyd.edu.au/super/AUTC/

# Contents



Further resources from the AUTC Learning Outcomes and Curriculum Development in Physics project, including electronic versions of this booklet and the 2004 Report are available from the project website at:

www.physics.usyd.edu.au/super/AUTC/

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The project team would like to thank all participating physics departments and the many individuals who contributed to the material in this booklet and to the project in general. These include department heads and physics programme leaders, those who acted as the project contact person at each department, all who participated at the National Workshop held in September 2005, members and office-bearers of the Physics Education Group of the Australian Institute of Physics. Your input has been invaluable.

# Contributors

Many individuals have contributed to the booklet in various ways, from planning, data collection, to writing and reviewing. For each example from departments a contact person is named, however several others may have contributed to the work. The principal writers and editors for this booklet are:

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# Introduction

*Snapshots* is a resource for tertiary physics academics. It provides ideas and examples that have been successful at their originating institution, and have the potential to be adapted for use at other institutions.

A survey of tertiary physics teaching and learning in Australia in 2004 showed that Australian physics departments* are adaptable and innovative, but that many also face the challenges of getting the best from limited resources. Outlines of their good learning and teaching practices are impressive in their scope and quality.

This booklet presents "snapshots" at this time and at selected locations. It is by no means a full panoramic view as many excellent practices had to be omitted due to space limitations. We have sought to cover a wide range of approaches, arranged according to some broad themes. Some materials have been reported previously via conferences, grant schemes and publications, some have evolved gradually over time – having them side by side in one booklet allows the reader to see a range of possibilities.

We thank the many individuals within departments who have provided the raw materials from which *Snapshots* was compiled. We hope that each reader will find resources and encouragement for good learning and teaching. Please contact the individuals named in the booklet for more details, and do give them feedback if you try something out.

We trust that links established and strengthened through this project will continue to thrive well into the future. We encourage each reader to connect with the Physics Education Group (PEG) of the Australian Institute of Physics and ensure that good learning and teaching developments in physics education are communicated widely and effectively.

* 'Department' is used to denote any academic group responsible for physics teaching within a university.

# Large Classes

**Students learn best when they are actively engaged, and yet much of our teaching takes place in large lecture classes. We have a challenge! Here are some approaches to promote active learning in large groups.**

### Role Playing Exercises in Classes

At the University of Queensland, students can build their understanding of a complex physical situation by taking the role of experts in specialised fields. The class is split into groups, and each group is provided with information (subject content) that makes them expert in a specific area. A question is posed which can be answered only by combining input from various areas. (e.g. How do galaxies form?)

During the information-gathering phase, students move freely about the room, talking to each other as experts. They choose who to talk to and what questions to ask; human foibles are allowed. Each group synthesise the given information, then some groups are selected to present to the class their version of an answer. Finally, the lecturer reinforces or clarifies points where needed. To provide incentive for active participation, the exercise is always followed by a written assignment on the material. For instance, the students might have to request and justify a second instalment of information. This strategy has been used in classes of 20 to 120 students at a variety of year levels. Feedback from students has included very high scores on standard student surveys of teaching.

The technique may be extended beyond the classroom with more open-ended exercises. Student interaction out-of-hours is facilitated by the use of an online bulletin board. The use of the bulletin board is encouraged by giving a small assessment mark for participation (full marks for a minimum of one message posted). In a recent class of 38 this was very well used with over 250 messages posted. (This activity was first developed by Paul Francis at ANU.)

*University of Queensland contact*: Dr Michael Drinkwater, Department of Physics

### A Classroom Communication System

Interactivity can be introduced into lectures through mini group quizzes, buzz sessions or a “show-of-hands”. An extremely effective version of these activities is operating at the University of Sydney, where a Classroom Communication Systems (CCS) is used. The system consists of 2 infra-red receivers, a large number of hand held keypads and software that can run on a PC or Mac. The receivers are connected to a computer that collects and analyses the data, and presents a variety of displays to the class using a video projector. A hand held unit is shared between two or three students.

A multiple choice problem is displayed on an overhead projector in parallel with the video projector displaying the CCS screen. Significantly, these problems are crafted from past exam questions, with answers derived from actual exam answers. The lecturer reads the question then starts the clock, giving the class 2 to 3 minutes to discuss the question. Each group of students records their selection on a keypad. The responses are collected by a receiver, processed by a computer, and displayed to the class in the form of a histogram.

The result provides instant feedback from the class to the lecturer who then provides instant feedback to the class by interactively discussing each option. Students are more inclined to interact because they become aware that others in the class think similarly to them. In addition, they have discussed and committed to an answer as a team and have a position to defend. The challenge for the lecturer is to find flaws in the argument without deflating student enthusiasm and confidence. The lecturer-students dialogue aims to resolve students' conflicting ideas. A follow-up multiple choice question is then displayed and each group of students again submits an agreed answer. The ensuing discussion summarises the ideas and reinforces the main points.

*University of Sydney contact*: Dr Manjula Sharma, School of Physics

## Animated Physics

Animations shown in lectures help students to understand and appreciate core principles in physics. At the University of Western Australia, a series of animations is being developed for use in lectures via a data projector presentation and for private study online via teaching webpages or within an electronic media environment (WebCT at UWA). Surveys of students have shown a distinct preference amongst them for use in lectures, though online material is also appreciated.

Since academic staff are time-starved, a key to producing the animations is an efficient, easy to use sequence of software: the mathematical model is laid out using Mathcad, and graphs generated are animated using an internal Mathcad "animate" function. Mathcad outputs the movies in AVI format, which is converted to animated gif format (infinite loop) for file size reduction and ease of use in web browsers (without plug-in installation). The use of Macromedia Flash movie format has also been explored since it allows the animation to be stopped frame by frame, so permitting the student to work interactively through a movie, analysing for particular physics features.

*University of Western Australia contact*: Dr Peter Hammond, School of Physics

# Service Teaching

**The quality of teaching in service subjects has been improved in many physics departments. The key elements are a genuine focus on the context of the other discipline and good communication with the client department or faculty. The students' interest and their appreciation of the contribution of physics can be greatly enhanced by these elements. Two examples are described here. Related ideas may be found in *Context-Centred Teaching*.**

## Interdisciplinary Biophysics Subject

A new third year biophysics subject commenced at the University of New England in 2005. It is taught jointly by staff in Physics and Electronics and in Human Biology. The rationale behind offering this subject is:

- Biophysics and biomedicine are areas of strong growth in terms of both research activity and employment opportunities. It has also been established that a significant number of science students at UNE saw this as a favoured career option.
- The subject provides training in areas that may lead to postgraduate research.
- The subject is truly interdisciplinary and fosters the interdisciplinary cooperation that is becoming increasingly important in many areas of science.
- The subject is designed for students with a background in either biology or physics and it encourages students to communicate and work as a team, building on their differing experiences.

This subject applies elements of physics to biological systems as a means of understanding health and disease. Students are introduced to a broad range of topics such as: mechanics of breathing and related pulmonary function tests; diagnostic tools used in medical imaging (such as X-rays, MRI and radionuclide imaging); protein interactions at the molecular level (using proteomics and fluorescence spectroscopy); fluid dynamics applied to the cardiovascular and respiratory systems and ultrasound applications; theoretical and technical aspects of mechanical power generation; and energy expenditure during exercise in humans.

Student interest in the subject has been promising. One perceived difficulty is catering for the different backgrounds of students studying towards a physics major and a biology major without including a significant level of background material. Careful consultation between teaching staff in both disciplines has resulted in material suitable for both. Further, the subject introduces students to some of the research interests of the staff where honours and postgraduate projects are available.

*University of New England contact*: A/Prof David Lamb, Discipline of Physics and Electronics

# Service Teaching

## Physical Modelling for Engineers

Providing the foundation for logical thinking and experimentation, Physical Modelling is a core subject for all strands of engineering at the University of Technology Sydney – mechanical, civil, environmental, electrical, telecommunications and software. The subject was developed in collaboration with engineering faculty members, who were keen to ensure that students had a grasp of a large range of physics topics considered "essential".

The Physical Modelling syllabus provides:

- a strong experimental base,
- ground-level physics in mechanics, thermal, fields and waves/optics,
- a streamed topic at a more advanced level, e.g. electrical engineers would be expected to choose the electric and magnetic fields option, while software and civil engineers would probably choose the mechanics option,
- online supporting feedback to keep the students apace with the material using "Mastering Physics" weekly assignments.

There are special safety nets in place for those with no previous exposure to physics concepts, those who have limited mathematics, and those who are repeating the subject. Some students directly enrol in the alternative Physical Modelling A/B stream. This takes 2 semesters to complete and builds on the increased mathematics they learn as the year progresses, as well as providing more time to master the basic tools of physics.

Students enrolled in the regular Physical Modelling subject can move across to the A/B version during the semester if they find they are struggling with the material. They can then complete the entire subject at the end of the second semester, with no academic penalty, and no HECS penalty if they make the move sufficiently early in the semester. A "Quick Quiz" is administered just before the HECS deadline to alert students to the potential need to change subjects.

Online materials and a face-to-face drop-in help centre are readily available to all students. For the A/B students, Mastering Physics material is provided as an additional tool, but not made assessable. The tutorial booklet provided to these students has a strongly guided set of tutorial problems. Streaming is not possible, but all topic areas are covered to a moderately advanced level. This makes the subject entirely equivalent to the mainstream Physical Modelling and is also chosen by part-time students, being an evening subject in both semesters.

*University of Technology Sydney contact*: Suzanne Hogg, Department of Applied Physics

# Context-Centred Teaching

**Many first year physics subjects are intended to provide a foundation in physics relevant to specific disciplines for students who have no prior physics studies. In particular, students in the many biologically-based disciplines have very different needs from those who require physics as a foundation for engineering.**

**The "connected" understanding developed through a context-based approach offers several advantages for student learning. Improvements in motivation, perceived relevance, and depth of student learning outcomes have been demonstrated. Putting context first helps define the content to be learnt and how it is learnt. Some features are identified below in the way this approach is used.**

## DETERMINING RELEVANCE AND DEPTH

As an example, the context of ultrasound may be used for learning many aspects of wave behaviour. Putting the context first gives a sense of immediate relevance. It helps decide whether or not a particular aspect should be included ("Yes, we do need wave speed, reflection at boundaries, diffraction"), and whether it is given a conceptual or mathematical treatment ("No, the mathematical form of a travelling wave is not needed for our purposes"). Many approaches discussed elsewhere in this booklet are appropriate (e.g. student seminars or posters). Paul Hewitt, author of *Conceptual Physics*, offers a helpful suggestion with regard to presenting mathematical relationships; always state it in terms of:

$$\text{result} = \text{cause} \times \text{constant}, \quad \text{e.g. } I = V \times (1/R)$$

## ESTABLISHING GOALS

Overall goals for such subjects may differ considerably from those for mathematically-based subjects. These are best determined collegially with the client faculty. Including a guest lecture from the client faculty which builds on physics learnt during the subject is one way of establishing the importance and relevance of physics. In determining goals, the primary aim is that students develop an understanding of physics as inter-related with their chosen field. As well as developing an appreciation for the discipline of physics (this may be their only exposure to physics), this should allow them to use their knowledge of physics in their future studies and/or everyday lives.

# Context-Centred Teaching

## CHALLENGES

A context-centred approach runs against the traditional approach to teaching physics: that physics principles, once understood, can be applied to any situation. The reality is that the abstracted approach requires that students have experience in modelling and a good working knowledge of the system being studied – and hence lies beyond the scope of an introductory subject of this type.

The work involved in context-based teaching should not be underestimated. The principal issues encountered in contextualising subjects are:

1. The need for substantial development time.
2. Breadth of knowledge of ideas outside core physics concepts (staff need to be familiar with the situations they are talking about to be credible, unless they are comfortable eliciting students' knowledge as part of the learning process). Students may have greater knowledge of context than do teaching staff.
3. An understanding of the philosophy underpinning this educational approach, by both lecturing staff and tutors.

Another issue which must be carefully considered is the alignment of parts of a subject – contextualising just one activity or topic may make the rest seem irrelevant, or students may be confused by differing approaches. Approaches to learning used in the students' other subjects also affect their receptiveness to a contextual approach.

### Physics for Physiotherapy and Biological Sciences

Implementation of context-centred teaching at the University of Queensland has taken a number of paths. In 'The Physical Basis of Biological Systems' subject there has been continuing revision of material. Learning of practical skills has been embedded in lab activities. In other subjects, the design has been driven by the context, then the individual teaching and learning activities which flow from this have been adapted. In 'Physics for Physiotherapy' for instance, the assessment was adapted first, then tutorial activities and lecture material were modified to meet the assessment goals.

*University of Queensland contact*: Dr Anton Rayner, Department of Physics

# Laboratory Work

**Laboratory work remains central in most physics departments despite its high cost. It provides a wide range of opportunities for developing a range of graduate attributes: teamwork, information literacy, consulting experts, note-taking, data analysis, interpretation, and report writing. Many institutions now require students to consider experimental design rather than simply following a recipe.**

**The examples reported below show some ways of enhancing the student laboratory experience. Further related material is found in the *Undergraduate Projects, Communication Skills* and *Teamwork* sections.**

### Pre-Lab Activities Suite

The University of Adelaide has developed a comprehensive suite of "pre-lab activities", with the aim being to expose students to the background of a given laboratory experiment in advance of the laboratory session itself. It was recognised that, with a strict timeframe to complete a laboratory experiment, many students were arriving un(der)prepared, and devoting an excessive amount of time to familiarising themselves with the experimental aims and equipment and working out what measurements to make, compromising the interpretation and communication aspects of the practical session. Students are now required to achieve a satisfactory standard in the pre-lab activity as a condition of entry into the laboratory.

The pre-lab activities are presented within an online learning environment, and consist of a set of preliminary tasks and a quiz, allowing students to gain familiarity with the theoretical concepts and calculations that will be required during the laboratory. For some experiments, a simulation of the experimental apparatus (in Macromedia Flash) is also provided, allowing students the opportunity to work with simulated data and explore technical aspects of the practicals before entering the laboratory. The students' pre-lab notes that result from these activities provide a useful template for setting up and recording "real" data. Demonstrators can also use the students' pre-lab notes to identify potential misunderstandings and misconceptions.

As well as the "stick" of being denied entry to the laboratory if a satisfactory standard in the pre-lab has not been attained, an assessment "carrot" is offered: if the standard of the pre-lab work exceeds that of the practical session, the pre-lab contributes up to 40% of the final mark. There is no time limit to the pre-lab work, and students may attempt the online exercises as often as they please. Adelaide also offers bi-weekly drop-in sessions for students experiencing difficulty with the pre-lab activities, giving maximum opportunity for students to address and fix problems before their practical session.

*University of Adelaide contact*: Dr Charles James, School of Chemistry and Physics

# Laboratory Work

## Cafeteria Style Laboratory

UNSW@ADFA has recently introduced a style of "cafeteria" laboratory, first discussed a quarter-century ago (Patterson and Prescott, Am. J. Phys. 48(2) 163-167, February 1980). To quote: "Not every experiment that is worth doing takes an exact multiple of three hours". Students choose from a "menu" of about a dozen experiments, ranging in expected completion time from two to five hours. Most experiments have optional extension work, if students find themselves interested by particular facets of the work. Thus, with some guidance from demonstrating staff to ensure a well-balanced variety of experiences, students may explore the physics that interests them. There is also a degree of pre-lab work, which under these conditions can also serve to provide a guide for what to expect in a particular experiment, and hence assist in student choice.

Each experiment has a "checkpoint" after each hour or so of expected work, where a demonstrator will review efforts to date and either allow progression, allow progression with some recommendations, or deny progression until some fundamental error or omission is rectified. At the end of each experiment a letter grade is awarded, reflecting overall standard of achievement, display of critical thought, etc. Assessment is on the basis of accumulated checkpoints, weighted by the letter grades. The better students will progress faster; and while less able students may not complete as many experiments (requiring more time to come to grips with the concepts, and/or requiring more time to achieve a satisfactory standard), their final understanding should be at a higher level than might otherwise be the case.

Students enjoy having choice, as well as the reduced time pressure (since there is no overt rush to finish an experiment in a given three-hour afternoon). While more teacher-preparation is required to teach in a laboratory with 6-12 ongoing experiments rather than just one, demonstrators have appreciated the opportunity to interact with students at a higher level, relatively free of the need to push students to completion in a short timeframe.

*UNSW@ADFA contact*: Dr David Low, School of Physical, Environmental and Mathematical Sciences

# Small Class Activities - Tutorials

**Well-designed small class activities are ideal in promoting active learning and encouraging peer networking to overcome the isolation experienced by many first year students. Collaborative tutorials, in particular, have captured the imagination of physics departments. The examples below show what these tutorials look like, how they are incorporated into curricula and what their special features are. Many departments also have physics clubs or student networks. Since building a sense of community is a critical factor for a healthy department, one example of this activity has been included.**

## Workshop Tutorials

The School of Physics at the University of Sydney has developed Workshop Tutorials – a teaching and learning environment for peer learning. They grew from the perceived need to provide students with an opportunity to use and discuss material presented in lectures in a supportive collaborative environment. The lecture class is divided into groups that meet weekly. At Sydney the lecture classes are of the order of a couple of hundred and each tutorial caters for 60 to 80 students.

The worksheets contain probing questions specially designed to facilitate conceptual change and support learning processes. The style of the questions and activities has been chosen to provide a mixture of quantitative and qualitative concept-based questions and concrete hands-on activities.

The students collect a worksheet and sit at desks forming teams of four. Over the semester some teams stabilise while others change. The freedom to choose who to work with and how to work with others is important for socialising. The teams can choose when to do what, with some teams starting off with the equipment while others choose to work sequentially through the sheets. There is no direct assessment, thus no pressure to complete or mark work done in the tutorials. In essence the tutorials are voluntary. As the students leave the room they collect solutions and return team answer sheets that are retained for research purposes.

Tutors are responsible for running the hour long tutorial. The tutor to student ratio is about 1:20. Tutors talk to teams not individuals, facilitate discussions, ask questions, prompt using the notes the students have written on butcher's paper and supervise the use of equipment.

Among the challenges in running the tutorials is the training of tutors to achieve consistency in their understanding of the educational process. Extensive resources are necessary for the initial startup.

Evaluations have been done at the University of Sydney, Australian Catholic University, University of Western Sydney, University of New South Wales and the University of

Wollongong. The Workshop Tutorials are popular with students and staff, and students' experiences with the learning style have been almost wholly positive. At Sydney about eighty percent of the students attend more than two thirds of the voluntary tutorials. On average, exam marks improve with increased tutorial attendance, particularly for qualitative concept-based questions.

*University of Sydney contact*: Dr Manjula Sharma, School of Physics

### Conceptual Understanding in Physics (CUP) Tutorials

CUP activities have been used at Monash University for 10 years to build understanding of key concepts. Using a key diagram to represent the physics process (e.g. a free-body force diagram, or a Minkowski space-time diagram) is central to the CUP approach. Students work on exercises alone, then in threes, and finally discuss their views with the whole class. Focusing on a diagram helps students discuss clearly, rather than using, say, a mathematical representation. The process encourages students to actively think about, and modify, their views and results in a high level of participation and satisfaction (claims supported by an ARC funded study). CUP materials are available for aspects of introductory mechanics, electricity, magnetism, thermodynamics, and special relativity. This tutorial scheme requires a well-trained facilitator for a group of about 16 students.

*Monash University contact*: Dr David Mills, School of Physics

### Studio Tutorials

At the University of Adelaide, all first year physics subjects offer a weekly tutorial for classes of 16 to 24 students. These are based around a set of questions prepared by the lecturer and distributed at the lecture during the previous week. We know from experience that tutorials are more effective if students are prepared, and that preparation is encouraged by an explicit reward. Therefore preparation is assessed via an online quiz completed before the tutorial; this result contributes towards each student's final assessment if it improves the result.

At the tutorial, students work in groups of three or four, comparing their answers to the tutorial questions and clarifying their understanding. A set of supplementary questions is provided, often with a hands-on component using simple equipment. Each class has a postgraduate student or academic as tutor. The tutor's role is to encourage productive discussion among the students and to support development of their conceptual understanding and problem-solving skills.

*University of Adelaide contact*: Dr Judith Pollard, School of Chemistry and Physics

# Small Class Activities - Tutorials

## Problem Based Learning (PBL) Modules

Avondale College has successfully introduced Problem Based Learning (PBL) modules into the first year subject 'Physics 1A'. The (rather self contained) PBL module on heat seeks to quantitatively introduce the students to concepts such as heat energy, thermal equilibrium, specific heat, thermal conductivity, thermal expansion and latent heat. A number of scenarios are envisaged, out of which arise questions intended to guide the student into an exploration of one or more properties of matter. Five hours of self-study time is followed by an hour of discussion, during which the lecturer probes the students' understanding and applies any structure needed.

*Avondale College contact*: Dr Lynden Rogers, Faculty of Science & Mathematics

## Building a Physics Community

The Department of Physics at Macquarie University provides an informal tutorial in which students meet regularly to discuss matters relating to being a physics student, what's going on in physics, and the future opportunities they might pursue - any physics matters or interests which are not specifically connected to units of study. This requires a number of "enthusiast" students to achieve the best possible outcomes but is helpful for all cohorts. It is a means by which the department can gain added insight into the overall motivation profile of a cohort. This insight can then be utilised to improve student motivation in their physics subjects.

*Macquarie University contact*: Prof Deborah Kane, Department of Physics

## Small Class Tutorials

The Department of Physics at the University of Queensland uses small class tutorials (~20 students) to give detailed feedback on weekly marked assignments. In some cases students present their solutions to the class as part of their assessment. This encourages active participation and continuous engagement with concepts. The academic achievements of students, as measured both quantitatively by marks and qualitatively by problem-solving approaches used, are also better than they were for larger tutorial groups.

*University of Queensland contact*: Dr Margaret Wegener, Department of Physics

## Weekly Tutorials

The School of Physics at the University of Melbourne offers weekly tutorials for groups of 20-24 students run by a graduate physics student. This approach aids the transition from secondary school to university and acts as a valuable training opportunity for graduate students.

*University of Melbourne contact*: Dr Michelle Livett, School of Physics

# Undergraduate Projects

**Projects are increasingly playing a valuable role in the undergraduate physics curriculum. Students' motivation is heightened by doing their own research, and is a major factor in encouraging students to continue in physics. Well-chosen projects are highly effective in developing research methodology, experimental skills and data analysis, and wider generic skills (problem solving, information literacy, written and oral communication, record-keeping and organisation).**

**Many universities offer undergraduate projects, ranging from short projects of only a few weeks duration as part of a first year program, to extended semester-long projects for third year students.**

## PROJECTS IN THE LABORATORY

### Laboratory Projects at Second and Third Year

At Edith Cowan University, undergraduate project work is used as a significant and essential part of the undergraduate physics teaching program. As students progress through the program, they are increasingly exposed to conditions they may experience as graduates – including equipment limitations, limited financial resources, time restrictions, limited access to facilities, etc.

*Second Year Lab Project*

Students are exposed to a flexible experimental program as a component (30 to 50%) of their laboratory work is performed in project mode. Students are given a particular goal – this may be to determine a particular property or investigate a phenomenon. They plan the experiment based on theory, perform the experiment with equipment available within the physics laboratory (and/or anything else they can obtain), record their work in a laboratory notebook, and write a formal summary report on their project.

*Third Year Lab Project*

The laboratory project is worth 50% of the total laboratory component, and the reporting aspects are demanding as they are required to prepare a major written and oral presentation. Many engineering students undertake investigation of the physics of sensor technology and its application in the Physical and Engineering Sciences. There is a large percentage of engineering students enrolling in this subject as an elective within their engineering programs, and the project aspect of the subject is particularly enjoyable and interesting to them.

# Undergraduate Projects

*Third Year Research Project*

Other students undertake a one-semester research project, although there is not a requirement for their work to be novel. The students are allowed to choose any subject within physics to study, and they define specific goals for their project. As with the second year projects, they plan and perform their own experiments. They are also required to write a formal summary report on their project and results (which may be in the form of a paper, written to the standards of the IEEE Computer Society, or a poster that would be suitable for presentation at a similar conference), and present their results to their peers.

*Edith Cowan University contact*: Dr Stephen Hinckley, Discipline of Physics

## Laboratory Projects in Large First Year Classes

All students doing first year physics at the University of New South Wales (around 1100 students each year) undertake an open-ended student research project as part of their laboratory work. The research project comes towards the end of the laboratory subject, and aims to both develop and assess student ability to plan and carry out independent research by modelling the way physics research is actually done.

Rather than giving the students a list of possible topics, they are given a list of equipment available and asked to define their own topic. They are encouraged to investigate something that interests them, or is relevant to their chosen major. The students work in groups and must present a research proposal before going ahead with their research. Assessment is by a group report and presentation.

Before tackling the project, students develop basic skills in collecting and analysing data by completing a number of standard first year experiments. They then do a “transitional” more open-ended experiment. Putting in this transitional step increases both the student satisfaction with the projects and their level of achievement in the research project.

The projects were introduced in 2002, and have been evaluated using a range of tools including reflective diaries, online surveys, subject evaluation questionnaires and focus groups. The projects have been found to be effective in improving students’ generic skills, in particular their planning and organisational skills, and in motivating students by providing an opportunity to explore an area of interest to them in depth, and in a hands-on mode.

*University of New South Wales contact*: Dr Maria Cunningham, School of Physics

# Undergraduate Projects

## PROJECTS WITHIN RESEARCH GROUPS

### Undergraduate Research Work

At Curtin University, third year physics students are enrolled in project subjects and attached to a research group where they undertake a supervised research project as a formal part of their program. The project typically constitutes one quarter of their third year workload. To minimise staff workload, students are often allocated in pairs or threes to work on related aspects of the same project. The students are required to submit a literature review and present a seminar in semester one and a complete report and another seminar in semester two.

Most students rate their project as the most useful subject they do during their program. The major issues with this approach are the tendency for students to not work as team but to wander off and "do their own thing" and the significant work load around the end of semester on staff who have a large number of projects.

*Curtin University of Technology contact*: Dr Robert Loss, Department of Applied Physics

### Third Year Mini Projects

At Queensland University of Technology, the experimental component for third year physics undergraduates is flexible, allowing students to tailor the learning process to their needs. Students can choose to undertake four-week mini-projects in QUT's research laboratories. They experience life as a research scientist by working alongside practising scientists. As many of these laboratories also undertake contract research for industry partners, the students are also exposed to employers and employment opportunities.

*Queensland University of Technology contact*: Dr Esa Jaatinen, School of Physical and Chemical Sciences

# Online Learning

**The online environment offers potential advantages arising from flexibility in where and when the student undertakes the task. Challenges which need to be addressed when designing online learning include motivation (how can the student be effectively "connected" with peers, tutor and lecturer?) and expectations (are they clearly communicated to the student who is studying without a support network?). The examples presented here address these challenges and provide both creative and meaningful tasks.**

## ONLINE QUIZZES AND ASSIGNMENTS

Correctly used, online quizzes have the ability to engage students in their own learning and in testing their knowledge. However, they must be used in a supportive environment and there is a danger of underutilisation without an incentive such as assessment weighting. This form of testing is most common in the first and second years of a program.

Online assignments are increasingly being utilised because many textbook publishers have evolved their simple quizzes/tests into more sophisticated systems providing formative feedback on student answers. This feedback can be in the form of hints or theory and is designed to encourage students to learn and get the answer themselves.

### MasteringPhysics™ (Pearson/Addison-Wesley)

This internet-based tutorial/assignment system comprises problems ranging from graded tutorials through to traditional problem-solving and numerical evaluations. The system is "Socratic" in that it guides students through problems, adjusting its responses in accordance with the student's answers. For many questions, there are hints that break the problem into sections that are more easily understood. Access to these hints can result in an adjustment of marks awarded for that question. The system also allows multiple attempts at problems. A clear strength of the system is the immediate feedback provided to help students arrive at the correct answers.

*University of Sydney contact*: Dr John O'Byrne, School of Physics

## STUDENT-AUTHORED LEARNING RESOURCES

Student-Authored Learning Resources allow students working in small groups to produce their own learning resources, either for class-mates or for use by student in later years. These tend to be time-intensive projects (usually replacing a written assignment) and students are required to use some commonly available website authoring tools, some of which are quite sophisticated.

Asynchronous discussion boards have the advantage that students with different work and study schedules can interact in an efficient manner. The tasks can usually be self-moderated although the quality (measured in terms of the sophistication of the language and the concepts involved) of the resultant questions is dependent in part on the guidance by tutors, lecturers and other students.

### Student-Authored Questions

This is an assessment task in first or second year where small groups of students write their own conceptual questions and discuss them using online discussion boards. Each student is required to explain why a particular answer is correct or incorrect to the satisfaction of their small group.

*Royal Melbourne Institute of Technology contact*: Dr Alex Merchant, Department of Applied Physics

### Student-Designed Content for Online Quizzes

In this first year astronomy assessment task, students sit in small groups to design and write questions. Each student is responsible for their own question, vetted for accuracy by tutors and uploaded via an online form. Students then take quizzes from the database at their leisure.

*University of Melbourne contact*: Dr Andrew Melatos, School of Physics

## COMPUTATIONAL PHYSICS

Many departments are including greater amounts of computational physics in their undergraduate physics curricula. A wide range of software tools and platforms are utilized; access may be via network servers or online.

### Mathematica in Physics Labs

Mathematica programming is being introduced into the laboratories at Flinders University. In each first year practical session, the students typically spend about 1.5 hours engaged in some form of measurement with its associated analysis. Then, instead of repeating the process with altered parameters, the students work through a Mathematica simulation of relevant concepts that are either met in the experiment or crucial to their understanding of the theory. Directed questions are used to encourage the students to explore the effect of different parameters upon the behaviour of the system they are investigating.

*Flinders University contact*: Dr Jamie Quinton, School of Chemistry, Physics and Earth Sciences

# Distance Learning

**The experimental component of physics has been a major challenge in providing distance learning. There is considerable ingenuity in the ways in which physics has been made accessible to off-campus students, as described below.**

### An External Physics Degree

Murdoch University has offered external studies in physics since its establishment in 1975. Currently around 40% of all physics applicants to Murdoch University choose to study completely off-campus and almost all physics students take at least one subject externally during their degree. A recent cooperative arrangement with the University of New England allows external offerings to be shared.

Initially, external studies in physics were offered using carefully prepared printed notes, study guides and experimental kits. More recently, WebCT has been adopted in all subjects, giving students an excellent working environment where they can interact readily with one another and their tutors. In addition, students have access to recorded lectures, tutorials and excellent reference collections. Assessment is carried out under supervision by a responsible local person selected by the student and approved by the Examinations Office.

Practical work is now done entirely off-campus using kits and real data obtained from complex equipment. Even third year subjects can be taught in this way – students do experiments such as the Hall Effect, the characteristics of solid state devices and band gap measurements using inexpensive kits sent out by the department. In a few cases, where dangerous materials or complex equipment would be required, students are instead sent detailed descriptions and collections of data to analyse.

*Murdoch University contact*: Prof Philip Jennings, Discipline of Physics

### Robotic Telescope

At the University of Southern Queensland, two complementary one-semester subjects in introductory astronomy are offered externally using printed and internet-based resources. The robotic telescope at Mt Kent Observatory near Toowoomba is operated remotely via a web browser. Students normally operate the telescope via queue-scheduled requests, to cope with the vagaries of weather and to optimally schedule allocation of telescope time to different observers. Formal student evaluation of the subjects is strongly positive.

*University of Southern Queensland contact*: Dr Brad Carter, Department of Biological & Physical Sciences

### Travelling Photonics School

It is expensive to assemble and run a photonics undergraduate teaching laboratory, more so if universities do not have appropriately-trained academic or technical staff. The

# Distance Learning

University of New England is offering a second year photonics subject to other university physics departments (via cross-institutional enrolment) with the laboratory component conducted as a five-day residential school in the partner university's undergraduate teaching laboratories. Put simply, the components have been designed to travel, with experiments involving laser optics, optical fibres and sensors. In 2003 the first travelling residential school in this subject was conducted at Murdoch University.

*University of New England contact*: A/Prof David Lamb, Discipline of Physics and Electronics

## A Bridging Course by Distance Learning

A Physics Bridging Program is offered in distance mode to University of Tasmania campuses remote from Hobart via a two-way AV link. Lectures, including lecture demonstrations, are given to a live audience in Hobart and transmitted to remote locations. Students there can see and hear the lecturer, and can also interact by asking questions. Two full-day practical sessions are conducted in Hobart, supervised by the lecturer in charge of the course.

*University of Tasmania contact*: Dr Melanie Johnston-Hollitt, School of Physics

## Household Introductory Physics

Since 1998, Edith Cowan University has offered a one semester conceptual introductory physics subject to both internal and external students. External students receive paper based resources and have access to additional materials online. The laboratory manual contains 31 short experiments which mainly require inexpensive and common household items (batteries, sticky tape, string, ruler, watch, etc). A shoebox sized laboratory kit with expensive and/or less common items (light globes and connecting leads, lenses, spring balance, etc) is also sent out to the students. Feedback from students has been consistently good.

*Edith Cowan University contact*: Dr Geoff Swan, Discipline of Physics

## Climatology Experimental Kit

A Remote Sensing and Meteorology experimental kit was developed to replace the need for external students to attend a residential school at the University of Southern Queensland. The kit consists of various off-the-shelf and ad-hoc items, ranging from a multimeter to a piece of aluminium foil. An instruction manual guides the students through a number of experiments, which they perform over a number of weeks. Essentially they end up setting up their own rudimentary weather station at home, as well as accessing data via the internet. The students submit experimental reports for assessment purposes and liaise with academic staff via the discussion area of WebCT.

*University of Southern Queensland contact*: Dr Jeff Sabburg, Department of Biological & Physical Sciences

# Tutor/Demonstrator Training

**Tutors and demonstrators often have more direct contact with students than do academic staff. They strongly influence retention, students' motivation, learning and progress, whether the department is regarded as friendly and supportive, and whether the discipline is regarded as interesting, with prospects for future study and work. Their crucial role merits investment in training and skills development.**

Extensive resources to develop the skills, attitudes and knowledge required for effective teaching in laboratory classes were generated through a National Teaching and Staff Development (NTSD) Grant between Curtin University of Technology and the University of Western Australia (1999). Some developments at Monash University complement those resources.

New tutors and demonstrators typically engage in around seven hours of workshops on science learning and teaching prior to training specific to their class activities. They are introduced to the different roles of sensory, short-term and long-term memory, the constructivist model of learning, the value of creating cognitive conflict in tackling deeply-held misconceptions, and effective questioning techniques. Through various scenarios, they discuss the different motivations of students, strategies to deal with dominant or passive students, and disruptive behaviour. To extend their knowledge and further develop their skills, experienced staff attend a different session to that presented to new staff.

Small groups work on questions such as, "As a demonstrator what is expected of you by the university? by the coordinator? by the students?" and report back to the larger group. They work on scenarios such as, "In your class you have a pair of students who are keen but lack confidence and demand a lot of your time. What can you do?" Some are invited to engage in role-plays such as, "Four students have two sets of equipment for the two pairs, but they're all clustered around one set, working together. The demonstrator has to get them to work in pairs. They don't want to split up."

Requirements and obligations relating to safety, equal opportunity and cheating are addressed, as well as administrative arrangements relating to their regular work and suggestions on how to structure their very first class. If possible, prior to their first class, new staff observe an experienced tutor or demonstrator taking a class. After their first sessions, the group of new staff attend a debriefing meeting.

The brief training described here produces confident staff interested in student learning and engaged in their own growth as teachers.

*Curtin University of Technology contacts*: Prof Marjan Zadnik, Dr Mauro Mocerino and Dr Shelley Yeo
*Monash University contact*: Ms Susan Feteris
*University of Western Australia contact*: Dr Bob Bucat

# Interface to Employment

**Physics departments have typically found it challenging to develop an effective industry interface, as there is no easily-identifiable "physics industry" in Australia taking a substantial number of bachelors level graduates. Some new degree programs have brought an increase in the industry contribution to, and involvement in, undergraduate physics curricula.**

## Medical Radiation Physics

In the 1990s a four year Bachelor of Medical Radiation Physics was introduced at the University of Wollongong to meet the demand for medical physicists trained for the operation and quality assurance of sophisticated high technology radiotherapy equipment. In 2000 an alternative entry point was introduced for science and engineering graduates via a one year specialist MSc Medical Radiation Physics program.

The degree programs are taught by the School of Engineering Physics and the Centre for Medical Radiation Physics (CMRP), a research team within the school. CMRP has a network of honorary fellows in the major hospitals in metropolitan Sydney and the Illawarra who act as co-supervisors and specialist lecturers.

The degree emphasises the development of skills specifically related to medical physics through subjects taught in part by outside specialists. There is a strong accent on practical laboratory work with relevance to medical radiation physics. A substantial research project is carried out in collaboration with community, local, state and federal organisations working in the area of medical and health physics.

*University of Wollongong contact*: A/Prof William Zealey, School of Engineering Physics

## Industry Seminar Talks

The first year subject 'Issues in Nanotechnology', offered in La Trobe University's nanotechnology double degree program (with a major in physics), includes an industry seminar series. Each semester, six seminars are presented to students by practitioners in the area of nanotechnology from academia, research organisations and industry. These cover significant areas and new developments in the nanotechnology field.

Assessment is through students' written responses to the seminars which represent a significant time commitment by students outside the assigned contact hours. The responses range from simple summaries to more detailed analysis of the ideas presented and researching more detailed information.

*La Trobe University contact*: Prof Peter Dyson, Department of Physics

# Communication Skills

**As physicists we weave together written and spoken words, diagrams, images, equations and hand gestures to communicate about physics. Our students in turn will need to communicate to a wide range of people, from experts in their workplace to members of the public.**

**Written communication has always had an important place with students reporting their laboratory findings. Students are now also learning to communicate using posters, articles, webpages, and orally in seminar presentations. Several examples below are carried out in teams (other examples are given in the *Teamwork* section). At some institutions students have organised their own conferences, developing effective teamwork and management skills alongside communication skills.**

### Student Conference and Website

Second year students at the Australian National University are asked to produce a website which explains some aspect of a physics field. Students work in small teams and the best of the sites are made publicly accessible with the aim of gradually building a resource collection for other students and for teachers, their peers, higher year students and staff. As well as communication skills, this task requires students to manage their time and group dynamics, and for at least some to learn web design skills.

This task follows from a conference held in the second semester of the students' first year. Students prepare talks or posters around an appropriate theme (quantum physics in 2004) which they present in a conference-style setting to their peers, higher year students and staff. Students chair the sessions and provide feedback to their peers including the selection of best poster and talk prizes.

*Australian National University contact*: Dr Kate Wilson, Department of Physics

### Student Publication

In a major assessment element of the third year optoelectronics subject at Macquarie University, students prepare a technology profile of a chosen optoelectronic technology. In order to provide motivation for students to complete this task to a high standard, to make it relevant to their professional development, and to provide an active disincentive against plagiarism, students are invited to submit their final technology profile to be a chapter in a book of the technology profiles of the class. The completed book is distributed to all members of the class.

*Macquarie University contact*: Prof Deborah Kane, Department of Physics

# Communication Skills

### Poster Presentations

Students at the University of Newcastle prepare a report and poster based on a simulation-based experiment they have performed. In the future a more applied experiment will be the focus, to ensure a greater range of outcomes and greater distinctiveness in posters. The poster presentation involves all academic staff in an interaction with students which is different to normal laboratory interaction and is appreciated by the students.

*University of Newcastle contact*: Prof John O'Connor, School of Mathematical and Physical Sciences

### Reporting a Research Exercise

Higher year students at the University of Queensland, as individuals or in groups, have been set the task of researching the literature related to a topic relevant to their subject. They are free to choose their topic, subject to approval of the lecturer who monitors the challenge of the topic chosen. Communication of their research outcomes has taken a variety of forms, including a poster or webpage together with a question-and-answer session, and a 1500-2000 word article for a magazine that is understandable to other members of the class.

*University of Queensland contact*: Dr Margaret Wegener, Department of Physics

### Student Conferences

From 1994 to 2003 Curtin University physics students enrolled in a 'Scientific Communication' subject in which they organised a scientific conference, with up to 60 local high school students attending. The students were responsible for all aspects of the conference, from selection of the conference theme and fund raising, to oral presentations and publication of formatted peer-reviewed proceedings. Due to the implementation of a unified science first year, the subject has been replaced by a new communications subject taught by the Department of Communication and Cultural Studies.

*Curtin University of Technology contact*: Prof Marjan Zadnik, Department of Applied Physics

At the University of Western Australia, the Third Year Conference is a successful annual event. Groups of two or three students complete an advanced laboratory project. They are given three weeks largely unrestricted access to excellent equipment, which may be in a research laboratory. Each group then presents a short talk and formal report in the format of a scientific conference. The entire department is invited, including undergraduates in their second and third years of study. The formal reports are incorporated in a volume of conference proceedings.

*University of Western Australia contact*: A/Prof Robert Stamps, School of Physics

# Teamwork

The capacity to work in a team is one of the generic skills now expected of all university graduates. It is also of intrinsic value to the student seeking employment or continuing in research. Undergraduate physics programs develop this capacity in various ways; in some, teamwork is implicit in the task and its assessment, in others it is explicit. Several of these activities are described elsewhere, particularly in *Small Class Activities – Tutorials, Undergraduate Projects* and *Communication Skills.*

## IMPLICIT TEAMWORK SKILLS

In the laboratory components of university physics programs students have mostly worked in pairs or larger groups, and the development of teamwork skills has been implicit in the laboratory environment. This continues today.

Tasks undertaken by a small group lend themselves to the fostering of teamwork. The preparation of a poster on a topic outside of the lecture material or the conduct of experimental project work are contexts where students explore new territory and support and complement each other, distribute tasks amongst the team and create a shared experience.

Team poster projects are undertaken at first year level in several institutions, with students choosing their own team members, selecting a topic from a list, and given several weeks to produce a poster within specified criteria. If students are aware that they will have to countersign declarations on each other's contributions, very few groups report difficulties; intervention to moderate the mark earned by each team is rarely needed.

Group project work is undertaken by first and second year level students at several institutions. At the University of Sydney, students suggest their own topic or select from a list. Assessment is by a group report and oral presentation. At the University of Technology Sydney, students take a subject with a substantial group project component. Students design and construct experiments to explore electrical, thermal or optical properties of materials and devices. The experiment itself, the students' analysis of data collected and a written report each contribute to assessment.

Group project work at third year level is quite common. At UNSW@ADFA, pairs of students work with an academic on major projects many of which are of direct relevance to the Australian Defence Force, often on topics suggested by them. At Curtin University, teams of two or three students are allocated to a research group for the year, to undertake a major project. They work on related tasks, and with research students and academic staff. Assessment is by a literature review, interim and final seminar, and report.

# Teamwork

## EXPLICIT TEAMWORK SKILLS

At Monash University, teamwork skills are explicitly addressed in a third year level 'Observational Astronomy' subject with a substantial group project component. Teams of three students are selected by staff, ensuring that each group has strengths in physics, mathematics and astronomy, splitting friendship groups and taking into account students' topic preferences. A three-hour session in week one includes team-building exercises and a description of the expected phases of team development. Students are required to submit confidential emails commenting on team dynamics and progress three times during the semester, and ultimately to quantify the contributions of each team member, which information moderates the mark earned by each of them from the group report.

# Physics Departments at Australian Universities*

**University of Adelaide**
School of Chemistry and Physics

**UNSW@ADFA**
School of Physical Environmental and Mathematical Sciences

**Australian National University**
Department of Physics

**Avondale College**
Faculty of Science& Mathematics

**University of Canberra**
School of Information Sciences and Engineering

**Central Queensland University**
Faculty of Engineering and Physical Systems

**Charles Darwin University**
School of Engineering and Logistics

**Charles Sturt University**
Department of Physics

**Curtin University of Technology**
Department of Applied Physics

**Edith Cowan University**
Discipline of Physics

**Flinders University of South Australia**
School of Chemistry, Physics and Earth Sciences

**Griffith University**
Physics Group

**James Cook University**
Division of Physics

**La Trobe University**
Department of Physics

**Macquarie University**
Department of Physics

**University of Melbourne**
School of Physics

**Monash University**
School of Physics

**Murdoch University**
Discipline of Physics

**University of New England**
Discipline of Physics and Electronics

**University of New South Wales**
School of Physics

**University of Newcastle**
School of Mathematical and Physical Sciences

**University of Queensland**
Department of Physics

**Queensland University of Technology**
School of Physical and Chemical Sciences

**Royal Melbourne Institute of Technology**
Department of Applied Physics

**University of South Australia**
Discipline of Physics

**University of Southern Queensland**
Department of Biological and Physical Sciences

**Swinburne University of Technology**
School of Biophysical Sciences and Electrical Engineering

**University of Sydney**
School of Physics

**University of Tasmania**
School of Physics

**University of Technology Sydney**
Department of Applied Physics

**Victoria University**
School of Electrical Engineering

**University of Western Australia**
School of Physics

**University of Wollongong**
School of Engineering Physics

* As at November 2005. The word 'department' is used generically.