Learning Outcomes and Curriculum Development in Physics

A report on tertiary physics teaching and learning in Australia commissioned by the Australian Universities Teaching Committee

February 2005

Editors
Manjula Sharma
David Mills
Alberto Mendez
Judith Pollard

AUSTRALIAN UNIVERSITIES TEACHING COMMITTEE
aUTC

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Project Leaders
David Mills (*Monash*), Manjula Sharma (*Sydney*)

Project Officer
Alberto Mendez (*Sydney*)

AUTC Chair
Adrian Lee, Alan Robson

Steering Committee
Brian James (*Sydney*), Les Kirkup (*UTS*),
Michelle Livett (*Melbourne*), Richard Newbury (*UNSW*),
Judith Pollard (*Adelaide*), Mike Prosser (*Sydney*), Marjan Zadnik (*Curtin*)

Working Party Members
Anna Binnie (*UTS*), Susan Feteris (*Monash*), John Furst (*Newcastle*),
Maria Hunt (*UNSW*), David Low (*UNSW@ADFA*), Alex Merchant (*RMIT*),
John O'Byrne (*Sydney*), Anton Rayner (*Queensland*), Michele Scoufis (*UNSW*),
Geoff Swan (*Edith Cowan*), Kate Wilson (*ANU*), William Zealey (*Wollongong*)

Experts Advisors Panel
Richard Gunstone (*Monash*), Barry Muddle (*Monash*),
John O'Connor (*Newcastle*), John Prescott (*Adelaide*)

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Project Website which includes the Appendices and the report in electronic format at:
http://www.physics.usyd.edu.au/super/AUTC/autc/

Executive Summary

Goals and Methods

The project's brief was to evaluate how teaching and learning in physics was responding to several factors including multidisciplinary areas, new technologies, student backgrounds and expectations, employment, career advice, industry input to the curriculum, teaching for engineering and the biosciences, staffing, and inputs to teacher training. This report identifies strategic directions and instances of good practice in relation to these factors.

The project was conducted by a team representing 13 universities, drawn largely from the Physics Education Group of the Australian Institute of Physics. International studies in the UK and USA and a recent comprehensive review of physics teaching practice in a leading international journal provided benchmarks.

A questionnaire on issues for mainstream, multidisciplinary and service teaching, changes, challenges and responses, new initiatives and strengths, the interface with employment, staffing and teacher training, was completed by all of the 34 groups or departments who teach tertiary physics in Australia. Its format was largely open-response to enable a clear description by each department. At nine selected departments, interviews with heads of departments and leaders of academic programs, and focus groups of students, were conducted to gauge how curricula are responding to change, what approaches are effective, how departments plan for teaching, and what they expect and need for their future. Expert advisors were consulted regarding employment and future directions.

Key Findings

Pressures from loss of staff, loss of service teaching, increased student to staff ratios and the necessity to provide numbers of new subjects, dominate the landscape and have determined most departments' limits to teaching quality and responsiveness to change. Departments are endeavouring to teach well, continuing to place high value on laboratory work, adopting or seeking sustainable approaches for their student to staff ratio, and at the same time improving their research output. In most cases they cannot do justice to all of these dimensions.

Multidisciplinary and other creative initiatives have been pursued by many departments, particularly in nanotechnology. Photonics, biomedical physics, medical radiation, space and astrophysics have been developed over a longer time-frame. Larger departments have tended to keep their traditional breadth and many departments have capitalised on their research-teaching nexus.

Departments have widely adopted on-line resources, primarily as a course delivery tool but with on-line assessment frequently used. Australian innovations using new technologies are isolated, perhaps reflecting the lessons learnt from the 1990s about the costliness of developing software and questions of efficacy in some cases.

Physics education research has guided several developments in introductory physics teaching in Australia, which have in turn increased awareness of learning and teaching issues through conferences, and provided valuable resources such as the CUTSD Workshop Tutorial Project.

A broader cross-section of the tertiary student cohort is now studying physics in an increasingly wide range of subjects. The project reports on different learning styles and changed expectations of Generation Y students, as well as their weaker background in mathematics and physics which ranks high on the list of challenges reported by departments. Departments' responses include remedial materials and adjusted expectations and styles of teaching in both service and mainstream physics, but concerns about these changes remain.

Generic skills have increasingly featured in the physics curriculum, and learning outcome statements are more widely implemented, with departments looking for effective practices in developing generic skills. Graduate employment opportunities with mainstream physics are, as in the past, very broad. While departments generally have strategies for informing students of physics-related careers, students in some departments found this information to be inadequate. Some departments do not have an effective industry interface but new degree programs tend to have better industry contribution to their curricula. Outside professional experience is not a strong feature of physics degrees but projects are now a significant component. The relationship between curriculum design and factors such as graduate and employer satisfaction is to be further explored in Stage 2 of this project.

Service teaching provides a large fraction of teaching income in many departments. The loss of service teaching, particularly for engineering, has been substantial in many departments, though this is partly offset by emerging areas including the biomedical and health sciences, and physics for agricultural industries. Departments report that they maintain the same quality in service teaching as for mainstream physics.

Many departments contribute to teacher education, both pre- and in-service, but innovation and further involvement are constrained by their workloads and the complexities of working across faculty boundaries and with state education departments. There is scope for departments to consider how their own courses could best contribute to the education of future physics teachers.

The quality and commitment of physics academics is recognised as a great strength by many departments. Reliance on sessional staff offers a short-term solution to staffing and financial pressures but comes at a long-term cost and conveys an impression that the discipline is not sustainable. Good training, support and mentoring are particularly needed for staff teaching in multidisciplinary areas, for sessional demonstrators and tutors, and for academics new to teaching.

The project has begun to identify good practice in the many areas addressed above. It was notable that many departments described their strengths and features of their teaching and learning in a student-centred holistic way rather than by focusing on a single special approach. With the help of the originating departments, good practices will be disseminated and showcased in Stage 2.

Recommendations

Chapter 3: The Changing Nature of Students: Implications for Teaching

Recommendation 3.1:
That physics staff include in the curriculum learning activities that cater for a variety of learning styles and contemporary technology. (§ 3.2.2)

Recommendation 3.2:
That physics staff recognise and value diversity of student background, such as previous physics and maths studies, work experience, gender and cultural background in designing the curriculum. (§ 3.2.5)

Recommendation 3.3:
That physics staff acknowledge the competing demands on students' time, including part time work, when designing learning and assessment tasks. (§ 3.2.3 & 3.4)

Recommendation 3.4:
That physics staff communicate their expectations of students clearly and explicitly. (§ 3.2.5)

Recommendation 3.5:
That physics departments involve younger academics and consult students in teaching and learning decision-making. (§ 3.4)

Chapter 4: Skills, Capabilities and Employment

Recommendation 4.1:
That physics departments and the AIP seek to identify and utilize effective methods to ensure that graduates are highly competent in the key generic skills.

Recommendation 4.2:
That physics departments and the AIP together with industry develop resources to help inform students of physics and future careers.

Recommendation 4.3:
That physics departments consult with, and take advice from industry and employers in developing their curriculum.

Chapter 5: What are we Teaching?

Recommendation 5.1:
That departments and the AIP pursue strategies to ensure that service teaching to engineering, biomedical sciences and other disciplines, is valued and promoted, by means which include effective inter-faculty or inter-departmental teaching liaison groups, dialogue with Deans of client faculties, sharing of good practice teaching syllabi and materials between physics departments, engaging in or having representation at engineering education conferences, and discussion with professional societies.

Recommendation 5.2:
That departments and the AIP consider how they may more effectively contribute to the training and ongoing professional development of physics and junior science teachers.

Chapter 6: How are our Students Learning and How are we Teaching?

Recommendation 6.1:
That Physics departments and the AIP through the Physics Education Group support and undertake research into the effectiveness of learning and teaching strategies such as the use of IT / e-learning, the contexts and benefits of undergraduate research projects, and opportunities for optimising our investment in and commitment to laboratory experience.

Recommendation 6.2:
That the Carrick Institute provide support for further research into effective physics learning and teaching in the Australian context, with particular attention to Generation Y.

Recommendation 6.3:
That heads of physics departments and the Australian Institute of Physics cooperate in establishing improved mechanisms for promoting and sharing good practice, such as supporting academic exchange visits and contributing to UniServe Science.

Recommendation 6.4:
That the AUTC project team identify academic staff with an interest in physics for biological and medical sciences, and encourage them to collaborate in the production of common course materials appropriate for the Australian context.

Chapter 7: Staffing Challenges and Responses

Recommendation 7.1:
That departments provide time, and resources for staff who contribute substantially to innovative and quality teaching, recognise their contribution to retaining students, and support their promotion based on their teaching.

Recommendation 7.2:
That Heads of departments and institutions ensure academic staff appointments address teaching capabilities alongside research, that new appointees have a good induction to teaching and learning, and that ongoing support is provided for physics-specific teaching and learning practices.

Recommendation 7.3:
That departments value the contribution that demonstrating, tutoring and sessional staff have on students and should ensure adequate training and support, both in terms of physics content and teaching and learning issues.

Recommendation 7.4:
That the AUTC project team in Stage 2 highlight and disseminate good practices and available resources for demonstrator and tutor training.

Chapter 8: Future Directions

Recommendation 8.1:
That the Heads of departments and the AIP consider means by which they can more effectively support tertiary physics education in Australia, including obtaining strategic government funding and strengthening the AIP Accreditation guidelines.

Recommendation 8.2:
That the Physics Education Group of the AIP play a more prominent role as a network which provides effective mechanisms for promoting and sharing good practice. To achieve this, it should invite a wider membership, have representatives from all departments and support for its activities from Heads of physics departments and the Australian Institute of Physics.

Recommendation 8.3:
That the AUTC project team, Heads of departments, and the AIP cooperate in establishing an effective means of sharing teaching resources and providing a database containing evaluations of and advice regarding resources.

Recommendation 8.4:
That the AUTC project team and Heads of departments work together to prioritise areas for evaluation or provision of teaching resources, with special attention to resources adapted to an Australian context.

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- University of New South Wales – Prof John Storey
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- Queensland University of Technology – Prof Jim Pope, Dr Bruce Cornish
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- Bob Aikenhead and Ron Miller – Physics department, La Trobe University
- Cathryn McCormack – Evaluation and Review Officer at the Teaching and Learning Centre, The University of New England
- Michele Scoufis – Director and Senior Lecturer in Higher Education at the Learning and Teaching Unit, The University of New South Wales
- Kwong Wong – Educational Development Adviser at the Learning and Teaching Support unit, Swinburne University of Technology
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Contributors to this Report

The project team as a whole has contributed to the report in various ways, through the overall planning and design of the methodology, advice, data collection and analysis.

Emeritus Professor John Prescott obtained and analysed detailed data on employment; Professors John O'Connor and Dick Gunstone provided advice on appropriate strategies for disseminating and take-up of the outcomes of this project.

In writing this report there was considerable interchange of ideas and materials.
The main writers of this report, by chapter and alphabetical order, are:

- Chapter 1 – Alberto Mendez, Manjula Sharma
- Chapter 2 – Alberto Mendez, David Mills, Manjula Sharma
- Chapter 3 – David Low, Kate Wilson, Marjan Zadnik
- Chapter 4 – Alberto Mendez, David Mills, Judith Pollard, William Zealey
- Chapter 5 – Les Kirkup, Alberto Mendez
- Chapter 6 – Richard Newbury, Manjula Sharma
- Chapter 7 – Susan Feteris, Michelle Livett
- Chapter 8 – David Mills, Judith Pollard

The editors were Manjula Sharma, David Mills, Judith Pollard and Alberto Mendez, with assistance for various chapters from Anna Binnie, Alex Merchant, Anton Rayner and Geoff Swan.

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Chapter 1: The Project in Context

1.1 Introduction

Progressive and innovative physics departments are essential in order to provide Australia with capable physics graduates for research and industry, and to provide a necessary underpinning for other disciplines such as engineering and the biomedical sciences. This situation is acknowledged by stakeholders within Australia and globally, including governmental agencies, leaders in other disciplines, physics professional societies, and university physics departments. This project is part of the ongoing effort to ensure that learning and teaching in physics leads to stronger physics departments.

As the first nation-wide study into curriculum development and learning outcomes, the project articulates a broad picture of the changes and challenges faced by Australian physics departments, and how departments have responded in their learning and teaching practices. One way in which the project will benefit Australian physics departments is by describing a range of good practices, each of which addresses issues faced by several departments. The extension of this project into Stage 2 in 2005 is aimed at further developing resources for sharing, based on these good practice cases. Equally important, the project identifies the commitment and abilities of physics academics, and the ways in which we can better harness our knowledge and experiences to ensure sustainable improvements.

1.2 Project Specifications

In 2003, the Australian Universities Teaching Committee (AUTC) published a project brief for an investigation of learning outcomes and curriculum development in physics in Australian tertiary institutions. The AUTC was particularly interested in learning more about the varying ways in which issues of teaching and learning in physics have been approached at the disciplinary level, in the context of the following factors:

- the response to the new requirements of multidisciplinary areas
- the increasing role of the new technologies and of globalisation
- the changing nature of the student body and of student expectations
- variations over time in graduate employment destinations and the requirements of employers
- the relationships between physics and engineering, and physics and biological sciences
- the need for academic physicists to give a lead on the preparation of teachers for physics in schools

As required by the AUTC project brief, the project team aimed to map current practices and future directions in the broad areas of curriculum relating to service, multidisciplinary and majors teaching, employer satisfaction and industry involvement, and student satisfaction. As tangible outcomes which will benefit all stakeholders, we aimed to identify, evaluate and communicate good practices in Australian undergraduate physics education. Specifically we sought data to describe:

- content, assessment, learning outcomes, the scope of information available to students
- the extent of adaptation to changes (in the student body and in the increasing multi-disciplinary study, work environment) and adoption of physics education research and innovative practice

- physics in multidisciplinary contexts and disciplines especially engineering and biomedical sciences, including the alignment of graduate attributes in those disciplines, and the extent of consultation and responsiveness to the client department or faculty
- mechanisms for evaluation and the extent of and response to student feedback
- advice to students about careers and the multidisciplinary nature of physics
- graduate employability and employment trends, employer satisfaction
- extent and type of industry involvement in teaching and curriculum development
- professional and industrial experience and its evaluation
- revitalising mainstream physics in the midst of other changes
- identifying probable future developments and other issues of significance to the tertiary physics sector
- student backgrounds, expectations and attitudes

1.3 Studies of Tertiary Physics Teaching

Concerns for the future of undergraduate physics tend to centre on the fact that the number of physics graduates is declining or static in several countries, the perception that physics is difficult, the emergence of attractive new disciplines such as genetic engineering or bio-technology, and physics employment industry. These concerns have prompted major studies in both the USA (AAPT 2003) and the UK (IOP 2001). These have informed this project and provided useful comparative materials.

In the U.S., project SPIN-UP (Strategic Programs for Innovations in Undergraduate Physics), was organised by the National Task Force on Undergraduate Physics as part of an eight-year long effort. It set out to answer the question: *"why during the 1990s, when student numbers in physics were falling all across the USA, did some departments have thriving programs?"* In-depth studies of 23 such thriving departments were conducted and the following common features emerged:

- The attitude that it was their responsibility to maintain or improve the undergraduate program (albeit in the face of funding difficulties).
- A supportive and encouraging program which includes advising and mentoring, an undergraduate research participation program and a strong sense of community encompassing students and staff.
- Strong leadership and a clear vision for its undergraduate program.
- Strong disposition toward continuous experimentation and evaluation of its undergraduate program.

In 2000/2001 the Inquiry into Undergraduate Physics by the Institute of Physics (IOP) surveyed physics departments and students throughout the UK and concluded that:

- Physics provides the foundation for all of engineering and many scientific disciplines: ICT, the geosciences, biomedicine and the life sciences.
- Physics education develops strong intellectual and practical skills, well matched to the evolving needs of employers.
- Overall numbers of physics degree graduates have been maintained in the last 15 years but there are growing employer demands for scientists and engineers which are not being met.
- There is a critical shortage of physics teachers in secondary school, two thirds of physics taught by teachers without a physics degree.
- There is an erosion of regional provision of undergraduate physics courses.

A network approach has been followed in Europe by the European Physics Education Network (EUPEN); however they have not reported any progress of substance since their initial efforts in 1996-7.

1.4 Physics Teaching and the Role of Physics Education Research

In the last two decades, new teaching methods and advancements in technology have been increasingly used by physics educators. This has happened mainly in response to the observed limitations on effective student learning with the traditional teaching framework of lecture, tutorial and laboratory. Whilst many innovative methods of teaching physics have been developed, there have been few, if any, that have been widely adopted to supplement the traditional framework.

In a major international review spanning primary, secondary and tertiary levels, Thacker (2003) identifies four factors in particular which have prompted change in physics teaching: 1) results from physics education research; 2) technology as a teaching tool; 3) a decline in the number of students choosing physics as a major field of study; and 4) concerns about the physics content knowledge of different groups of students with particular career goals. She reports changes which have resulted as including a greater focus on conceptual understanding and the cognitive skills required to understand and apply physics concepts, interactive engagement methods, teaching physics in different contexts, and the use of technology.

Physics education research has increased its profile and has begun to establish itself as a field in its own right in this period. There is a wealth of literature in physics education research but, as much of it is quite specific and narrow in scope, a detailed review is not warranted here. Only a limited number of surveys have been made to look at the overall picture of tertiary physics education and these are given above/below.

Physics education research differs from teaching development initiatives in that, in common with other research areas, it allows for the development and growth of a body of knowledge. Findings from previous research, specifically designed instruments, evidence and models are used to evaluate methods and compare results. Consequently, findings are disseminated leading to better understandings of the teaching and learning of physics. Physics education research is making advances on several fronts; some examples of relevance to the present project are as follows:

- The development, validation and reliability testing of conceptual tests, such as the Force Concept Inventory (FCI) and Mechanics Baseline Test (MBT) (now collected in Redish, 2003).
- The design, implementation and evaluation of specific interactive strategies, such as Peer Instruction (Crouch and Mazur, 2001; Hensinger, 2000). Such methods use interaction to engage students and Hake (1998) shows that such methods provide significant gains in student understandings of concepts.
- The adaptation of the Studio Physics environment (Loss and Thornton, 1998).
- The use and evaluation of computer technology (Niedderer et al, 1998; Yeo et al, 1998).
- The improvement of the quality of physics education for those not majoring in physics (Bernhard, 2000; Bilsel, 2001).
- The alignment of physics education with employer requirements (Ripin, 2001; Kessell, 1998).
- The training of physics teachers using education research based methods within physics departments (University of Washington, 2004; Arizona State University, 2004; Kansas State University, 2004).

In Australia considerable effort has gone into applying physics education research in the areas of interactive teaching and learning strategies, and the use of computer technology. The changes in technology and the cost of support has resulted in several of these innovations being no longer viable, hence one aspect discussed in later chapters is how best the physics community can provide resources with substantially longer lifetimes.

1.5 The Project Team

The majority of the physics project team belongs to an existing network, the Physics Education Group of the Australian Institute of Physics (AIP-PEG), with vast expertise in the teaching and learning of physics in Australian tertiary institutions. The team comprises two project leaders, a steering committee with working party leaders who have responsibilities for specific tasks, a wider group of working party members, a dedicated project officer and a group of expert advisors. Representing 13 tertiary institutions, the physics project team provides excellent coverage for obtaining an accurate and representative picture of the teaching and learning of physics in Australian tertiary institutions.

1.6 Definition of Terminology used in this Report

Different terms are in use at different institutions. To avoid ambiguity, terms used in this report have the following meanings:

Physics department is a team of academics that teach physics in Australian tertiary institutions. This may in fact be a small group within a department or faculty, rather than actually being called a department.

Subject is a study of a particular set of topics usually over a period of about 12 or 14 weeks, which is assessed as an individual element within a degree program.

Physics service subject is one delivered, maintained and assessed largely by the department of physics, specifically designed for non-physics majors (including interest courses such as Physics for Life Sciences and Astronomy).

Multidisciplinary subject is where the teaching of a subject is substantially shared between physics and other departments, schools or faculties.

Mainstream subject is one that physics majors or potential physics majors take. A mainstream subject can also be taken by non-physics majors.

Program is the complete 3 or 4 year degree study schedule.

Physics major is the physics degree with which we are familiar, often comprising mostly physics and mathematics subjects with electives in earlier years and increasing physics content in higher years.

Multidisciplinary program is one of the newer types of 3 or 4 year specialised degree programs, for example Nanotechnology, Biotechnology, Environmental Science, Medical Physics and Computational Science. Physics may make a significant contribution to such a program.

Joint or double or combined degree program (with physics majors) is a degree program which fulfils the requirements for two degree programs, for example, Science/Arts, Science/Law, Physics and Computing, Engineering and Physics.

1.7 Summary of Data Collection

In Stage 1, the project identified 34 Australian tertiary institutions with a physics department. There were two phases in the data collection:

- all 34 departments completed a questionnaire
- nine departments participated in an in-depth study

The questionnaire covered all areas specified in the project brief. It provided an overview of the diversity of challenges and approaches in the teaching and learning of physics. Based on the results of the questionnaire, nine institutions were selected, for an in-depth study: to draw out how, in practice, departments decide, develop, and resource their academic programme. This in-depth study comprised an interview with the Head of Department, an interview with the chair of academic programs, and focus groups with students in mainstream and service subjects, in first year, third year and postgraduate studies. The nine departments were selected to be representative of the full range of departments in terms of size, subject offerings, and types of challenges, as well as geographical spread.

A detailed description of the data collection instruments and their implementation can be read in Appendix A.

The project team also consulted with individuals with particular expertise in specific areas.

1.8 Structure of the Report

Chapter 2 provides a snapshot of tertiary physics education in Australia: departments, degrees and subjects offered, student numbers and the main challenges.

Chapter 3 describes the changing nature of the student body both at the secondary and tertiary level and how these changes impact on the teaching and learning of physics.

Chapter 4 deals with graduate employability and the skills students develop in their physics studies.

Chapter 5 details what physics departments are teaching and the drivers for change.

Chapter 6 details how physics departments are teaching and responding to change.

Chapter 7 outlines staff-related issues including training and support for teaching.

Chapter 8 looks towards future directions in physics teaching and provides ideas for sharing and developing resources.

Each chapter highlights good practices that have emerged and concludes with a set of recommendations towards good practice.

The Appendices, which contain a full description of the data collection instruments, methodology and analysis, have not been included in this publication but can be viewed in electronic format at: http://www.physics.usyd.edu.au/super/AUTC/autc/

Chapter 2: Physics Education in Tertiary Institutions in Australia

2.1 Introduction

Physics has a place both as a fundamental science that provides explanations of why and how phenomena occur in nature and as an enabling science underpinning a wide range of disciplines and everyday technologies. The frontiers of research, for instance in medicine, are often advanced by instrumentation developed in physics. This report demonstrates how the fundamental nature and breadth of physics is reflected in teaching which is evolving at the forefront of research and application. The importance of a knowledge of physics to students of other disciplines is seen in the increasingly broad span of subjects provided. Yet at the same time, the marginalisation of physics in some disciplines at some institutions calls for an increased effort to show the importance and relevance of physics to the widest audience.

This chapter provides a snapshot of tertiary physics education in Australia. It outlines the variety of departments, degree programs and subject offerings, the role of the Australian Institute of Physics, the numbers of students and introduces the major challenges for learning and teaching identified by physics departments.

2.2 Physics Departments, Degrees and Subjects

2.2.1 Physics Departments

The project identified 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. Whilst each department is unique, we have found it helpful to introduce three broad categories of departments: broad-traditional, specialised-contemporary, and enabling-service. These labels characterize the main emphasis of the curriculum; they do not imply the absence of other characteristics. These categories have been used to ensure that in taking a sample of 9 departments for detailed study, and in drawing conclusions and offering recommendations, we have covered the broad range of Australian physics.

The broad-traditional departments are characterised by large full time staff numbers, a full student program (undergraduate and postgraduate), a traditional and broad range of physics subjects offered, relatively large student numbers in third year and regularly more than10 Honours students.

Specialised-contemporary departments are similar to broad-traditional ones but often have fewer traditional subjects, and specialise in one or two strength areas in the third and fourth years. Service teaching is a major contributor to student load. Student numbers at the higher levels and staff numbers are generally lower than for the larger broad-traditional departments.

Enabling-service departments are smaller, both in staff numbers and in mainstream physics student numbers. In many instances there is no distinct physics department, but a number of physicists are part of a larger department, school or faculty. They rely heavily on service teaching to other programs. Some of the smallest departments do not provide a full physics major. In some institutions included in our study, there are effectively only two physics lecturers. We note also that physics is available through Open Learning Australia which offers two introductory physics subjects designed for students who do not have Year 11-12 physics, but do not discuss this further.

2.2.2 Degree Programs

The undergraduate degrees into which the 34 departments teach range from the archetypal Bachelor of Science degree, with a major in physics to relatively new degrees such as nanotechnology, photonics and security technology. Some of these new degrees are termed multidisciplinary because a significant component is taught by other disciplines. A more detailed discussion of these degrees is found in Chapter 5.

At the time of this report, 26 institutions are listed with degrees accredited by the Australian Institute of Physics (AIP, 2004a). One of these listed institutions no longer offers the course which was accredited and one department included in this project offers a non-accredited major which has a substantial physics component. The majority of accredited programs are Bachelor of Science or of Applied Science. Variety is provided by double degrees, usually with Engineering and by designated-degree versions of Bachelor of Science degrees in which the program of study concentrates on a particular specialty.

2.2.3 Physics Subjects

In the main questionnaire, the 34 physics departments were asked to list all subjects taught in undergraduate years 1 through 4 (or Honours). A list compiled of physics subjects offered by each department in 2004 can be found at the project website:
http://www.physics.usyd.edu.au/super/AUTC/institutions/index.html

Not surprisingly, given the role of service subjects in providing foundations early in a degree program, the majority of first year offerings are service subjects. Smaller institutions may only have one (first year) physics subject in a semester, while larger institutions may be teaching as many as 20 distinctly different first year subjects in total. There is a particular challenge in teaching classes with a mix of students, some who have done year 12 and others without year 12 physics. A few larger departments provide an ‘honours’ or advanced stream at first year as well as mainstream and service subjects. The majority provide a mainstream subject and a service subject each semester, each of which caters for students with diverse backgrounds.

In second year there are relatively small numbers of service subjects. For some courses e.g. for electrical engineering, there are still physics service subjects at second year, but this has been changing. In second and third year the mainstream physics subjects generally move from being foundational (for instance, basic quantum and atomic physics, electromagnetism, and optics), towards greater depth and specialisation. The third year offerings tend to provide a broad physics base, irrespective of the specialisation of the department. Chapter 5 provides greater detail of what mainstream and service subjects are taught.

2.3 Major Challenges for Australian Tertiary Physics Teaching

The questionnaire to all the participating physics departments asked “*What challenges has your department faced in physics teaching and learning in the last 3-5 years?*” The dominant response categories are presented below in Figure 2.1, with the number of institutions citing that response given in brackets.

- declining staff numbers and the general downsizing of departments **(21)**
- the inability to upgrade/upkeep laboratory/IT facilities and laboratory staff **(14)**
- counteracting the decline in student numbers **(13)**
- the loss of traditional service teaching and the need to find new ones **(13)**
- the amount of degree and subject restructuring that has been required **(11)**
- the poor mathematical (and physics) background of incoming students **(11)**
- the increased teaching loads on staff **(10)**

Figure 2.1: The dominant challenges to teaching and learning for Australian physics departments, with number of departments in parentheses.

In this overview chapter, it is important to note the key that almost all departments report challenges adversely affecting learning and teaching which are related to staffing, student numbers and budgets. In particular the loss of service teaching is largely outside the control of the affected physics departments. The detailed data, discussed in Chapter 5 and 6, will show the creativity and substantial effort by physics departments to survive, and to provide a relevant physics curriculum.

2.4 A Snap-shot of Students doing Physics

2.4.1 Students in General

In Australia, the total university enrolment has more than doubled in the last twenty years; the fraction of the high school cohort continuing to university has also increased. There are more courses and institutions are larger. The make-up of the student body has changed significantly: there are now more female students than males, and large numbers of international students.

There are several plausible reasons why physics has not experienced a proportionate increase in student numbers. First, physics has not been an attractive discipline for female students. Secondly, international students in the main do not choose to do science. Thirdly, as physics is traditionally seen as being both difficult and mathematically based, it continues to be taken by the same sort of students who did it in the past, but has not benefited from the broader spread of student interests and academic offerings in tertiary education. Finally, students whose interests may have been met in past decades by studying physics, can now choose from a wider range of options whose origins may have been in physics, for example, space engineering, photonics in engineering, computer visualisation in IT.

Students are likely to have part time work accounting for perhaps 25% of their total time at study and work, and may also have long travel times – they will be ‘time-poor’ compared to the undergraduate of ten years ago. They face a much wider choice of courses, and will eventually enter a more competitive job market, than a decade ago.

Chapter 3 provides a more detailed analysis of the changes and characteristics of our students and consider the implications for learning and teaching.

2.4.2 Numbers of Students doing Physics Majors and Honours

The project has not sought to obtain total physics enrolments at all year levels, in part because the data are not central to the purposes of the project, and in part because it would be a major project in itself (as seen by the Dobson 2003 report interpreting DEST data for the sciences). Chapter 5 identifies the broad range of service teaching and innovative multidisciplinary programs into which physics departments teach. At this point we focus on physics majors.

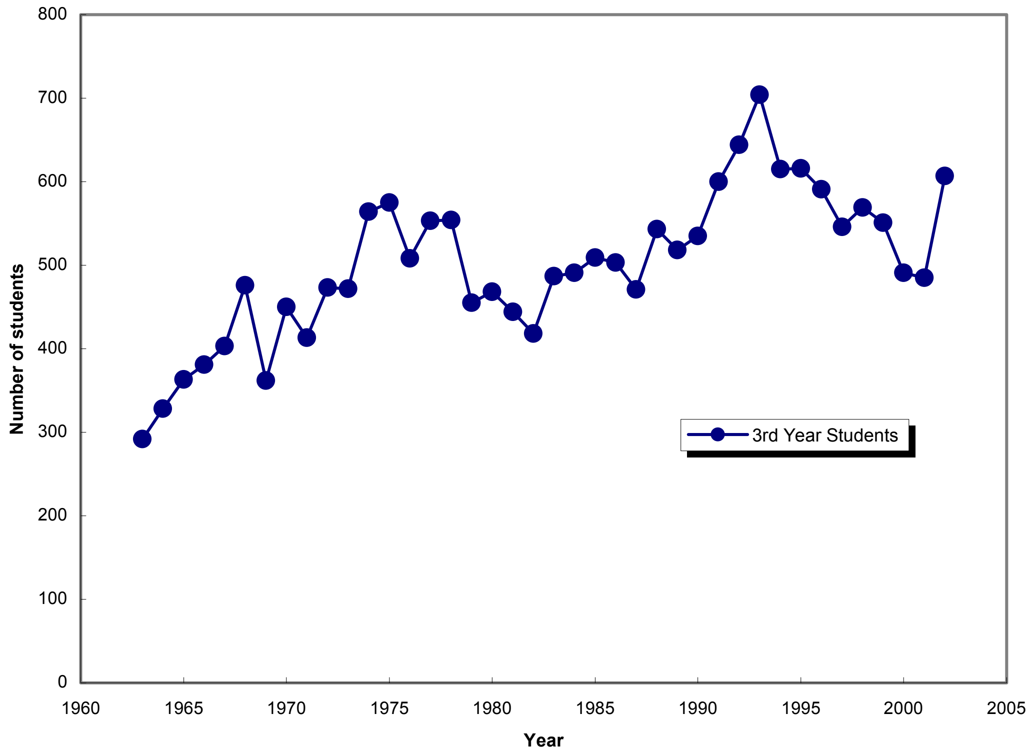

Figure 2.2: Third year physics program enrolments at Australian universities 1963 – 2002 (adapted from Jennings et al, 2003).

Third year numbers in physics (as shown in Figure 2.2) gave cause for concern in the period 1994 to 2001, coming off an all-time high in 1993. It is yet to be seen if the reversal in 2002 will be sustained, although there are indications that numbers are increasing. More disturbing are fourth year enrolments (as in Figure 2.3) which are currently about the same as at 20 to 30 years ago. One possible factor underlying the third year numbers in 2002 may be the sharp drop in popularity of IT in the last two-three years, after a long period of growth.

The project did not seek to explore the reasons for the decline in honours numbers, however they may be related to the increasing number of physics majors in double degrees which lock them in to four or five years of study without honours (and, in the case of Engineering, provide an honours award on the basis of their regular years of engineering), to the inability of the smallest departments to sustain an honours program and to the general perception that most physics departments are struggling. The larger physics departments do continue to attract good numbers of honours students.

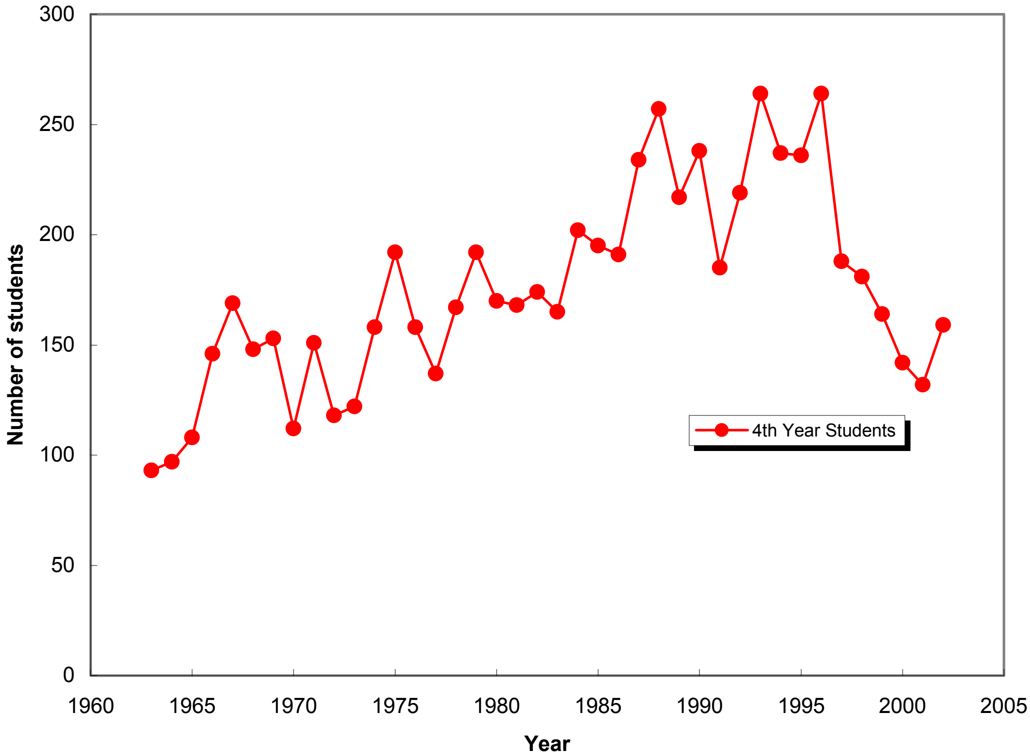

Figure 2.3: Fourth year physics program enrolments at Australian universities 1963 – 2002 (adapted from Jennings et al, 2003).

2.5 Networks of Physics Academics

In taking a close look at departments across Australia in this project, it is clear that their subject offerings and resources for teaching are affected by local factors. These include their university and/or faculty's (or school's) staffing and funding arrangements, the scope of their degree programs and the range of physics taught in those programs, the diversity of students taught, and the special emphases of their majors and multidisciplinary programs. Many service physics subjects are custom-made to suit the local situation. Because of these differences, the approaches to good learning and teaching which are identified as good practice in this report will need to be adaptable to suit a variety of situations. Nevertheless, there are enough similarities to make sharing of resources and strategies worthwhile. Several networks already exist to facilitate this sharing.

2.5.1 The Australian Institute of Physics

The Australian Institute of Physics (AIP) promotes the role of physics in education by supporting physics learning and teaching in schools, colleges and universities. The AIP presents the following argument at its website:

Physics training at the tertiary level is fundamental to the support of high technology industry and physics based research in Australia. It is also an increasingly important aspect for the support of traditional industries, where scientific advance has increased reliance on technology. Without healthy physics and other science and engineering programs, Australia must return to a 19th century agricultural economy supplementing its national income from mining and tourism without recourse to local technological support. This is a poor option for the nation. The AIP therefore supports the development of industry and technology in Australia and the training of qualified people to support the development of industry. The AIP also recognises the wider experience gained by university graduates in obtaining an education. The personal ties forged in the universities, the broader skills learned, the development of problem solving abilities and the social interaction that occurs, help to *create whole people, educated in life skills as well as a science discipline. These aspects of a physics education are also to be encouraged.*

The AIP recognises that there is a general decline in support for the discipline of physics and for all the enabling sciences. We therefore support the maintenance and strengthening of physics as a discipline within the University environment.

The AIP has a significant influence on the curriculum through its accreditation process. The need for this process to support the development of generic skills is explored in Chapter 4, and its role in encouraging sharing of innovations is discussed in Chapter 8.

2.5.2 The AIP Congress

The single event which is most effective in facilitating communication between physics academics is the biennial National Congress of the AIP. This Congress comprises parallel conferences organised by 10 or more specialist groups of associations with links to physics, and brings together academic and research physicists with a range of research interests from across Australia, giving them an opportunity to share research findings and to form networks. This event also provides an opportunity for heads of physics departments to meet for discussion about the challenges they face and the strategies being used to meet them.

2.5.3 The AIP Physics Education Group

The Physics Education Group of the AIP started from OzCupe (Computers in Physics Education - Australia) about a decade ago. It currently has about 80 members, 50 of whom are active tertiary physics academics while others are secondary teachers and active retirees. Its major activity is the two-day conference on Physics Education held in conjunction with the AIP Congress. The Physics Education sessions are well attended by both those who are actively involved in teaching and learning developments, and those who are not. The AIP awards a series of medals and awards for research and industry. In 2005 a Physics Education Medal was instigated to reward achievements in, and contributions to the teaching and learning of physics in Australian Universities.

2.5.4 The Heads of Departments Occasional Meetings

Heads of departments form an informal network, which meets every year or so, sometimes in conjunction with the AIP Congress. Their agenda usually addresses areas of common concern, such as resources, workshops, students' backgrounds from secondary school physics.

Chapter 3: The Changing Nature of Students: Implications for Teaching

3.1 Introduction

In order to teach more effectively, we need to have a clear understanding of who our students are, what motivates them to study physics, what are their backgrounds and what are their plans. In this chapter we outline how students have changed over the past three decades, from the era when many older staff were students, to today's "Generation Y". We explore the implications of these changes for tertiary physics teaching.

3.2 Who are our Students?

3.2.1 Generations of Tertiary Students

Baby Boomers and Generation X

In the 1960s when many of the current physics academic staff were students, only about 5% of the 17 year old cohort went to university ("elite" education). Those who did were typically white male Anglo-Saxon Australian students coming straight from high school. Typically they did not pay fees to study, did not work to support themselves financially during their academic year and studied full time. The number of degree courses available was comparatively small and "bright" students were attracted to the sciences and engineering as well as medicine, dentistry and law.

With the changing value systems of society over the last few generations, for example the emphasis on personal wealth and achievement which became prevalent in the 1980s, the reasons that students took up tertiary study may have changed. Anecdotally, there has been a growing increase in the number of students who choose to study to further their careers as compared to study for the pure intellectual enjoyment. The increase in youth unemployment and the increase in numbers of students completing high school have also contributed to the changing expectations of our students. The expectations and experience of Generation X (those born between 1960 and 1981), many of whom did accrue substantial HECS debts (HECS was introduced in 1989) and are still paying them off, were somewhat different to those of the Baby Boomers (born 1945 to 1959). Generation X had an experience of paying fees, a larger student cohort, and a more market driven education system, more similar to the experience of Generation Y (those born after 1981), than the preceding Baby Boomers.

Generation Y

In contrast to the Baby Boomer generation, students entering university today make up 30 to 40% of their age cohort ("mass" education), 70% of them work (many between 10 and 20 hours per week (Fullarton et al, 2003)), pay HECS, often are not full time students, and take longer than the minimum number of years to complete their degrees.

The student body is more varied. In the last 15 years the number of females studying science has increased by over 70%, and the number of overseas students has more than doubled. The percentage of school leavers in the first year cohort is now only 66%, hence our students are arriving with a greater diversity of previous experience (Dobson, 2004). Students have a greater variety of reasons for pursuing higher education, ranging from the very pragmatic view that it will lead to a good job, to further study as an end in itself.

While some students pay their HECS upfront (or have it paid by their parents), the majority, over 75%, will leave university with a substantial debt. Within science, the percentage that defers their HECS payment is approximately 80% (Dobson, 2004). At the same time housing is becoming less affordable, employment less secure and the need for financial planning for retirement more necessary than ever before. The career expectations of the Baby Boomers, i.e. having a single or small number of different jobs, are very much a thing of the past. It can be little wonder that the expectations and concerns of Generation Y are substantially different to those of the Baby Boomers given the pressures they will face on completing their education.

The current generation of students are sometimes described as "digital natives". While Baby Boomers grew up doing calculations with slide rules, and many of Generation X only started using email and the internet as post graduate students, the current generation (generally, but not always) take for granted rapid, easy access to information via the internet and access to communication 24 hours a day wherever they are via mobile phone. The way in which students access and use information is changing. Twenty years ago, a typical first year physics textbook was filled with dense text and equations, had black and white diagrams, and only occasional pictures. Almost every current first year textbook has many colour photos, the page layout has one or more main blocks of text with smaller blocks of text, images and diagrams at the sides. Textbooks come with CDs as a matter of course, and most have websites with supplementary material for students including interactive simulations and quizzes. The linear way in which previous generations accessed information is a thing of the past with random and parallel access now the norm.

3.2.2 Gender

The number of women studying at university overall, and in science, has increased rapidly over the last 20 years. Between 1989 and 2002 the total number of females enrolled at university increased by over 80%, compared to a 59% increase in male enrolments (Dobson, 2004). The percentage of women studying science at university is now around 40% to 42%, and if information technology courses are excluded, as at 2002 the percentage of female students in science was around 80%. However the percentage of women in physics courses is still much lower than this, being typically around 20 to 30% in mainstream physics courses, 34% in physical sciences overall, and in engineering it has only increased from 12% to 15% since 1992 (DEST, 2004; Dobson, 2004). The absolute increase in numbers of female physics students since 1989 is actually very small (Dobson, 2004).

Females in physics are often less confident than their male counterparts, for example a survey at the University of Sydney showed that only 3% of females surveyed expected to do very well in the subject compared to 21% of males (O'Byrne, 2004). This is consistent with other studies of females in science and education in general, which suggest that when women do poorly they consider it to be because of a lack of ability, while when men perform poorly they more often explain it as lack of preparation (van Leuvan, 2004). However, while the ratios are low, there has been substantial improvement, particularly at higher year levels, as reported by Jennings et al (2003). Between 1991 and 2003, the percentage of females in physics in Australian universities increased substantially, from 15% to 23% for third year physics, and from 16% to 23% for fourth year (including honours, diploma and masters preliminary students. The proportion of females undertaking higher degree studies in physics increased steadily from 12% in 1991 to nearly 24% in 2002. It is believed that one of the reasons for this steady increase has been the restructuring of physics courses at universities to provide new courses that are flexible and attractive to both male and female students, as well as the increasing diversity of physics research.

There are differences in what male and female science students report learning from their science degrees, with female students reporting greater learning of skills such as written communication and team work (McInnis, 2000). It has also been found that women students are more likely to choose subjects, when the choice is available, in which collaborative learning dominates over individual and particularly competitive learning and assessment tasks.

It is important that the needs of women students and the possible differences in learning styles or learning preferences of females be considered by course and subject convenors, particularly when designing learning and assessment tasks.

3.2.3 Students and Work

More than 50% of male students work part time as do over 60% of female students. Almost a third of tertiary science students work more than 10 hours per week, in addition to being full time students (Vickers, 2003). While many academics express concern over students' ability to maintain employment while meeting their course requirements, working up to 20 hours a week does not appear to significantly increase the chance of dropping out (Vickers, 2003). Furthermore, it may well be in a student's interest to work part time, if they can do so without adversely affecting their studies, as employers rate skills such as time management, communication skills, and team work more highly than subject specific knowledge (McInnis, 2000). In contrast, universities rate these skills as of lower importance, and this is generally reflected in the design of learning activities, and in students' responses to Course Evaluation Questionnaire items on generic skills. Hence, a student who can point to a work history and the skills gained from it, may have a competitive advantage in the employment market over a student who has not worked, but who has focussed exclusively on their studies (the latter fitting the traditional model of what a tertiary student should be better than the former). Skills for the workplace are further discussed in Chapter 4.

Many of the academics surveyed in the course of this project report an increased student demand for resources such as lecture notes to be available online, due to students' outside commitments, in particular part-time work. Students are less likely to be able to attend extra activities such as seminars, drop-in tutorials, and discussion groups, and it is likely that this will have an effect on their levels of engagement with the subject and the community of scholars into which we hope they are being inducted.

In summary, we need to recognise that many of our students are working and that working is valuable to them not only in terms of immediate financial rewards, but also in terms of developing their skills and abilities. This does not necessarily imply that we make major changes in the way we teach or timetable subjects, but that some sensitivity to students' other activities may be necessary. Lecturers need to consider the amount of time they require students to spend on assignments, the spacing of assignments, and the amount of time between the handing out of an assignment to students and the due date.

3.2.4 Motivations for Studying Physics at University

Surveys of physics students show that most students in mainstream (non-service) physics subjects are there because they find physics interesting. While it may be that for the majority of students at university the motivation for studying is related to employment prospects, this does not seem to be a significant motive for physics students. This has been found in surveys at several universities (O'Byrne, 2004; Mills, 2004, Loss and Zadnik, 1994), with Loss and Zadnik also reporting that the main factors in developing interest in physics are enjoyment of the subject at school, teachers, and success in the subject at school.

Students taking service subjects generally do so because it is a course requirement, for example for engineering or biomedical science. The wide range of first year physics service subjects, for students in courses as diverse as food sciences, physiotherapy, paramedic studies and environmental science, means that students arrive with very diverse high school backgrounds. In particular, they may only have basic mathematics and physics, as taught in science up to year 10.

3.2.5 The Changing Expectations of Our Students

The greater diversity of student backgrounds, in particular the increase in overseas students and the fraction of students who are *not* coming direct from high school, means that there is a greater diversity of expectations. It is important that we recognise this diversity, and value it. It is also clear that it is becoming increasingly important that we are explicit in telling students what our expectations are. Interviews with departments signalled that some departments do not have ways of knowing what the expectations of their students are. It is extremely important that departments develop ways of discovering what their students expectations are when they first enter a physics course. By recognising differences in expectations, and making sure our expectations are clearly communicated, many of the issues associated with the changes in the student body may be constructively solved.

In terms of what they hope to get from doing first year physics, most first year students see physics as a foundation, which gives them useful knowledge and skills for their subsequent studies and careers. In focus groups in this project, students were asked "What do you think are the valuable skills and knowledge you have gained from your physics studies?" Both the first year mainstream and service subject students frequently identified problem solving and knowledge which is widely applicable, with less frequent mention of analytical, report writing and experimental skills. In response to questions which probed how their first year physics related to their own field (for service subject students) or other sciences and technologies (for mainstream physics students), almost all described the big picture in which physics provides a useful foundation for sciences and engineering. In the words of one group *"physics opens eyes to applications in the real world"*.

It is vital that students are given prompt and helpful feedback on their work. If students are to develop the skills that they wish to gain from a physics course, whether a service or mainstream course, we need to provide them with explicit statements of what we expect and the criteria which we will use to mark their assessment tasks. Their assignments, reports and exams need to be returned to them quickly and with adequate comments such that the assessment task is also a valuable learning experience for the student.

In terms of how they learn, today's students want lectures and other face to face classes to be supplemented with material and activities online. While there is some debate on exactly what they expect, on the effectiveness of some types of on-line activities, and on what it is reasonable and desirable to provide, most departments have responded by increased use of online learning (to be discussed in detail in Chapter 6).

3.3 The Changing High School Student Body

We have discussed who our current students are, and how they differ from previous generations of students. We must also consider what our students will be like in the near future, hence we need to consider the changing high school student body. The way in which physics is taught and what physics is taught at secondary schools is also constantly changing. There have been changes in syllabi in terms of content and emphasis, as well as learning activities. These changes must be considered when we decide how and what to teach our undergraduate physics students.

3.3.1 Changes in the High School Student Body

The percentage of students remaining to the final year of high school has risen steadily, from 35% in 1980 to over 73% in 2001. In 1993 there were 20.4% of year 12 students studying physics, falling to 16.6% in 2001 (Fullarton et al, 2003).

It has been noted that the rate of high school completion has increased dramatically in the last 25 years. In particular, more females now complete high school than males (Fullarton et al, 2003) and the gap between the participation levels has risen to the extent that boys education is now a serious concern, (see, for example, DEST 2003), changing the nature of the cohort from a previously male dominated group to one in which girls are now a majority. In spite of this females are still under represented in the physical sciences at all levels. In 2001 almost 75% of year 12 physics students were male; this is a much bigger gender difference than in any other science, including chemistry. Aboriginal and Torres Strait Islander students are also under-represented in physics (Fullarton et al, 2003).

A study in the US found that high school girls often underestimate their ability at mathematics and science and hence have lower expectations for success in mathematics and science when compared with boys. High school boys are more likely to feel confident in their mathematics and science abilities and to believe that they are good in mathematics and science even when their school achievements are the same or lower than those of girls (van Leuvan, 2004 and references therein). The study by van Leuvan found that girls' expectations and aspirations changed throughout high school, the general trend being a lowering of expectations of further education in science, and a decreasing interest in and desire to continue studying mathematics and science. It is likely that similar trends exist in Australia.

Fullarton et al (2003) found that students who choose to study physics are likely to have been high achievers early in high school: students in year 12 physics are six times more likely to be from the highest quartile than the lowest quartile. Nearly 75% of year 12 physics students have aspirations to higher education – far more than for most year 12 subjects. What this means, is that in spite of concerns amongst the academic community, it is *still* the "bright" students who are choosing to study physics.

The increasing trend in students working exists at high school as well as tertiary level. In 2000 the percentage of school students over 15 years of age who were working part or full-time was 34%, and the median number of working hours per week for year 9 students with part time jobs (around 25%) was 7 hours (Vickers, 2003).

It was noted above that working a small to moderate number of hours a week does not increase the probability of a tertiary student dropping out. Similarly, the probability of not participating in year 12 does not increase for high school students working five or fewer hours per week, but above that level it does increase. However, one must be wary of oversimplifying, since other factors, such as non-English speaking background, correlate highly with year 12 participation, but negatively with working part time. The opposite is observed for low socio-economic status. Hence while it is possible to identify an association between work and participation or success in high school, it does not imply causality.

3.3.2 Changes in High School Teaching

Over the past 10 years there has been a fall in student numbers in advanced mathematics (calculus subjects and math method subjects) and a rise in numbers doing intermediate and fundamental-level mathematics. A good pass in calculus-based mathematics is generally a prerequisite for entry to a physics major subject; however students in many new types of service courses are likely to have substantially less mathematics background then those of previous generations. In addition, changes in syllabi in some states, including the most recent change in NSW, mean that students will have had less of the traditional physics preparation which includes a highly mathematical approach to physics. The current generation of high school physics students spend more time exploring the implications of physics and the applications and history of physics than previous generations of physics students. They are also exposed to some of the exciting leading edge of physics. The new syllabus is to be commended for helping students to understand the role of physics in society, and for making it more interesting and accessible to a greater number of students. However, many physics academics are concerned that students will not be as well prepared for entry into mainstream physics classes as they have been in the past. In particular, their facility with mathematics and physical equation solving will be reduced (Binnie, 2004). "First hand investigations" as a compulsory part of the syllabus are representative of the growing importance placed on problem solving and enquiry based learning. First year physics students have already been noted to have increased expectations of the role physics laboratory classes will play in developing their skills (Wilson, 2002).

3.4 Implications for Teaching Strategies

Table 3.1 summarises the characteristics of today's incoming students and what may therefore be considered appropriate teaching strategies. In essence it suggests that we should be trying to build a community of learners by encouraging cooperation rather than competition, and provide opportunities for group work, hands-on real-world activities with clear goals and explicit assessment criteria. Examples of good practice will be provided in Chapter 6 and in greater detail in the second stage of this project.

Interviews carried out as part of this project indicate that departments may need to pay more attention to what students expect from a course upon entry. Departments may feel that they need to "set the standard" and that it is up to students to meet that standard. However, it is recognised that departments (and universities in general) have a responsibility to respond to societal changes; while continuing to provide an education which will suit the needs of the future. There is often perceived to be a tension between maintaining the quality and quantity of course content in the face of an increasingly diverse student body, and ensuring equality of access. This is compounded by decreasing staff to student ratios.

Values	Characteristics	Communication Preferences	Learning Preferences	Teaching and learning strategies
be smart	confident	electronic	technology	Include opportunities for electronic communications and interaction
equitable and diverse	hopeful-optimistic	positive	entertainment and excitement	include opportunities for experiential and authentic learning activities
connected 24/7, inter - dependent on family, friends and teachers	inclusive (team oriented)	respectful	teamwork	include group activities to allow friends to work together
achieve now	goal and achievement oriented, practical	motivational and goal focused	"doing rather than knowing"	include opportunities for experiential, hands-on and authentic learning activities. Set goals and provide frequent feedback
community service, sustainability	civic-minded	respectful	experiential activities	build in opportunities for community related learning activities

Table 3.1: Characteristics of Generation Y (or digital native) university students and appropriate teaching and learning strategies (adapted from Jonas-Dwyer and Pospisil, 2004).

We need to take into account the increasing diversity of our students. The fact that many of our students are working is a challenge, but also an opportunity. They bring with them greater experience of a range of working environments, many have better skills in terms of their time management and communication skills, and thus may contribute in different ways. Classes in which students may share differing experience and viewpoints may enable us to take better advantage of our students' diversity. We must also recognise and be sensitive to competing demands on our students' time. Even those that are not working part time are generally engaged in studying up to three other subjects at first year. It is a common complaint from students that they have assignments due from different departments all on the same day. While this is in some cases inevitable and time management is an important skill, it is important to give students reasonable notice of when assessment tasks are due.

A range of different types of learning experience are being introduced in Australian universities to cater for differing learning styles, including "exploratorials" at UNSW, workshop tutorials at Sydney University and the Conceptual Understanding Program in Physics at Monash University, and provide good practice models along with others. A common characteristic of these innovative teaching approaches is that they use group work and enquiry based learning. These approaches may provide a better learning environment for female students, while also enhancing the learning experience for other students.

The increased numbers of females studying physics, and the drive to continue to improve the gender balance, means that we must create more female-friendly learning environments as well as providing appropriate female role models and ensure that there is a culture of inclusiveness in physics Departments. This must be done in a meaningful way, including more collaborative learning activities, having female staff teaching at all levels of undergraduate courses and supervising research students are ways in which females can be better welcomed into the discipline.
Rather than trying to fit all our students into the same mould, we should take advantage of their diversity in background, and be aware of their diversity of expectations.

Generation X academics are generally outnumbered by Baby Boomers, and as younger academics are more likely to be in junior positions and hence have less influence on policy. Baby Boomers, who make up the bulk of academics, had an educational, and particularly a university experience substantially different to that of the students they now teach. Obviously, this needs to be taken into account in both broad curricula design and in designing and implementing specific learning activities. It may be desirable to involve younger academics in some of the decision-making processes and curriculum design that they would not otherwise be asked to contribute to. It is also important that there is an atmosphere of open discussion and respect for different experience so that younger academics feel they have the ability and the right to provide input into planning and decision-making.

3.5 Recommendations

Our students are continually changing. Our students come from a wider range of cultural and socio-economic backgrounds, they are likely to be working part time, and more of them (although not enough) are female. It is our responsibility to respond to changes in students' needs, expectations, and roles assumed in society after graduation. Universities are already responding by providing a wider range of physics courses, a greater variety of learning activities including those described above, and by gathering information about the student body. Some specific ways in which physics departments can respond are given below.

Recommendation 3.1:
That physics staff include in the curriculum learning activities that cater for a variety of learning styles and contemporary technology. (§ 3.2.2)

Recommendation 3.3:
That physics staff recognise and value diversity of student background, such as previous physics and maths studies, work experience, gender and cultural background in designing the curriculum. (§ 3.2.5)

Recommendation 3.3:
That physics staff acknowledge the competing demands on students' time, including part time work, when designing learning and assessment tasks. (§ 3.2.3 & 3.4)

Recommendation 3.4:
That physics staff communicate their expectations of students clearly and explicitly. (§ 3.2.5)

Recommendation 3.5:
That physics departments involve younger academics and consult students in teaching and learning decision-making. (§ 3.4)

Chapter 4: Skills, Capabilities and Employment

4.1 Introduction

Physics is recognised as one of the enabling sciences. Its enabling role is twofold: equipping graduates in other disciplines with valuable skills and knowledge, and educating graduates in physics who are capable of contributing in a range of workplaces, often involving multidisciplinary teams and cross-disciplinary projects.
This chapter focuses on the physics-related skills and generic skills obtained from undergraduate physics studies. It has relevance to students majoring in other disciplines, such as Engineering and the Biosciences, who can gain from their experience of the methods, scope and potential of physics in contexts relevant to their field.

The recognition of the importance of integrating specialist and generic skills in a degree program is a recent development, as both universities and government have become aware of the need to ensure that graduates have the skills demanded by the workplace. In this chapter, we seek to establish how this has affected the physics curriculum on a broad scale. We first describe the workplace destinations of Australian physics graduates and the intention of universities' broad statements of graduate attributes. We consider the extent to which course accreditation by professional societies, including the Australian Institute of Physics, has incorporated capability statements related to generic skills.

Australian and overseas studies on the skills and knowledge utilized in the workplace by physics bachelor graduates are then considered. From close-up studies at selected Australian physics departments, we then map the students' perceptions of the skills and capabilities developed in physics, how they are valued by departments in terms of time and assessment, and how the importance of these capabilities is communicated to students. We look at a range of ways in which departments seek input from employers, and how information about physics employment is communicated to students.

4.2 Graduate Destinations

Identifying careers for, and destinations of, students who have completed a physics undergraduate degree is a difficult task as there is no identifiable 'physics industry' in Australia employing first-degree graduates. A major workplace study in the USA (Czujko, 1997) reported a similar situation. Czujko noted that such graduates are unlikely to identify themselves as physicists in the workplace, which may be also true of many physics graduates in Australia (where the substantial fraction graduating with double degrees may further blur their identity as physicists).

The Graduate Careers Council of Australia produces annual statistical data on graduate destinations, placing physics in the *Physical Sciences* group which also includes applied communications, applied electronics, astronomy, hydrology, meteorology, nautical science, oceanography and physical science (GCCA, 2004). Detailed figures for physics graduates have also been supplied to the AUTC project team for the period 1998 to 2002. The percentage of physics bachelors going into further full time study for this period (either within or outside physics) was 57 ± 1%. Destinations by industry sector for those in full time employment are shown in Figure 4.1. Similar surveys have been carried out in the UK (HECSU, 2002) and elsewhere, but they do not allow direct comparison due to differences in educational systems.

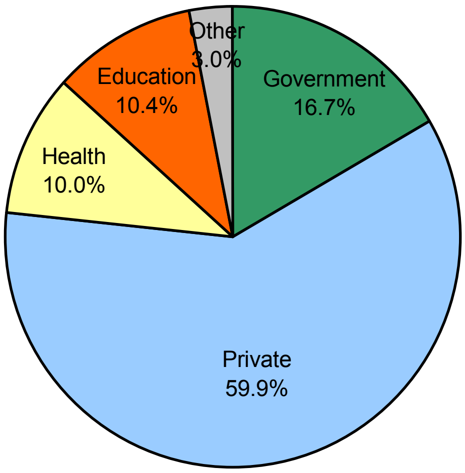

Figure 4.1: Distribution of Australian physics bachelors in full time employment by industry sector for graduates in the period 1998 to 2002.

In this period, the distribution by industry sectors is similar to that of bachelor degree graduates in mathematics, whilst the fraction in further study is about 10% higher than for mathematics, chemistry, and geology. These data are consistent with the view that while a 3-year degree is a basic preparation for the work-force, as for many other disciplines, students completing a 3-year physics major add at least a further year (in honours, a diploma, or a double degree) to position themselves well in the job market.

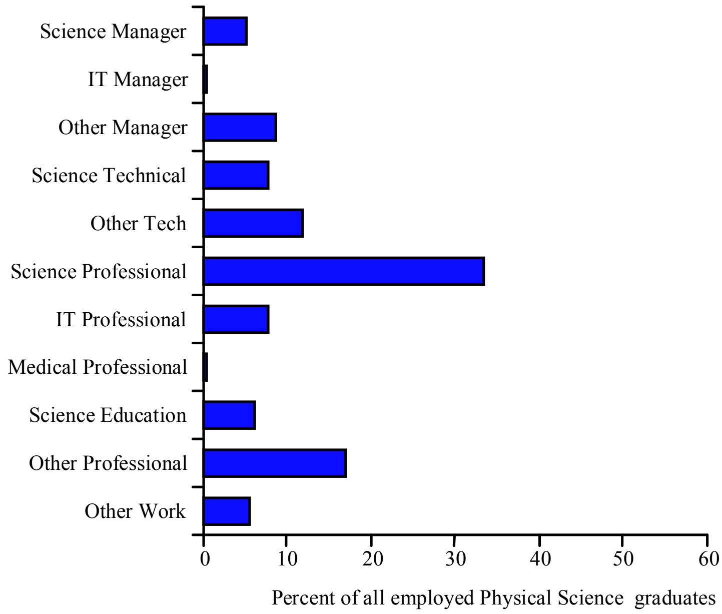

Figure 4.2: Occupation outcomes for Physical Sciences graduates (% of all employed Physical Sciences graduates), N=177.

Information about career destinations of physics graduates is also provided by the annual survey of Australian job advertisements for positions which are suitable for physics graduates (at all levels) (Prescott, 2004). This shows a different distribution of employment, with government positions dominating at nearly 40% and private accounting for only 3%. Several causes for the difference can be suggested:

- there are differences in the opportunities available to new graduates with a bachelor degree and to experienced physicists with or without higher qualifications

- the distribution of job advertisements differs from the distribution of positions because different fractions of positions are advertised in some sectors than in others, and because the average tenure varies from one sector to another
- positions may be filled without advertisement, for instance through recruitment agencies

In a study commissioned by the Australian Council of Deans of Science (McInnis, 2000), occupation outcomes were analysed for 177 Physical Science graduates who completed degrees with majors in physics and chemistry in the period 1990 to 2000. Figure 4.2 (reproduced from McInnis et al, 2000, p34) shows that more than 50% of these graduates are employed in professional Science positions.

4.3 Graduate Attributes and Skills

The emphasis placed on specific physics knowledge, understanding and skills in the undergraduate physics degree is justified by the extent to which these attributes are used by graduates proceeding to further study, and also by graduates moving into employment, particularly the large fraction in professional Science positions. However, there is increasing awareness that generic skills are also important.

The integration of specific and generic skills in degree programs and subjects is now mandatory in most universities. Details of how these are linked to assessment and content are required when new programs or subjects are being developed, or existing ones reviewed. University-wide statements of graduate attributes usually cover the points found in the following example (Wright, 2004):

1. Is equipped for continued learning, intellectual development and critical thinking.
2. Has coherent and extensive knowledge in a discipline.
3. Communicates ideas and information clearly and fluently.
4. Works with others and in teams.
5. Solves problems and makes decisions.
6. Uses and applies technology.

In its Science Policy, the Australian Institute of Physics (AIP) refers to other skills required in the training of qualified physicists, though without specifying them:

"The personal ties forged in the universities, the broader skills learned, the development of problem solving abilities and the social interaction that occurs, help to create whole people, educated in life skills as well as a science discipline" (AIP, 2004)

As the professional body which accredits physics degree programs, the AIP bases its accreditation (AIP, 2001) on structural details of the program and on the specialist physics knowledge a student is expected to acquire (Appendix D.1). In its visit to the university, the Accreditation Panel explores the way generic skills are addressed in the degree program, but theses skills are not currently specified. It would be appropriate to have a clear statement of expectations, following the example provided by Engineers Australia (formerly the Institute of Engineers Australia) in its accreditation program (Refer to Appendix D.2 for the generic skills developed in a four year Bachelor of Engineering program).

One question in the project's interviews with chairs/leaders of academic programs in selected departments asked "Has your department's teaching benefited from interaction with peers in Australia or overseas? If so, how?" Four departments commented that (beyond the immediate requirement of reviewing their course) the AIP accreditation process provided opportunity for discussion about what other departments were doing. (For three departments, accreditation was yet to come, not applicable, or more than five years ago, while two departments commented on other ways they had benefited but did not mention accreditation.) One department noted how accreditation had assisted its self-review: "We have also benefited recently from an AIP review which forced us to look more closely at what we offer our students and brought many staff up to speed with aspects of the course that they were not fully conversant with."

The departments' views are supported by Johnston (2003) who, as chair of the AIP accreditation process, reported on the value of a site visit to departments for improving the quality of their offerings. From this and other project data, we conclude that departments may welcome a better exchange of ideas and resources.

4.4 The Workplace View

It is important to know what employers expect from physics graduates. Interviews of Australian employees and graduates have been trialled and are planned for Stage 2 of this project. A study of physics bachelors graduates in the USA in 1994 focused on the skills used in the workplace (Czujko, 1997). The predominant occupations were: scientist, engineer, manager, computer scientist, technician, manager, and teacher. The study noted that for most positions taken by physics graduates (except as a physics teacher), being a physics graduate was not a requirement. Figure 4.3 shows the importance of generic skills in that study, with problem solving high on the list for all sectors. Problem solving may be interpreted as an integrated ability to harness the range of thinking skills, knowledge and experience, to address the challenges faced in these occupations. Notable is the relatively low use of specific physics knowledge. A more recent physics employment survey in the USA confirms that the common occupations are similar to those found in 1994, and noted that half of the responding bachelor graduates wished that their programme had been more applied (American Institute of Physics, 2004).

A UK study of physics postgraduates (Jagger et al, 2001) noted that, while they ranked high on problem solving, the generic skills of communication and team-work were often not well developed. This situation is repeated in Australia, where written and oral communication skills and the ability to work with others were among the attributes identified by McInnis et al (2000, p69) as falling short of employers' expectations. Ridley (2001) argues strongly for the need of "soft" skills such as management, leadership and business awareness for physicists working in industry, but recognises that some of them can only be developed in the workplace. In Stage 2 of the project we will seek detailed information on the workplace skills of physics graduates.

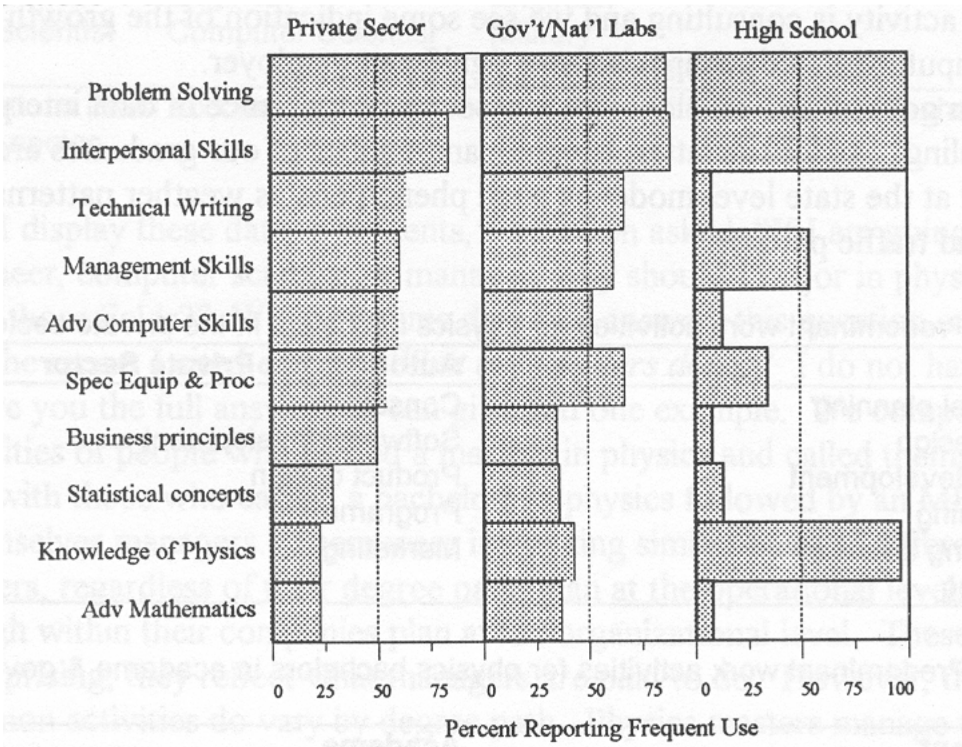

Figure 4.3: Skills used frequently by physics bachelors in selected employment sectors (Czujko, 1997).

4.5 The Students' View

In the project study, a total of 118 first and third year and postgraduate students from 7 selected institutions participated in focus groups to reflect on their physics education. They were asked to specify the level to which they believed certain skills had been developed or used in their undergraduate physics studies. (Physics knowledge was not included in this question.) The results are presented in Figure 4.4.

Of the first year students in our study, 28 were 'mainstream' students enrolled in programs leading to a major in physics, and 37 were enrolled in 'service' subjects. There were some differences in the responses of the students in these categories, though these may not be significant, given the small numbers of students in the sample. In particular, service students reported a lot of experience or use about 20% **less** frequently than did mainstream students in the categories of experimental design, information retrieval (electronic and print), project planning and problem solving. However, they reported a lot of experience in teamwork about 20% **more** frequently than did mainstream students.

Nearly all of these students believe that they have acquired 'some' or 'a lot' of skills in relation to problem solving, laboratory and experimental design. They are least sure about possessing skills in project planning, oral communication and social and ethical, issues. In their responses to open-ended questions about the most valuable skills and knowledge gained from their studies, practical and problem solving skills were frequently included while other generic skills were rarely mentioned.

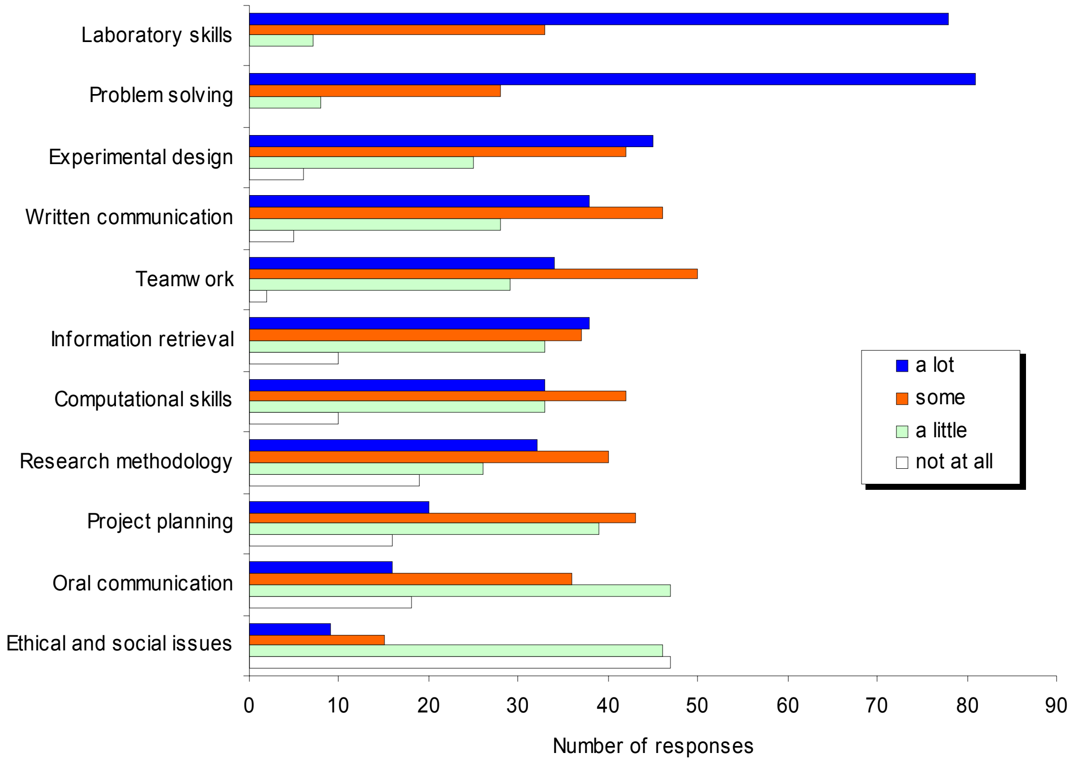

Figure 4.4: Students' ranking of skills developed or used in their undergraduate physics studies.

4.6 The Departments' Views

In the main questionnaire, departments were asked to indicate the percentage of time spent by students on specific skills and the assessment percentage assigned to each skill category, as well as to physics knowledge and concepts. Figure 4.5 shows the mean for each of the ten given categories as measured by time spent by students and assessment weighting.

The standard deviation for each skills area is 40 to 50% of the respective mean, as are those associated with the assessment, indicating that there are considerable differences between physics departments in the fraction of student time spent on individual skills and the assessment weight assigned to those skills. A considerable degree of estimation underlies these data, as two or more skills may overlap in many learning activities, and concepts and knowledge are intertwined with skills. In general, the percentage of assessment attached to each skill is comparable with the percentage of student time spent in acquiring that skill, though this agreement may be artificial because some departments used the assessment weighting to estimate the time spent.

Problem solving and physics knowledge carry a slightly higher average assessment weighting than is justified by time spent. These two aspects account for nearly 70% (on average) of the assessment weighting, and the relatively low emphasis given to the other skills stands in contrast with the rankings found in the workplace. (It should be noted that the term ‘problem solving’ may be interpreted differently in the two situations; it is likely to be used in the sense of ‘applying recently studied theory to solve a given assignment problem’ in department responses to the questionnaire, whereas in the workplace it would generally refer to a new situation with an open-ended solution.)

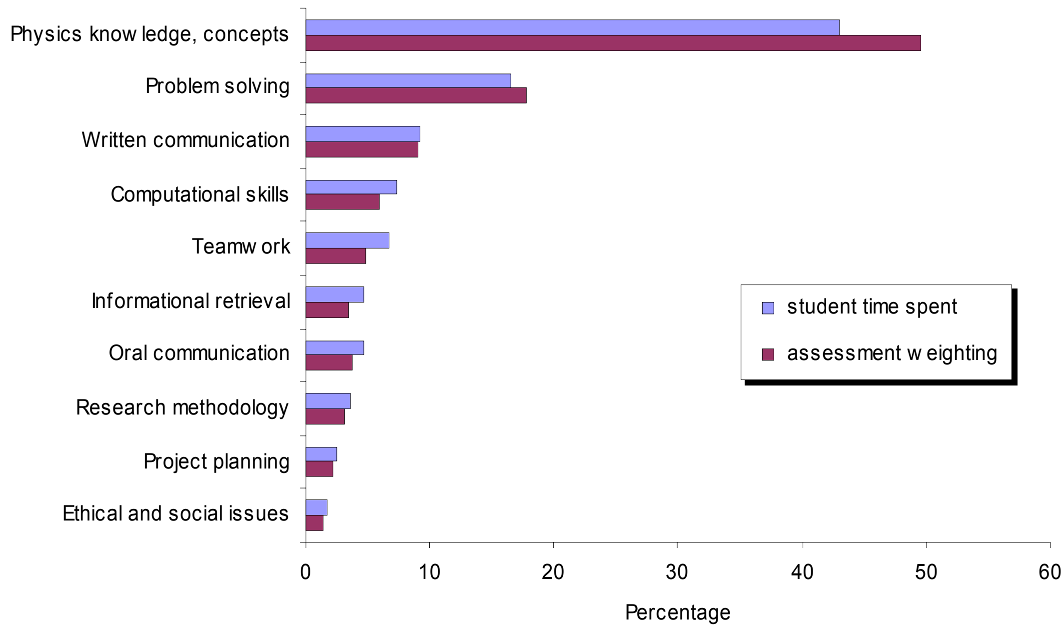

Figure 4.5: Prioritisation of skills developed by students in undergraduate physics studies, as measured by time spent by students and assessment weighting, averaged over departments.

From the students’ perceptions reported in the previous section, and from this analysis, there is a gap between the skills developed in an undergraduate physics education and the desired skills for a physics graduate in the workplace. Oral communication is one area where improvement may be made with appropriate learning activities, though the additional resources to support these improvements may not always be available. Curtin University (Zadnik, 1998) reported a successful initiative in the form of a physics conference for secondary students, planned and managed in its entirety (including sponsorship and publication) by second year students. Unfortunately re-structuring of the course at Curtin resulted in the demise of that particular subject. Embedding activities and assessments relevant to generic skills within regular subjects is often possible, and various formats are used, including poster presentation and brief oral defence (Sharma et al, 2004), even with large first year classes.

From interviews with Heads of the selected departments, it was evident that consideration was being given to integrating generic skills into their physics degree programs with an “overall goal to produce a rounded physics graduate”. This was particularly the case at the younger universities and those heavily involved in servicing other disciplines. In many cases the integration was driven by university policy. An example of good practice is to be found at Swinburne University where the Teaching and Learning Service met with the coordinator of each subject in the university, developed objectives and mapped the generic skills against the University's generic and graduate attributes and against Engineers Australia’s accreditation requirements.

The selected departments were also asked how students were made aware of the subject and program objectives. Common mechanisms for communication of objectives relating to generic skills were by subject handouts and first year orientation programs. However, there was a general feeling that students were unaware of, or lost sight of, these objectives. From the department perspective, this aspect appears not to be a priority since no department referred in any way to the development of generic skills in responding to “What are the strengths of teaching and learning in your department?” in the main questionnaire.

4.7 The Employer–Department Interface

The main project questionnaire to all departments asked “How does your department ascertain the suitability of your graduates for their various employment destinations? Do you obtain feedback from employers? If so, how?” The answers shed some light on the interaction between employer and university which is crucial in developing integrated skills in a physics degree program.

In 10 cases the process of gaining feedback was informal and based on word of mouth from colleagues in research networks. Five had formal mechanisms in place to gather feedback from employers. Two departments reported that their program was developed in conjunction with industry, and one department conducted a survey of local employers to ascertain their perceived need for physics graduates. However, in 11 departments, feedback was not directly sought.

The selected institutions were asked “What mechanisms are used to inform students of career prospects and the usefulness of further studies in physics?” It appears that career information relies largely on job advertisements on noticeboards and the university's career services. Industry projects and seminars by visiting employers were examples of good practice. The student physics society was mentioned in one case, and one department reported that career information suffered as a result of increased workloads for academic staff.

While some departments are making efforts to advise their students of career opportunities, our student surveys present a more pessimistic picture. Information about the research interests of the department is provided, often from first year, in many departments, but there is little information about career paths outside research. Of the six groups of third year students interviewed, only two groups gave positive responses to the question “Have your physics studies helped you find out about employment opportunities for physics graduates? If so, how?” These groups cited physics careers seminars and talks by special guests as their sources of information.

4.8 Recommendations

The challenge facing university departments is to produce physics graduates who are capable of working effectively across the main career destinations in research, in science-technology based industry and government organizations, and in physics teaching. Graduates who join the workforce with a three or four year degree have a range of physics knowledge, experimental, analytical, computational and problem solving skills. Employers expect these to be complemented with good generic skills.

This study shows that physics departments are improving the way in which they help graduates develop the range of generic skills expected by employers. Physics knowledge and traditional problem-solving still dominate the assessment, although practical work and projects (to be discussed further in Chapter 6) can contribute towards the desired improvements.

Opportunities for students to develop team-work, communication, and other skills such as business, project-planning or management skills can be harnessed to enhance these graduate attributes, without necessarily displacing physics knowledge from the undergraduate curriculum. Examples of good practice described in Sections 4.6 and 4.7 have the potential to improve significantly the capabilities of physics graduates.

Cooperative efforts between departments, industry, research organizations and the AIP could draw on the body of experience and provide common resources to assist departments to improve the way students are informed of how their degree fits them for future careers. The AIP in the mid 1990's, provided publicity brochures and posters aimed at promoting physics careers to secondary school students, and it is perhaps timely to re-visit the possibility of web- and/or print-based careers materials.

Recommendation 4.1:
That physics departments and the AIP seek to identify and utilize effective methods to ensure that graduates are highly competent in the key generic skills.

Recommendation 4.2:
That physics departments and the AIP together with industry develop resources to help inform students of physics and future careers.

Recommendation 4.3:
That physics departments consult with, and take advice from industry and employers in developing their curriculum.

Chapter 5: What are we Teaching?

5.1 Introduction

In this chapter we offer an overview of what is being taught in physics departments across Australia. We will explore the factors that have driven changes in what is taught in physics departments across Australia and to whom it is being taught. The responses to these changes reflect a strong commitment across the physics community in Australia to nurture highly capable students with the necessary attributes to contribute in industrial and research environments.

In its service role, physics has broadened its context and applications, and sought to enrich the students' appreciation of physics to their chosen disciplines. Equally importantly, we will see how physics departments are expanding their profiles to include multidisciplinary elements in their degrees and double degrees as well as contributing to, or in some cases being the prime mover for, the development of new multidisciplinary degrees such as photonics or nanotechnology. This chapter also considers the contribution to teacher training by physics departments.

This chapter builds on the discussion of Chapter 3 (current generation student characteristics) and Chapter 4 (skills of a physics graduate) and prepares the ground for exploring the "how?" of learning and teaching in Chapter 6.

5.2 Drivers for Change

5.2.1 Downsizing of Departments and Declining Staff Numbers

Perhaps the prime driver for change in what is taught, as expressed by heads of departments (or equivalent) across the country, is the reduction in the size of the departments over the last five or so years (reductions of 40% are reported as typical). In some cases departments have merged with other entities such as Faculties of Engineering and occasionally a physics department has lost its identity completely, to the extent that remaining staff have been moved into areas where they can provide local support.

5.2.2 Loss of Traditional Service Teaching

In response to question *D.4 Approximately what fraction of your departmental income from teaching is from service and multidisciplinary teaching (not joint degrees)*?, 14 out of 34 departments stated that 50% or more of their teaching income is derived from service or multidisciplinary teaching. At the other end of the spectrum, six departments reported that this income was 20% or under (refer to D.4 in Appendix C).

Though reasons vary, the loss of service teaching to engineers is a particular theme that recurs. The loss has been attributed in some situations as a 'grab for EFTSUs' while in others the restructuring of the ways in which engineering is taught and the changes in philosophy of an undergraduate education in engineering (with the prominence of problem based learning and the expansion of 'soft' topics such as 'sustainability in engineering') has led to reduction in the space available in the curriculum for physics. In other disciplines, such as the biosciences, the perception of lack of relevance, and unreasonable/unnecessary mathematical complexity has resulted in some universities removing physics as a core subject from the bioscience degree. Once the service subject becomes elective, and there is competition from other electives, it is likely to be only a matter of time before it becomes economically unsustainable.

5.2.3 Decline in Student Numbers

In several departments the number of students wishing to major in physics has remained static or declined. This has happened at a time when the total number of students attending University in Australia has increased. A consequence is that physics departments receive a smaller fraction of a 'pie' that has itself decreased. In many departments, this has resulted in a decline in staff numbers.

For some departments, the trend in recent years has been an increase or 'healthy' stability in student numbers. This should be further investigated.

5.2.4 Student Preparedness for Study

Two major influences appear to be affecting students' preparedness for study in physics. The first is the decline in mathematical attainment and/or capability of the 'average' student compared to, say, ten years ago. The second (and generally perceived as connected) feature is the major alterations that have happened (or are underway) in the senior high school physics curriculum.

There has been a general move away from traditional teaching styles and topics in senior high school physics over the last ten years. For example, the HSC in New South Wales has been redesigned to include context and skills such as writing and experimentation, without compromising mathematical rigour. The implementation of this redesign appears to have had two major effects. First and worryingly, the time spent in including context in the physics presented at years 11 and 12 appears to have left students less well prepared for study in a demanding first year of university physics. Secondly, and quite pleasingly, there is evidence to suggest that the number of students taking (and continuing with) physics at years 11 and 12 is on the increase.

5.2.5 Emphasis on Research in the Department

The need to maintain a viable research profile with staff numbers that are likely to increase only slowly at best, has encouraged some departments to reduce or remove completely some elements of their undergraduate programs ('fewer subjects, but more students' is a view expressed by several heads of departments). The research–teaching nexus has lead to other developments which will be explored further in Chapter 6.

5.2.6 Students Expectations of e-learning Tools

The increased availability and user friendliness of such e-learning tools as WebCT and Blackboard has potential to change the learning landscape for some students. For the moment it appears that the dominant influence is the increased expectation by students of the availability of materials and online support.

5.2.7 Perceptions of Employment, and Industry Demand

Though not a new phenomenon, the question of 'what can I do with a physics degree?' is one which physics departments must continue to negotiate. Such a question implies concerns over the relevance and long term worth of studying for a degree in physics. The attractiveness of 'named degrees' (such as nanotechnology), and the acknowledgement of industry needs (for example in the area of contemporary optics) have been drivers for change in many universities across Australia. The interface between course design and industry needs, and satisfaction of employers and graduates is a matter for study in Stage 2.

5.3 What is Taught

5.3.1 Service Teaching

Service teaching is a major constituent of the profile of more than half the departments of physics across Australia with the financial viability, and certainly the prospect of general expansion, closely related to maintenance and growth in this area. Profiling physics departments around Australia, indicates that the most common service subjects are those for engineers and for biomedical/bioscience students at the first year level, with service type subjects for physical science/environmental science less in evidence. In particular, service subjects to engineers and bioscience/biomedical type students, while having declined in recent years (for example 10 departments reported a reduction or loss in service teaching to Engineers), is experiencing something of a renaissance in some departments with expansion in evidence.

Views were expressed that 'EFTSU wars', which were perceived to be at the root of some decisions made about the need for service subjects, had abated, though others indicated that university funding models still encourage some schools to do their own service teaching and to dispense with the input of others. There is doubtless the feeling that loss of service teaching impacted heavily on morale and a consequence of the loss left members of more than one department feeling 'impoverished and dispirited'.

Several departments commented that medical degrees had reduced or discontinued physics service subjects, in some cases because those degrees had become postgraduate only, while other courses had been restructured over the past 10-15 years, with more clinical and problem based learning displacing physics.

Whether service teaching has ever been 'taken for granted' is a moot point, but evidence gathered in the survey across 34 institutions reveals that, with minor exceptions, service teaching is afforded the resources equal to that of the physics subjects which are part of physics majors, double degrees or multidisciplinary offerings.

In providing service subjects, the needs of client faculty or department are paramount. In the in-depth interview with selected departments, for the question '*who decides subject content?*' [with respect to service subjects], the most common response was that a team consisting of academics from physics and the serviced department was charged with this responsibility. Several departments described the move towards making subjects more relevant by integrating physics into context rich situations. In one case of good practice, the effectiveness of restructuring and reforming units designed for biomedical type students was such that, not only were the units well received by students, but the impetus created by the reforms led to the development of a third year service subject for mainly biomedical students.

5.3.2 Multidisciplinary Courses and Subjects

There has been a growth in the number of custom or 'boutique' degrees offered by faculties or schools of Science in recent years. This is partly due to the perception of improved job opportunities that such a degree will secure over a 'straight' Bachelors with major in physics. There are examples of such degrees (for example in Forensic Science) being popular and attracting substantial numbers of highly motivated and capable students. Many physics departments have taken a leading role in the creation of new multidisciplinary degrees which are intended to attract high quality students.

The benefit to the 'bottom line' of each physics department has not gone unnoticed. As one HOD expressed it:

"*Multidisciplinary programs intended outcomes are to stabilise the budgets of physics departments by offering a more marketable degree than just physics.*"

One field that has been particularly successfully introduced is nanotechnology: 14 departments reported having a nanotechnology component. Some of these departments report that both good numbers of students and students of good quality are being attracted. To accommodate such courses, physics departments have often modified subject content in existing majors. In addition, the degree of overlap between the degree programs in, for example, nanotechnology, and that of physics has led to the boosting of class sizes, allowing fledgling courses like nanotechnology to become established while course like mainstream physics are able to remain economically viable.

Some departments characterise their nanotechnology degree as consisting of various contributions from physics, chemistry, engineering and the biological disciplines, while another indicates that it is more akin to a physics/chemistry double degree. It is fair to say that it is difficult to tease out to what extent subjects within a nanotechnology degree are taught in a multidisciplinary manner or whether existing subjects from difference disciplines have been brought together under the convenient 'umbrella' name of nanotechnology.

A lack of mention of new initiatives in nanotechnology does not mean that an institution has no nanotechnology content in their teaching or lacks initiative. Many nanotechnology topics are found in both chemistry and physics, and some physics departments nationally and internationally consider that continuing in their research strengths which impinge on nanophysics is the best way to prepare graduates for a future in nanotechnology (Jesson 2004). Several universities hold to a model of a generic bachelors degree, in which a nanoscience stream is one of many options.

While nanotechnology has been the most obvious of the multidisciplinary degrees to be created in the 21st century, many departments have reported the creation of multidisciplinary degrees which have been intended to tap into a 'niche' market, or a market which is of local importance. Examples of these include degrees in Space Science, Biophysics and Medical Radiation Physics.

Another multidisciplinary degree begun in several physics departments in response to student interest and growth in industry in the late 1990's is that of photonics. Six departments refer to setting up such a multidisciplinary degree. Some of these have small enrolments, possibly attributable to the downturn in the fortunes of optical communication related industries across Australia, and to the availability of optical communications studies within electrical engineering degrees. As noted earlier in this chapter, photonics topics may also be taught within broader optics subjects.

5.3.3 Mainstream, Combined and Double Degrees

Recurring themes that emerge with respect to mainstream physics is the increased emphasis on graduate attributes as a key to driving curriculum development in recent years, the crucial role that experimental work, and in particular research-based project work plays in developing those attributes, and the recognition that double degrees are a significant attraction to many able students. In some universities, double degree students make up more than 50% of students taking senior mainstream physics subjects.

Established subject areas such as solid state, quantum mechanics and electromagnetism still form the 'backbone' of many mainstream and double degrees incorporating physics. Several departments report modifications to their senior offerings, for example, the inclusion of greater amounts of computational physics. This was in part in recognition that physics graduates in 'non-physics jobs' are valued because of their computational capabilities. Similar comments can be made about the inclusion of electronics, photonics and instrumentation subjects into mainstream degrees.

Thirteen departments reported the importance of graduate attributes of capability statements in the development of the curriculum. Their responses were found predominantly in questionnaire items *B.2* (*… responses to challenges (faced by your department) …*), *C.1* (*What is the focus of your* *undergraduate physics majors program?*) and *F.1* (*how your curriculum has changed …in response to changing perceptions of employment opportunities?*). In several cases the explicit inclusion of a graduate attribute statement has come about due to a requirement laid down by the university in such documents as strategic plans.

Those attributes most often referred to, with respect to physics graduates, were the development of generic skills such as independent and critical thinking, communication skills, group working skills and problems solving. Of those arguably more closely aligned with the technical content of mainstream physics, were mathematical and numerical analysis, the ability to cast problems in mathematical terms and a critical awareness of the capabilities and limitations of modern instrumentation.

Half the departments surveyed indicated that the double degrees they offered (very often with engineering) had been particularly successful at attracting high quality students. Often more that 50% of students majoring in physics were taking a double degree. In some cases students who begin as double degree students choose not to complete the engineering stream of the double degree, but carry on within the physics department to do honours and then move on to postgraduate study. Concern was expressed by some departments that the extra time needed to complete a double degree acts as a disincentive for able students to go on to honours and beyond.

The research strengths of each department had most influence in the final years of the degree for several universities. While specialist topics were available as subjects in several universities, the issues of economic viability of small classes meant that offerings had been reduced in recent years. Several departments indicate that research topics were entered into the first year through the medium of guest lectures in order for researchers to both share and to enthuse students about their latest work.

Project work and laboratory based experimentation emerged as major themes which brought together the benefits for students of engagement with research staff, working on 'real' research problems, while at the same time acquiring, perhaps through stealth or subliminally, many of the attributes of team work and problem solving that are so valued. What is also evident is that, far from being 'final stage only', projects were an integral part of the curriculum at first and second year level. Departments reported that, though they encountered difficulties in maintaining and upgrading physics laboratories in the face of cuts to funding, the project work was vital to the development of the students.

5.3.4 Mainstream Physics Subjects

Figure 5.1 shows those subject areas which are currently being emphasised in mainstream physics teaching (including double degrees). All departments were asked to provide the amount of student time an assessment devoted to each area which appears in the plot.

Not surprisingly, the traditionally established subject areas of electromagnetism, quantum mechanics, optics and solid state, dominate most mainstream and double degrees. Plasma physics, which was prominent in technologies and physics research up to the 1960s, has a tiny presence. Fluids and relativity also make up a small percentage in current programs. Photonics is at the lower end of the scale in mainstream physics, but this may be misleading because there may be substantial overlap with optics. Photonics may also be offered in electrical engineering courses.

Larger 'broad-traditional' departments were able to offer from 7 to 18 subjects in mainstream physics at third year, excluding subjects which were designated projects or laboratory/experimental, whereas specialised-contemporary and service-enabling departments ranged from high numbers down to a minimum set required for a physics major.

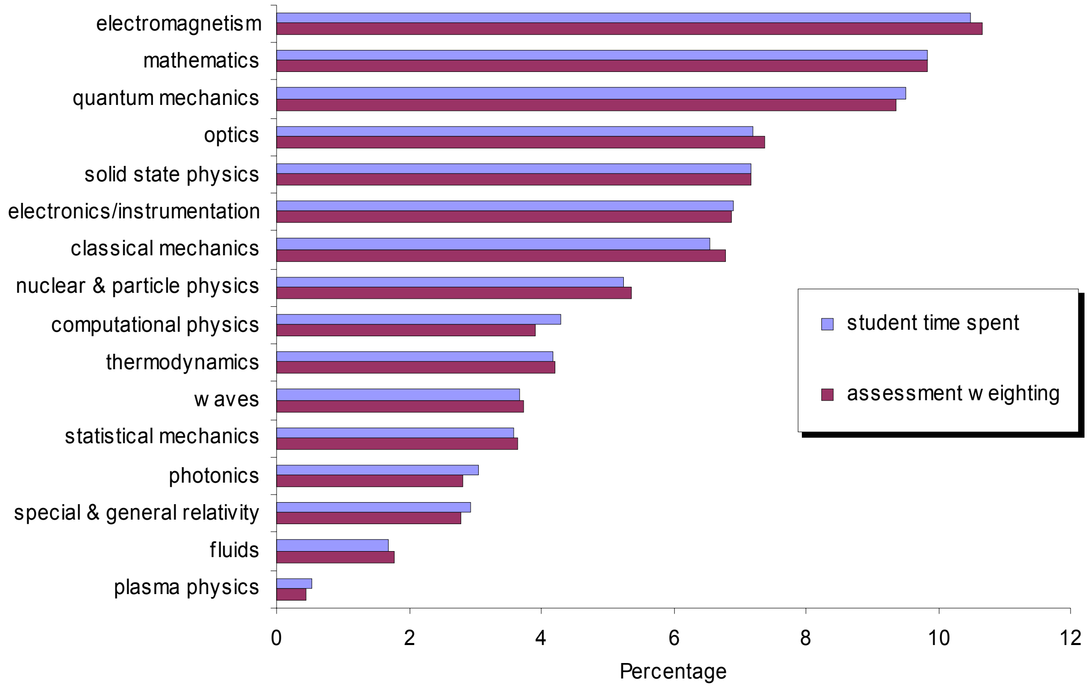

Figure 5.1: Subject area as a percentage of the mainstream physics degree program, averaged over all departments.

5.4 Responses to Students Preparation

Many heads of department expressed concern about both the mathematics and physics preparation of students entering university intending to major in physics, as well as those from other disciplines required to take physics service subjects. In general, departments have not been complacent regarding the lack of preparedness for study in physics and there are many examples of strategies being put in place to assist students in the transition to study at university.

In several cases concern about their lack of physics preparedness was linked to changes in the high school curriculum. At the same time it was recognised that changes in the curriculum had added to the attractiveness of physics at high school. A typical comment:

"The NSW HSC physics syllabus moved to a context related basis three years ago. The numerical content is low and the theoretical background poor compared to that of ten years ago. However the subject is attractive and the number of students is rising. It should be noted that previous changes to the syllabus meant that students have had no background in key concepts like rotation, calculus based physics, lens equations, etc for a decade or more! The change has not been sudden."

Other HODs reflected that it was not just changes in the physics taught at school that warranted consideration, especially in the case of engineering students doing physics services subjects:

"A large group of engineers who are mature age, TAFE qualified or been in the workplace for a long time find the standard physics course too rapid, and need a period of adjustment."

In response to this at least one university has taken steps to leave subject content unchanged but present the subject over two semesters instead of one, giving the students more time to come to terms with the material. With respect to responding to the lack of mathematical capabilities of students taking service subjects, one approach has been to move to all algebra-based physics subjects, reserving calculus based approaches for mainstream physics students.

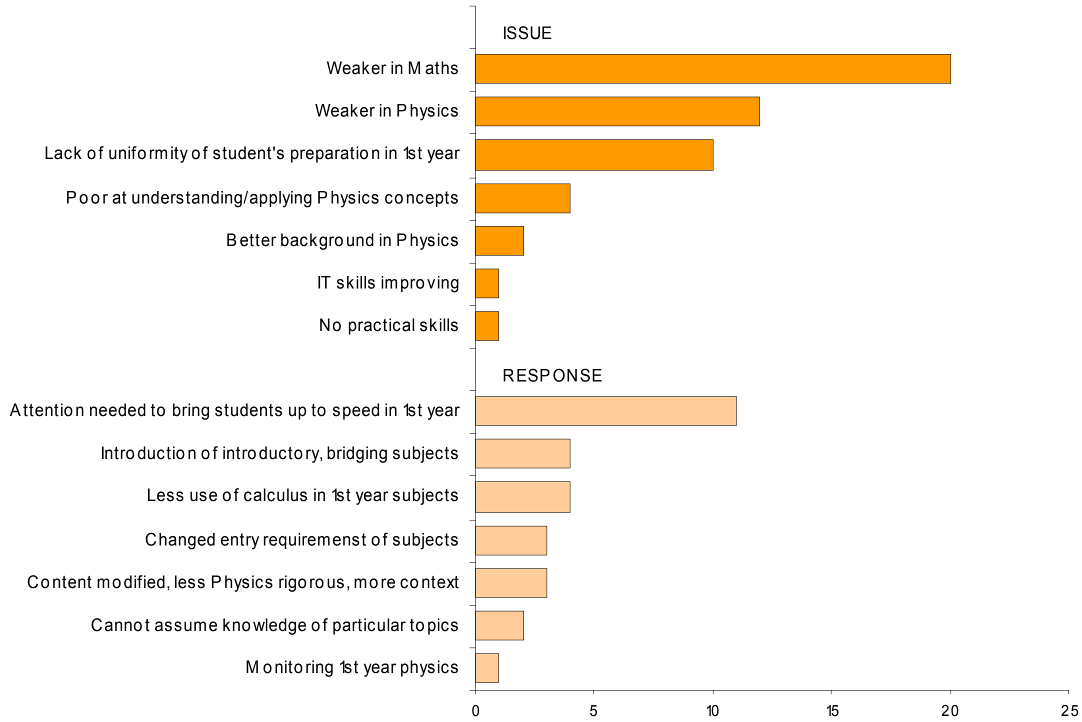

Figure 5.2: Categorised and quantified questionnaire responses to "B7. Please make any general comments regarding student backgrounds entering physics, including effect of changes to high school physics or mathematics. How has your own department adapted to these changes?"

Other strategies for responding to the changes in preparedness of students have included the introduction of bridging subjects, identifying 'at risk' students early and streaming the students with a view to providing extra support where it is felt necessary. Another approach has been to lessen the mathematical rigour in the first semester at university in order to give students time to 'come up to speed'. Another approach (to respond to the lack of preparedness in mathematics) is to introduce mathematics tutorial material within physics subjects. Figure 5.2 summarises the issues expressed by heads with respect to the preparedness of students and how they have responded to those issues.

5.5 Training High School Physics Teachers

All departments have expressed a concern regarding the shortage and training of high school physics teachers. Eighteen departments report that they have, or are planning to put in place, programs to deal in some way with shortcomings in the present situation. The main barrier seems to be prioritising this issue ahead of more immediately confronting funding concerns.

When asked how the department contributes to the training of school teachers the responses ranged across the passive-proactive spectrum. The passive mode simply involves the teaching of physics to prospective high school physics teachers, whilst the proactive approach entails training specific to teaching high school physics, both pre and in-service.

A small number of departments are offering courses specifically developed to train high school physics teachers **(7)**. Over half of the departments teach into double degrees with Education (BSc/BEd) **(14)** or into the single BEd degree **(5)** in what is likely a passive mode. While these departments, and those which feed into a Dip Ed, are directly teaching physics content and an overall appreciation of the methods of physics to potential high school physics teachers, it is unlikely that any part of the (physics) curriculum directly addresses the teaching of physics. Aspects of physics learning and teaching aspects are left to the education faculty, which may not be an ideal situation. A suggestion could be made that some awareness of physics education research within the tertiary physics curriculum would benefit both future teachers and future tertiary academics.

It is encouraging that a large number of departments are tackling this issue in more proactive ways. There is an increasing amount of involvement and managing of subjects with Education faculties, to bridge the gap between general and discipline specific teaching as outlined above. In other instances departments are taking it upon themselves to provide the necessary teaching assistance. Approximately half of the physics departments are involved directly in in-service teacher training **(15)**, by running a variety of courses, development days and workshops for high school teachers. About one third have established links with schoolteachers **(10)** via networks like the AIP, Physics Olympics and regular school visits. Physics teachers conferences run in some states also draw on expertise of tertiary academics.

5.6 Recommendations

Physics departments are interacting with a wider variety of disciplines for the provision of service teaching, are taking up opportunities in multidisciplinary and innovative areas, and are responding to changes in their students' profile. The design of the curriculum is heavily dependent on each institution's local environment and student cohort, hence there is no unifying recommendation on curriculum design to bring at this point. For some departments, the trend in recent years has been an increase in student numbers, which is worthy of further investigation in Stage 2 of this project. Matters related to the quality of teaching, staffing, and shared resources for physics teaching, are discussed in Chapters 6, 7 and 8.

The contribution by physics as an enabling science is acknowledged by leading scientists as vital for the future of Australian science and technology as a whole. Individual students who will become engineers, chemists, medical or environmental scientists also need to carry this awareness into the community. There is a need for proactive endeavours to ensure that physics provides ongoing valuable service teaching for engineering in particular, and for other new disciplines.

Recommendation 5.1:
That departments and the AIP pursue strategies to ensure that service teaching to engineering, biomedical sciences and other disciplines, is valued and retained. These strategies may include development of effective inter-faculty or inter-departmental teaching liaison groups, dialogue with Deans of client faculties, sharing of good practice teaching syllabi and materials between physics departments, engaging in or having representation at engineering education conferences, and discussion with professional societies.

Recommendation 5.2:
That departments and the AIP consider how they may more effectively contribute to the training and ongoing professional development of physics and secondary school science teachers.

Chapter 6: How are our Students Learning and How are we Teaching?

6.1 Introduction

The ways in which we are currently teaching physics to our undergraduates are determined by a host of factors. These include institutional and departmental constraints and the rise and fall in popularity of enabling basic sciences, which in turn are influenced by social and economic factors. Closer to home is the need to teach differently to meet the challenges posed by the changing nature of tertiary education as a whole and the circumstances and needs of the students themselves.

In this Chapter we look at current approaches to teaching and learning of physics across Australian universities from the perspective of both the academic and of the students on the receiving end. Our aim here is to identify the main features of current good practice and how this can be achieved. Chapters 7 and 8 discuss staff training, support, and sustainability of good and innovative practices.

6.2 Overview of Teaching and Learning: The Academic's Perspective

Information on a broad range of teaching and learning related issues was collected via the questionnaire completed by each of the 34 institutions. The questionnaire was supplemented by interviews conducted with the heads of the nine selected physics departments and with their chairs of academic programs. These responses provide an overview on teaching and learning of physics, from the perspective of senior academic staff. We will limit the discussion here to issues of challenges and responses, new directions and strengths, and to a range of other strongly recurring themes in HOD interviews which highlight factors which impact (positively or negatively) upon teaching and learning.

All graphical data presented in this chapter is derived from this questionnaire. (The main response categories for all the questions are presented in Appendix C.1.) Numbers in parentheses in this chapter are the number of departments giving a specified response.

6.2.1 Challenges

Overwhelmingly, the greatest challenge to teaching and learning over the last 3-5 years is seen by department heads as being the **decline in staff numbers (21)** (see Figure 6.1). Ranked below this is the **downgrading of laboratory, IT facilities and staff (14)** and the **loss of, or conflicts with, service teaching (13)**. These are all serious challenges, they are issues that are presumably driven by economic factors, and all will have direct impact upon good practice in teaching and learning.

The **restructuring of courses and degrees (11)**, the **weaker physics and mathematics background of the student intake (11)** and the **increased load on teaching staff (10)** are cited as important challenges. However, these rank significantly below the primary concerns that are essentially problems connected with insufficient departmental funding (including failure/inability to implement a staff replacement schedule or to upgrade facilities over the years). Curiously, whilst **reduced funding (7)** appears explicitly in the heads of departments concerns it ranks only equal ninth, alongside **increased administration** and the **changing teaching environment**. An **increase in lecture class**

sizes (5) may not appear to be, of itself, a factor impacting directly upon teaching and learning although it certainly imposes an additional burden of work on academic staff (feedback, assessment, marking) and course administration.

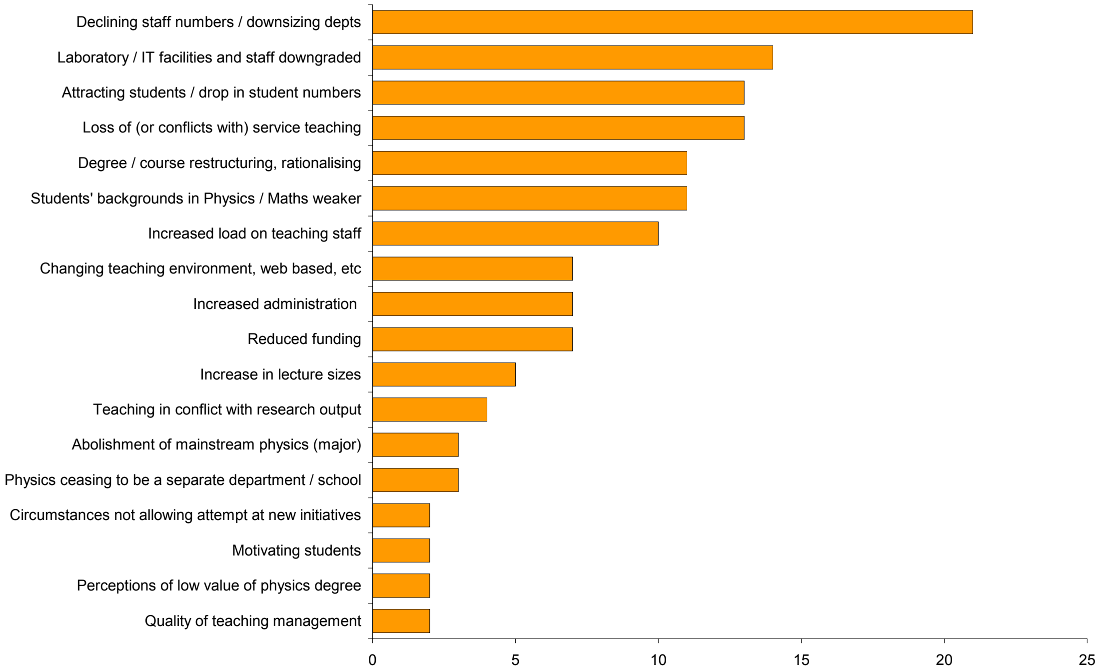

Figure 6.1: Categorised questionnaire responses to "B1. What challenges has your department faced in the teaching and learning of physics in the last 3 to 5 years?"

Potential teaching conflict with research output (4) ranks twelfth over all 34 departments. This factor will presumably be more important in research-focussed institutions and where it is the 'research card' that must be played for academic promotion. It is worth noting that heads have responsibility for the success of all aspects of their respective departments' activities so that this conflict may not be to the fore of their thinking as they responded to the questionnaire. It is also possible that research success is seen as a 'must' while excellence in learning and teaching is desirable, and hence any conflict is seen to be resolved, by default.

6.2.2 Responses to Challenges

Looking now at some of the ways in which departments have responded to current challenges (see Figure 6.2) the leading five responses are: **restructuring of the curriculum, restructuring of laboratories (14)**; the **introduction of new courses and degrees (11)** (double degrees, and new degrees like Nanotechnology); the **introduction of new technology (e.g. WebCT) (10)**; **rationalisation and/or reduction of subjects (8)**; and **shared service teaching (7)**.

Each of these is broadly an issue in teaching and learning but further examination is needed to ascertain whether or not these responses are to the benefit or the detriment of good teaching and learning. Restructuring of the curriculum might be a good thing whilst restructuring of laboratories hints at economies which are often negative.

In the same vein, WebCT/Blackboard is all *a la mode* and can be a very positive thing if implemented properly, offering flexibility of delivery and imaginative teaching with access to multimedia enhancement and judiciously chosen information sources. On the down side, if for example it is used primarily to save money in replacement of expensive staff for 'live' tutorials, it is obviously a step in the wrong direction. More research is needed to evaluate the impact of restructuring and electronic/web delivery.

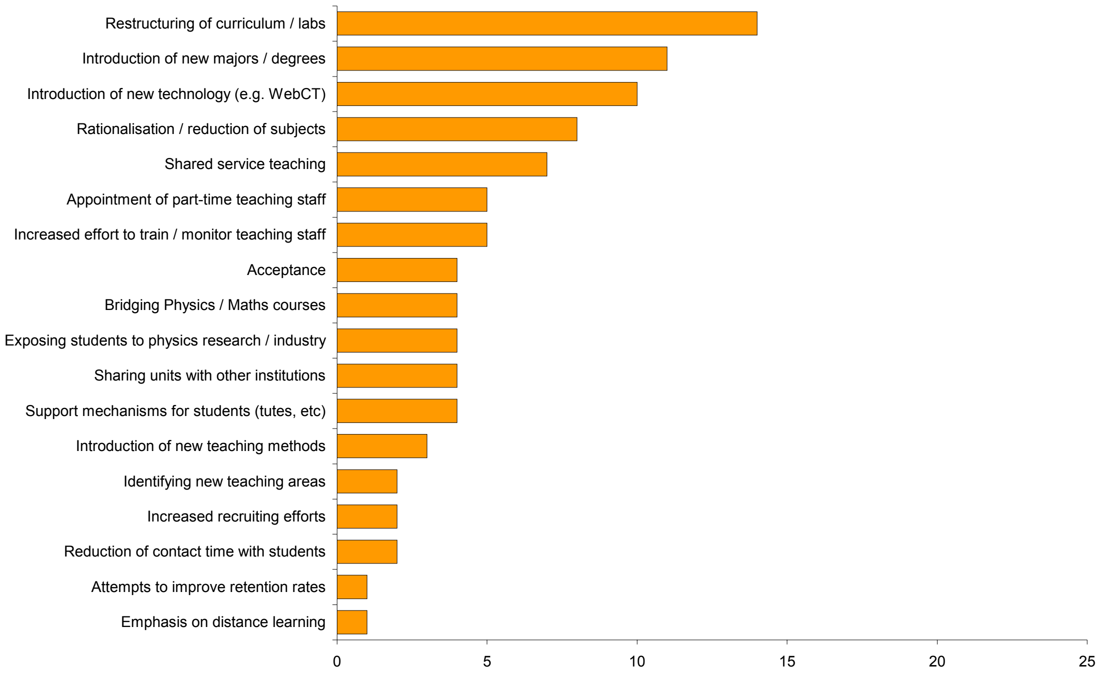

Figure 6.2: Categorised questionnaire responses to "B2. How has your department responded to the challenges mentioned above?"

Some of the other responses are clearly in the right direction. Increased effort to train/monitor teaching staff and outcomes, exposing students to physics research/industry, support mechanisms for students and introduction of new teaching methods, e.g. active learning, all set about meeting the challenges in a positive way.

6.2.3 New Directions in Teaching and Learning

Figures 6.3 and 6.4 below summarise responses across all 34 departments to questions about the introduction of new teaching methods, both current provisions and those planned for introduction in the near future.

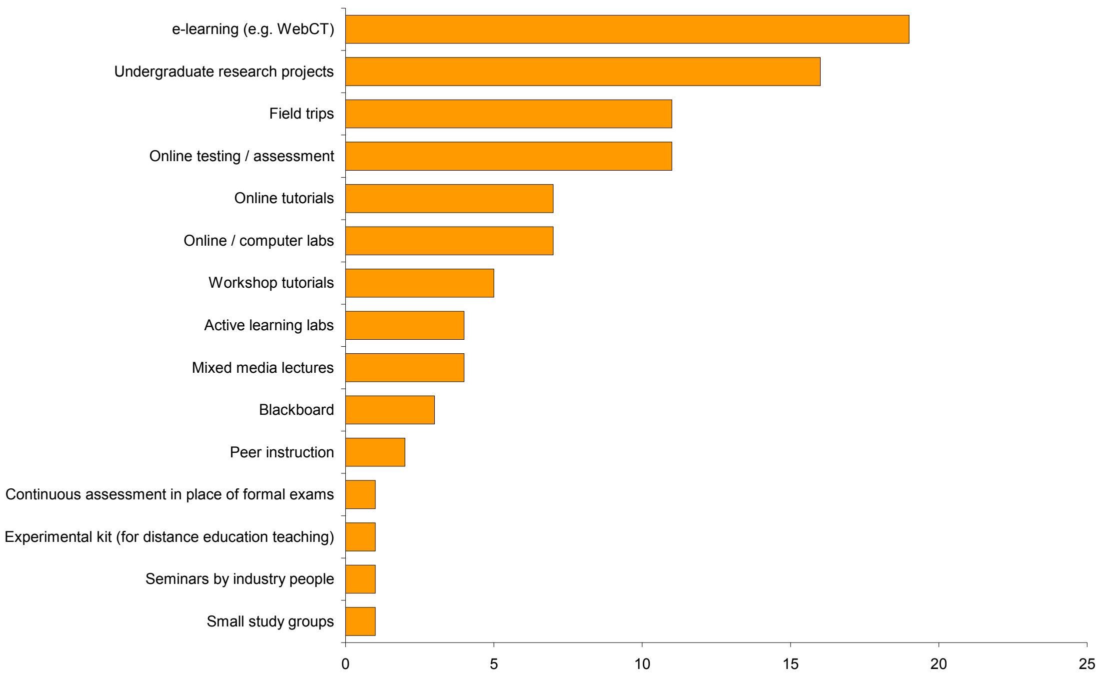

Figure 6.3: Categorised questionnaire responses to "B5. Aside from traditional lectures, laboratories and tutorials, have you introduced new modes of teaching and learning (e.g. web based or e-learning, active learning laboratories, undergraduate research activities, field trips)?"

The use of electronic delivery and learning support is quite widespread. Over half of our physics departments have **introduced e-learning in some form (e.g. WebCT) (19)** and just under half **will introduce on-line delivery of subjects in the near future (15)**. Just under a quarter of physics departments offer **on-line tutorials (7)** and **on-line/computer laboratories (7)**. A third of departments have **on-line testing and assessment (11)**.

A somewhat smaller number of departments plan to **introduce further on-line assessment in the near future (3)**, and a similar number of departments will also **reduce contact time with students (3)**. The inference might be that on-line methods are replacing 'live' contact time.

Almost half of the 34 departments offer **undergraduate research projects (16)** and a third have **field trips (11)** as part of the curriculum.

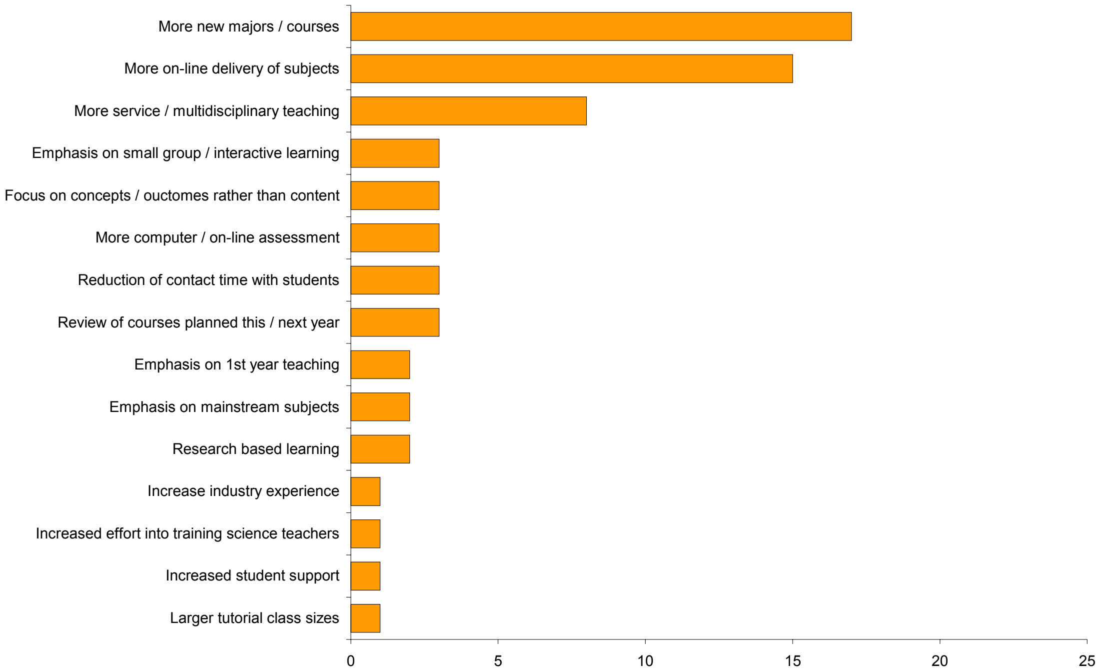

Figure 6.4: Categorised questionnaire responses to "B3. What directions will the teaching and learning in your department take in the near future?"

Only comparatively small numbers of departments currently have **workshop tutorials (5)**, **active learning laboratories (4)** or **mixed media lectures (4)** so that these particular newer modes of teaching are in evidence but are far from being widely implemented at present, and are likely to be at first year level. This situation is unlikely to change dramatically in the short term. Only a handful of departments report that there will be **emphasis on small group/interactive learning in the near future (3)**.

Whilst this might be viewed as disappointing it is, nevertheless, unsurprising when viewed against the background of the 'rearguard' action being fought by many departments, particularly the smaller ones. Adventurous and attractive new approaches to teaching require more staff time, more resources and a greater level of financial support, all things which departments do not have at their disposal. Particular note should be made of the enormous effort, in the recent past (and anticipated in the future), in introducing new majors, degrees and subjects: ranking first and second in the responses shown in Figures 6.2 and 6.4.

6.2.4 Individual Departmental Strengths

The responses to question *B4. What are the strengths of the teaching and learning in your department?* (see Appendix C.1 for graphical representation) proved very interesting. The following are significant factors which have a bearing on the quality of physics teaching and learning on offer.

Almost half of the institutions pointed to the **experienced, high quality teachers on their staff (15)**. These and other departments also report a **very good rapport with their undergraduate students (11)** and a collegial atmosphere, especially where small class sizes are concerned. These very positive facets tie in precisely with the view from the student perspective obtained in the focus groups which were run by personnel outside of respective departments. Also worth noting is the importance placed by departments on the **research/teaching nexus (14)**.

It is illustrative to quote, verbatim, from the written responses of individual departments:

"High quality and experienced staff. Modern laboratories with good equipment."
"Extremely dedicated, competent, enthusiastic and hardworking staff...Students develop a good rapport with staff…"
"We have several very able teachers able to excite and motivate students….."
"Being a new university…….and we have got dedicated staff to deliver the knowledge of physics"
"A good generalist and specialist expertise, genuine interest in teaching and an excellent collegiate atmosphere."
"Extremely good rapport between students and staff…….We are a small department, everyone knows each other and gets on reasonably well……Good understanding of recent educational developments and general T&L issues in science education. Strong commitment to generic T&L issues (we have a departmental T&L committee that meets weekly)"

6.2.5 Undergraduate Research Projects

Another recurring feature of individual departmental responses is the identification of a strong teaching-research nexus. The close interplay of research/teaching and the benefits to teaching and learning at undergraduate level are identified as an explicit strength by about a quarter of the 34 departments responding to the questionnaire. Typical comments from departments on the benefits of research activity include:

"We have strong research groups which feed into level three lecture courses and, particularly, into project work at all teaching levels."
"…Close access to staff, [undergraduate students are] involved with research at an early stage…"
"The department has a strong research base, this expertise feeds through into the undergraduate curriculum, particularly in higher year courses.'
"[One of our department's teaching and learning strengths is] the expertise of the academic staff (and some casual staff) in key areas of physics…as a result of their research and background."
"The broad range of research groups within the department has greatly strengthened the experimental aspects of our degree program."

6.3 Laboratory Programs in Undergraduate Physics

At this time when many Australian physics departments are experiencing a sustained period of challenges, particularly staffing and financial constraints, it is notable that a number of institutions are able to report quite positively on the equipment and infrastructure of their teaching laboratories:

"[The department has] Modern laboratories with good equipment…"
"…we have got very well equipped laboratories with new pieces of equipment…"
"Well equipped laboratory teaching spaces, with laboratories at third year containing research level equipment."
However, it would be sending the wrong signal to assume that the pride these departments can take in their teaching laboratories is a common feature across all departments. Whilst there are few direct references to teaching laboratories and equipment being in dire need of upgrade and replacement, of the thirty four physics departments responding to our questionnaire, only the three departments quoted above make explicit mention of laboratories being a teaching and learning strength of their respective

institution. One tends to hear, anecdotally, that it is the laboratory element of courses in the enabling sciences which faces danger of being weakened or eliminated. For example, quoting again from individual departmental responses to our questionnaire, when asked about contact time, strengths and challenges concerning laboratory:

"An issue is the first year laboratory programme, which requires a substantial investment to improve its quality and relevance. Resources are being set aside for this but it requires a major investment."
"…Recurrent funding to the department is insufficient to make any realistic contribution so that funding for any laboratory work initiatives must be sought from competitive institutional funds."
"Experimental sciences across this university are suffering because the weighting per EFTSU has not been passed on to the teaching faculties. Our management seems to equate technology with 'having access to a computer"
"Our labs need upgrading but low student numbers means limited funds available"
"In first year units, due to economic pressures, we now have three hour per week prac sessions in alternate weeks (i.e. students do 6 lab sessions per semester). Up until a few years ago we used to have 12 lab sessions for first year per semester. When we had a BSc physics major most of the second and third year subjects had a laboratory component. This used to be 3 hours per week per subject but by 2003 had cut back to 2 hours per week for about 10 weeks of the semester because of economic pressures."

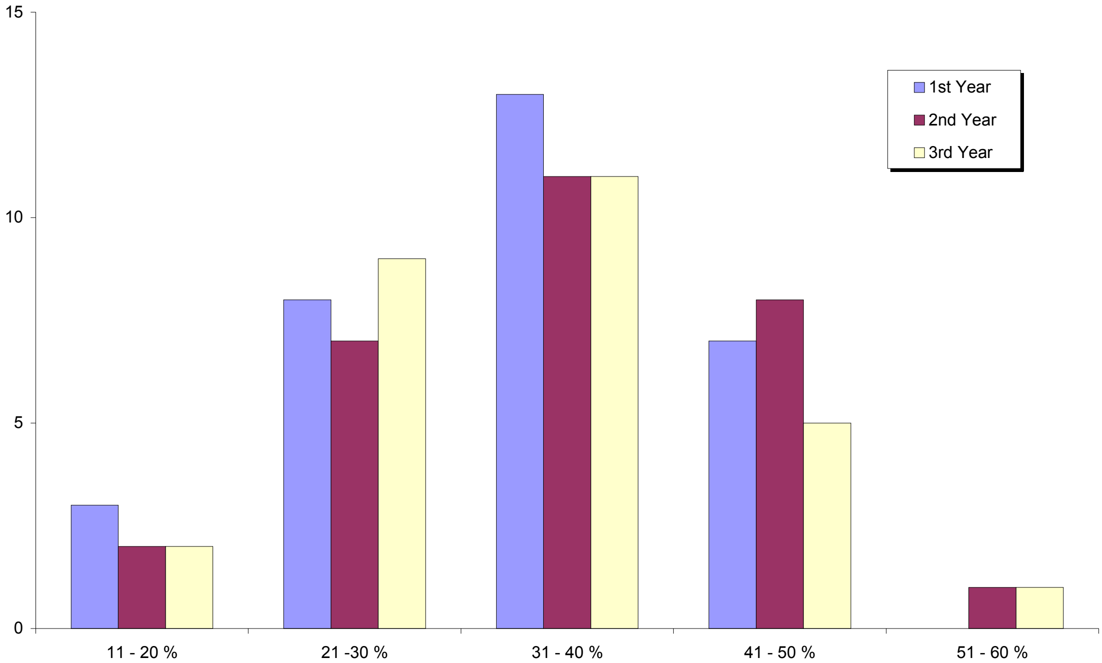

Figure 6.5: Binned questionnaire responses to "C3. For each of the years (1 to 3), approximately what fraction of the students' contact time in physics is spent in experimental laboratories?"

While cuts have been made to undergraduate laboratory programs over the last decade, they still make up a substantial element of the total contact hours of courses as Figure 6.5 illustrates.

At a quarter of all departments in first to third year, 20-30% of total contact time is spent in laboratories. At roughly a third of all departments, the time spent in laboratory physics in first to third year, is in the range 30-40% of total contact time. A smaller number of institutions report that time spent in the laboratory is up to half of the total course contact time.

It is for third year laboratory which the majority of departments with full laboratory programs report particular strength. However, there are also strengths and some newer features identified in the first year laboratories by some departments. These include teamwork, continuous review of the experimental programme by a dedicated laboratory director, and computer-based pre-laboratories and data analysis.

Precise ratios of teaching personnel to students in laboratories are difficult to gauge from available data but typical numbers in first year would be 15-20 students per demonstrator (a graduate student or sessional teacher) with one academic staff member supervising. More favourable student ratios for first year laboratories are also indicated:

"Our laboratories have a high proportion of teaching by academics (one academic per 16 students in first year, one per eight students at second year, one per 2-4 students at third year). Academics are supplemented by casual technical staff [with the same staff/student ratios as for the academic staff]."

But it would seem unlikely that the majority of departments would have such a high proportion of academics' time available for first year laboratories.

6.4 Teaching / Research Nexus

Anecdotal evidence would suggest that there is at least some degree of conflict for most full time academics in juggling teaching and research priorities. There is a widespread belief, or perhaps an acceptance, that career advancement is determined largely by research performance (funding success, publications and so on).

With smaller academic staff numbers in departments, increasing institutional focus on fiscal considerations and accountability (leading to additional administrative load), the balancing act that academics must perform *vis-a-vis* teaching and research priorities is made more difficult. If courses remain static, it must surely stifle innovation in teaching and learning and imaginative and sustainable response to changing student needs. So what is the evidence from departments that, under current constraints, there is a healthy and positive teaching-research nexus in departments?

The range of core lecture courses/electives and the course content reflects directly the research interests of academic staff at many institutions (see Figure 6.6). More than half of departments report **subjects offered in the specialist research areas of the staff (18)**. Approximately one-third of departments have **students undertaking a research project within a research group (11)**. A smaller but significant number of departments report that **examples from departmental research are discussed in lectures (7)**.

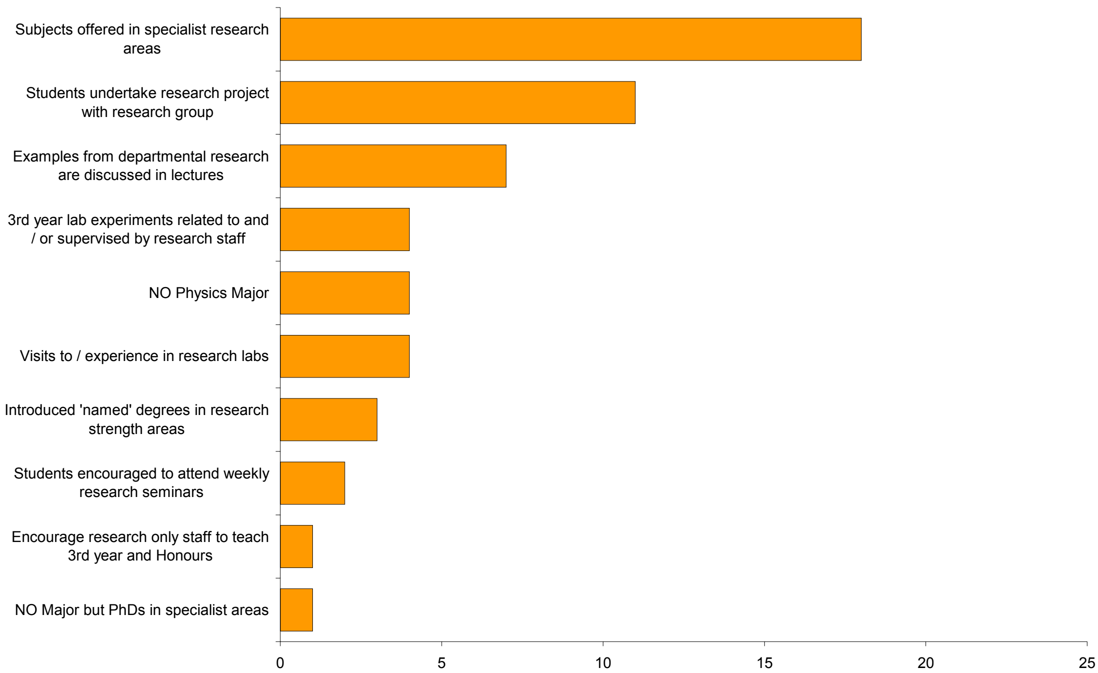

Figure 6.6: Categorised questionnaire responses to "C2. Physics departments have particular strengths within certain research areas. How is this reflected in your undergraduate curriculum? Are undergraduate students exposed to these research areas within the department?"

To give more substance to the bare numbers here it is useful to quote from the written responses of selected departments:

"Our undergraduate curriculum is strongly flavoured by our main research areas (advanced materials, astronomy/astrophysics, meteorology). These themes, together with staples such as electromagnetism and electromagnetic waves, are used both directly and as examples of fundamental physical principles…"
"Examples from departmental research are discussed within undergraduate courses, from first year upwards…"
"In lecture courses links are made [with] the research areas of the department through problems and extension of basic theory. We have developed specialist degrees related to our two research areas of space physics (Batchelor of Space Science) and surface and materials science (Nanotechnology/Science double degree to start in 2005)."
"…The first year curriculum includes a number of guest lectures in which research and academic staff present an overview of their research activities and achievements."

In laboratory physics, particularly in third year, and in project work in third year and honours, the teaching-research nexus has a clear and positive impact at some institutions:

"The third year laboratory experiments use equipment of research standard and are supervised by staff and postgraduate students with research expertise in the appropriate field."
"Our students do not take formal third year laboratory classes. Instead they take a one-quarter time or more research project in conjunction with one of our research groups. These students become part of those research teams and experience working as team members."
"Undergraduate students are exposed to research mostly through the project-based courses such as 'Applied Physics Techniques' with projects dependent on current staff interests"

There is little evidence in the data, however for research having positive impact upon the undergraduate curriculum at first and second year. The overall situation might be characterised by the response made by this department:

"The School encourages (and rewards financially) participation by research only staff in their fields of speciality, particularly at third and honours level."

Whilst taken in isolation this approach is a desirable one, it does tend to reinforce the view that there are fewer teaching and learning benefits from departmental research that are 'trickling down' to first and second year.

6.5 What are the Students Saying about How they Learn Physics?

Student perspective on current approaches to teaching and learning was obtained through focus groups conducted at the selected institutions. Focus group size ranged from four to six students: from each of first year mainstream (physics major), first year service students, third year (physics major) and postgraduate level. All students interviewed in these focus groups are in regular full time enrolment. Students were asked to respond to four questions. Of particular relevance to the discussion in this section are:

1. What features of your physics studies has most helped your learning?
2. What do you think are the valuable skills and knowledge you have gained from your physics studies?
3. Have your physics studies related physics to other areas of science and technology? If so how?

The top 3 responses from each individual focus group of students are given in graphical form in Appendix C.2. **Regular assessment**, **quizzes**, assignments and **worked examples/practice problems in both lectures and tutorials** feature strongly in the responses of first year students both in mainstream and service courses. One must be careful not to over-interpret these data. However, if the reasons for these responses are to be generalised, with a healthy degree of circumspection, it is probably not surprising that first years rate these features highly as they will recognise the style of the formal course assessment (traditional examinations) that they are likely to be measured against. It should be noted that the student focus group interviews were conducted in the second semester of first year by which point students will have had ample exposure to the types and styles of assessment used. A second feature apparent in the responses of first years is the rating students give to **handouts in lectures**, **notes on the web** and **helpful/talented/interesting lecturers**. This would appear to indicate that students are concerned about having confidence over the content of a course (perhaps 'trusting' handouts or notes on the web more than lecture notes they record themselves), but content delivered in an interesting way. One can see, therefore, students find regular assessment and feedback helpful. They also appreciate **good staff–student communication** and helpful lecturers and they are able to recognise good lecturing. These first years' responses would tend to underline the importance accorded to the transition from high school and the quality of the first year experience.

Interestingly, however, responses from third year students highlight similar features. third year students also identify **regular assessment**, **problem solving** and **examples in lectures/tutorials** and **good study guides** (a reliable guide to the required course content?) as the features that most helped their learning. A secondary feature identified is the availability of **web-based resources** and **notes on the web**, again something identified by first years in both mainstream and service categories.

Overall, the student perspective on the features of their studies most helped them learn does not uncover any startling findings. If anything, these responses might be characterised as indicating a rather conservative attitude to the mechanisms of studying physics.

Question 2, which addresses *skills and knowledge* the students feel they have gained from physics studies, shows clear evidence for perceived enhancement of **problem solving**, **analytical skills** and **logic** across all focus group categories from first year service students to third year. A particularly strong response concerning these skills is made by postgraduate students. The fact that this identification is made strongly by the focus groups imparts some level of confidence in the data itself and in what we are currently achieving with the way we are teaching. Analytical and problem solving skills would be identified by most academics as one of the foundation skills which should be enhanced through the students' physics studies. An **understanding of fundamentals** and **'description of everyday things'** together with **application of basic physics concepts** (to other disciplines) also features very strongly in responses from first and third year students, again showing that students recognise that the objective of connecting physics to real and practical issues is being realised.

Looking lastly at what students have to say about how their physics studies have related physics to other areas of Science and Technology, first year mainstream students focus very strongly on the connection with, and motivation for, **mathematics studies**. Identification is also made by the mainstream students of the connection to **engineering** and to **(physical) chemistry**. First year service students identify the mathematics connection far less strongly, focussing rather on the **broad applicability of physics** to other courses, or they refer specifically to the usefulness of physics studies to Engineering, or to Chemistry. No mention is made of the biological or life sciences or of the 'newer' courses (e.g. biotechnology, nanotechnology) that would have significant biological content. In the open-ended discussions that occurred in the focus groups, the absence of comment cannot be taken as proof, but the question is raised as to whether knowledge in the sciences is still compartmentalised.

Third year students cite a range of connections to other areas of science and technology that includes most of those identified by the first years, but in the case of third year students the grouping of responses is not as strong – connections to **chemistry**, **astronomy**, **electrical engineering**, **communications** and **mathematics** are all identified explicitly.

6.6 Identification of Good Practice: Special Features in Methods of Delivery and Assessment

All departments were asked, in the questionnaire, about particular or special features in methods of delivery and how the success of these methods is assessed. The responses form the basis for an overview of 'good practice' (see Figure 6.7).

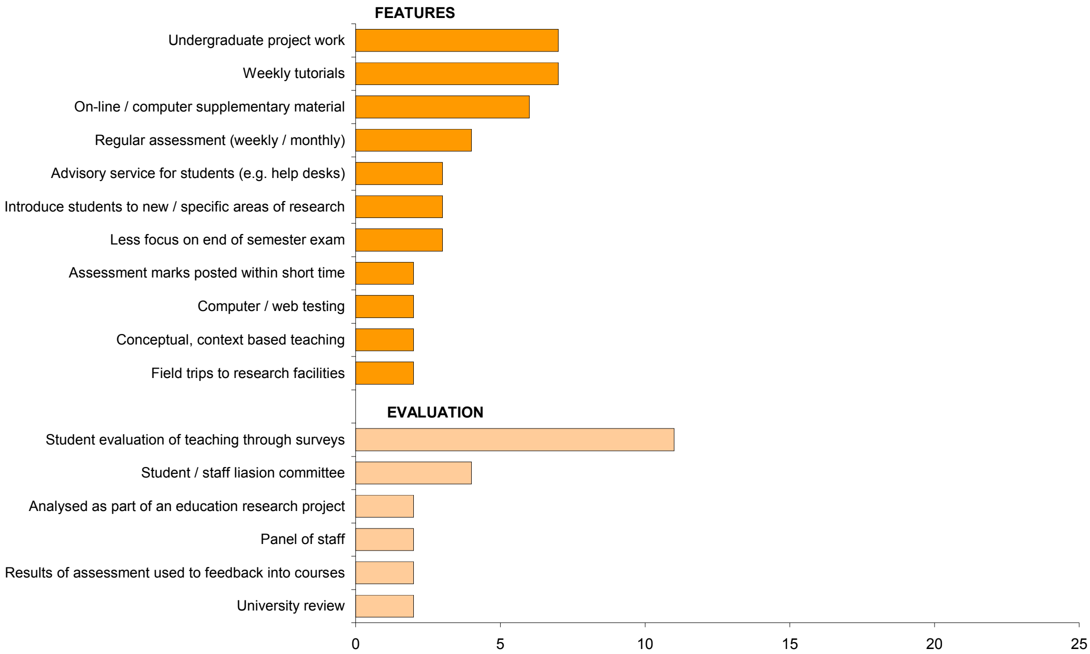

Figure 6.7: Categorised questionnaire responses to "E1. Are there any special features associated with teaching, subject content or assessment of students that are particularly effective / successful in your situation/department? How have you measured their effectiveness and what are the outcomes?"

The recurring successful/effective features are **weekly tutorials (7)** and **regular, weekly or monthly assessment (4)** (as well as **project work (7)**, discussed above in Section 6.4). Some of the comments made include:

"Regular (fortnightly/weekly) assessment of students has been a feature of our first year subjects for some time. It is currently completed on-line. Students – in post facto surveys – have supported this process as 'making them work early and consistently'"
"There has been a move away from a focus on end-of semester-examinations as a primary means of assessment…In the first year subjects tests are regularly carried out in tutorials."
"Laboratory subjects – continual assessment only. Theory subjects 50% continual and 50% examination"
"Highly successful teaching practices associated with the laboratory [include] draft report writing, report writing workshops including learning in a group. Highly successful teaching practices associated with assessment [include] detailed, explicit breakdown of components of assessment, feedback on draft reports, staff and student feedback, both written and verbal, on presentations. Highly successful teaching practices associated with content [include] informal tutorials, student liaison committee. Highly successful teaching practices associated with motivation [include] publishing student work (posters, 'proceedings'), involvement in community outreach, involvement in research projects. [Success of these is measured by] student academic results, surveys, focus groups, open feedback sessions with classes, student liaison committee."

Another area cited as successful is introducing students to new or specific research areas, an approach which is presumably a strong motivational factor for students.

Posting of marks promptly after assessment tasks (2) is undoubtedly an example of 'best practice' but is mentioned explicitly by only a couple of departments. Students certainly like to have the results of their assessment tasks returned promptly - something that most lecturers will be only too aware of. Prompt feedback, even in the form of a disappointing grade, is pedagogically effective.

Conceptual and/or context based teaching (2) was also identified as a successful and effective feature, but only mentioned by two departments.

The departments' reporting suggests that there is evaluative evidence for the benefits of these special features in most departments, but that it is not well formulated in most of them. A third of departments reported that feedback is obtained via student surveys. These may be general surveys with questions relating to the overall course and not specifically targeting a certain feature. Using staff–student liaison committees and education research projects to evaluate these practices is encouraging but only occurs in a small number of departments at present.

6.7 Summary

This chapter has reported a variety of approaches, emphases, and issues related to learning and teaching in Australian physics departments, from the perspective of department leaders and of students. Departments have been adaptable in the provision of a range of new subject offerings e.g. for multidisciplinary fields, as described in Chapter 5. They have also sought to provide good teaching, particularly in areas such as the laboratory which is generally viewed as an essential strength of a physics education.

No simple solution has been identified for the problem of how to continually improve the quality of teaching in the face of diminished financial resources. Higher student-staff ratios, higher demands on staff due to technology, and (in most institutions) the increased number of subjects offered relative to the available staff, and the effort of producing new course materials, in combination, have resulted in teaching development efforts being focussed on continuing to provide acceptable teaching rather than producing fundamental change. Students have reported learning best in the ways which our physics teaching has traditionally emphasised, including small group activities and projects, and have appreciated on-line materials, regular assessment and effective feedback. E-learning has largely been limited to providing ready access to resources and some on-line diagnostics and testing, rather than revolutionising the learning and teaching process. There is no reported use of virtual experiments replacing the traditional laboratory. Some of the responses indicate that teaching developments were being guided by physics education research or modelled on good practice at other departments which was in turn founded on physics education research.

This study confirms the general conclusions of world-wide physics education research, that good physics learning is fostered by small group activity in which interactive learning occurs (tutorials, workshops, laboratory or projects). There is no evidence in the literature to suggest that these activities can be replaced effectively with alternatives such as on-line learning and virtual experiments.

There are underlying principles which are widely applicable in terms of good learning and teaching. For example, the seven principles of good practice in undergraduate education are widely used as a guide. As first described by Chickering and Gamson (1987, 1991), such good practice:

- encourages contacts between students and faculty
- develops reciprocity and cooperation among students
- uses active learning techniques
- gives prompt feedback
- emphasizes time on task
- communicates high expectations
- respects diverse talents and ways of learning

These principles are embedded within many of the good practices reported by departments for this project.

6.8 Recommendations

Overall, it would appear that the goal of improving learning and teaching quality in Australian physics departments depends on teaching staff having a better awareness of approaches and resources which have been evaluated and demonstrated to be pedagogically sound and efficient in terms of human and financial resources. Such resources need to be accessible, physically and financially, to departments and staff. Any progress toward this goal ultimately depends on our physics academics, so in Chapter 7 we consider how best to support staff in order for them to be more effective teachers, and to be able to make better use of the best approaches and resources.

In Chapter 8 we look at possible strategies for achieving this goal against the current realities faced by Australian physics departments, and explore means of more effective cooperation. We recognised that most departments need to have confidence that approaches implemented now will have a lifetime of at least a decade and not fall down as a result of being tied to specific computer platforms or being dependent on the enthusiasm and extraordinary time-commitment of one member of department, or being linked to a passing trend. Hence our recommendations for this chapter seek to benefit the majority of physics departments and our students. The recommendations
assume both a favourable environment of cooperation and a recognition that focussing on pedagogy, on a better understanding of how students learn, will provide a better basis for decisions about physics learning and teaching for the future.

Recommendation 6.1:
That Physics departments and the AIP through the Physics Education Group support and undertake research into the effectiveness of learning and teaching strategies such as the use of IT / e-learning, the contexts and benefits of undergraduate research projects, and opportunities for optimising our investment in and commitment to laboratory experience.

Recommendation 6.2:
That the Carrick Institute provide support for further research into effective physics learning and teaching in the Australian context, with particular attention to Generation Y.

Recommendation 6.3:
That heads of physics departments and the Australian Institute of Physics cooperate in establishing improved mechanisms for promoting and sharing good practice, such as supporting academic exchange visits and contributing to UniServe Science.

Recommendation 6.4:
That the AUTC project team identify academic staff with an interest in physics for biological and medical sciences, and encourage them to collaborate in the production of common course materials appropriate for the Australian context.

Chapter 7: Staffing Challenges and Responses

7.1 Preamble

The people teaching physics in Australia's tertiary institutions are both at the forefront of the challenges facing physics teaching and the reasons for confidence of a promising future.

A significant majority of departments report that the major challenge facing the department is related to staffing. In many departments this is due to declining staff numbers and loss of identity of the physics teaching unit. However, even where staff numbers and coherence have been maintained, increasing student numbers and escalating expectations and demands of students and the university are stretching personnel resources.

While staffing provides the major challenge to most departments this occurs in parallel with teaching staff being held in high regard by their leaders and colleagues. When asked about the strengths of teaching and learning in their department over 90 per cent of respondents cited as highlights the dedicated and experienced staff committed to excellent teaching, the research-teaching nexus leading to high-quality teaching by staff, and the rapport apparent in staff-student interactions. In addition, the collegiate nature of the physics teaching unit was often reported as a feature, influencing co-operative teaching and teaching development and the mentoring of junior members of teaching teams. Some responses to the main questionnaire item *B4. What are the strengths of the teaching and learning in your department?* included:

"*Extremely dedicated, competent, enthusiastic and hardworking staff.*"
"*…genuine interest in teaching and an excellent collegiate atmosphere.*"
"*Extremely good rapport between students and staff.* " [evidence cited]
"*Enthusiasm and approachability of staff.*"

Questions arise, however, about how well these fine teachers are supported. Do they have the time to capitalise on their teaching strengths and to develop their innovative ideas? Do they receive encouragement, through practical recognition of their efforts, to improve further the learning experience of their students? Are the experienced and accomplished teachers able to inspire and pass on to younger colleagues – the next generation of academics – their enthusiasm, insights and skills?

Incentives and rewards for quality teaching play an important role, and several are mentioned by departments surveyed in this project. One which may influence initiatives in the immediate future is the Learning and Teaching Performance Fund established in 2004 by the Australian government, through DEST, which provides substantial funding (in 2006-2008) to reward institutions that best demonstrate excellence in learning and teaching. "The Government believes that rewards and incentives for excellence in learning and teaching will promote the overall quality of the sector, enabling excellence in learning and teaching to be placed alongside delivery of research excellence..." (DEST 2004)

7.2 Issues in Staffing

Of the 34 institutions, 21 reported the impact of declining academic staff numbers and/or the general downsizing of departments. As discussed in Chapter 4 these staffing changes have provided impetus for change in what is taught as well as the methodologies being used.

Departmental responses have included reduction of the range of subjects offered to students, co-operative teaching with other departments and universities, merging of previously separate streams of physics offered to different course cohorts, scaling back of the teacher-intensive components of the physics sequence such as laboratory-based teaching, introduction of online supporting materials, and other restructuring of the curriculum.

Academic staff are being asked to be more flexible in the areas of physics they teach and the breadth of the physics expertise they offer. Where diversification of the physics being taught has extended into multidisciplinary subjects and courses, institutions referred to the need for academic staff to teach across a broader range of the curriculum than was once the case. The capacity to teach into multidisciplinary courses, seeing physics as an underpinning discipline with diverse applications, is becoming increasingly important.

The maintenance of staff numbers in some institutions has been achieved by increasing the student load through diversification of the courses offered, with a growth in the number of boutique courses or majors, such as nanotechnology or biomedical science. Where students in these courses or majors are taught in common with other students with similar physics needs, the diversification has not led to greater teaching demands. However, where this is not possible, staff are doing more teaching and the available staff resources per student have decreased.

Some institutions have become more reliant on the employment of casual teaching staff. Moving to a higher proportion of staff who are employed primarily for face-to-face teaching time has led to a reduction of availability of staff for ongoing consultation with students and curriculum development. Where these teaching staff are inexperienced there has been a concomitant increase in the resources needed for staff training.

7.3 Recruitment and Training – the Teaching Dimension

7.3.1 Recruitment

Interest and skills in teaching are becoming increasingly important in the appointment of new staff members. This issue was explored with the Head of Department, or delegate, of nine departments spanning a range of types of institutions and states. They were asked about the extent to which teaching influenced decisions about staff profile.

In only one of these departments was teaching experience stated to have a minimal role in appointing new members of staff. In the remaining eight departments a range of approaches is taken, from teaching and research being given equivalent weighting in selection to departments in which significant effort is being invested into attracting the best possible teachers. Selection processes routinely include a research presentation intended to provide some indication of communication skills of potential appointees. Of the nine department heads interviewed, two recounted that the presentation of an undergraduate lecture, evaluated by both students and staff, is included. One department also requests a written statement about the candidates' approach to teaching.

Several departments spoke of the desire to appoint dynamic young teachers. This strategy has the dual purpose of motivating students and appointing people the department hopes will lead existing staff to a revitalised interest in teaching and innovative teaching approaches. The reasons cited for an increased emphasis on teaching within the selection process ranged from the difficulties experienced as a result of people with little interest in teaching appointed in previous years to the need to gain academic staff with appropriate teaching expertise for the range of subjects being offered.

7.3.2 Induction to Teaching for New Teaching Staff

With declining numbers of staff in continuing appointments the need for recruitment and training of sessional staff has increased. Training programmes have been used for a number of years, but the resources required to accommodate an increasingly casualised staff have increased.

Most universities offer formal training for new academic staff – short induction courses or more extensive courses in higher education teaching. There were some doubts expressed as to the value of such courses. In some universities completion of a formal Certificate course is required prior to confirmation of the appointment.

Several departments referred to informal training as new staff mix with others in the department. Some had had very few recent appointments so had not considered the issue for some time whereas some others described well-established procedures.

Some departments had quite explicit arrangements for mentoring of new staff, and easing them into teaching roles with direct support from subject coordinators.

7.3.3 Tutor and Demonstrator Training

There is a range of approaches taken to tutor / demonstrator training, which is fairly superficial and limited at most universities.

Some departments have one-day training sessions for their own tutors and demonstrators, but many have only generic training offered by their university, with less applicability to physics as a discipline. Much of the training relates to legal, safety and 'housekeeping' requirements, very little at all to teaching techniques or strategies.

Most departments require that demonstrators conduct an experiment before they may supervise students performing it. Some have ongoing training and mentoring of tutors and demonstrators. This mentoring occurs through pairing up with more experienced tutors or demonstrators, regular meetings with lecturers, tutorial or laboratory co-ordinators. The mentoring may be informed by student feedback from surveys.

Several (perhaps smaller) departments referred to ad hoc training and the climate of the department that encourages informal discussions of teaching issues, and implicit training of tutors and demonstrators.

7.4 Developing, Rewarding and Sustaining Good Teaching

The development of innovative teaching practices that lead to improved learning for students rests on academic staff with an interest in student learning and the capacity to become knowledgeable about how students learn physics. These people need time to develop and implement effective teaching approaches and to evaluate the success of these approaches in their local situation, and the encouragement to communicate with others about teaching strategies.

7.4.1 Learning and Teaching Forums

Departments were asked about the availability of forums in which staff could discuss elements of curriculum development and teaching strategy, the encouragement provided to pursue new approaches to teaching and the role of teaching in the important process of gaining promotion.

Responses to the main questionnaire item *H1. Are there any forums for discussion of physics education (teaching innovation) within the department? If so, please provide examples of some of the forums* included the following:

"*We have regular Subject Panel meetings but they end up as more administrative process. We have a once a semester Teaching and Learning forum: in the past they have involved Plagiarism, Writing objectives, Assessment…The next one in May will focus on Active Learning in small and large groups…*"
"*…Weekly teaching and learning committee – about 50% of staff attend. Fortnightly meetings of sessional staff to discuss problems. Student teaching forums once a year for each course we run.*"
"*The physics group meets weekly, but much of our agenda is concerned with the mechanics of course offerings.*"
"*The University has various forums for these activities and physics has always been strongly represented at these events both a participants and presenters. The department is small enough to facilitate active discussion between all members.*"

Responses from 34 departments, summarised in Figure 7.1, show that many encourage participation in forums for the enhancement of teaching and learning. These may be a university-wide initiative of a University Teaching and Learning/Staff Development Unit or more focussed faculty-based meetings. Ten departments referred positively to the value of such forums to their programs.

The types of forums listed in Figure 7.1 do not all represent a 'solid' commitment to reviewing and supporting teaching and learning, or indeed a platform for discussing or promoting innovation. For example, of the 26 departments that do have forums 7 of these are in the form of 'discussions at staff meetings' and 7 others are in the form of 'discussions about teaching over tea/coffee'.

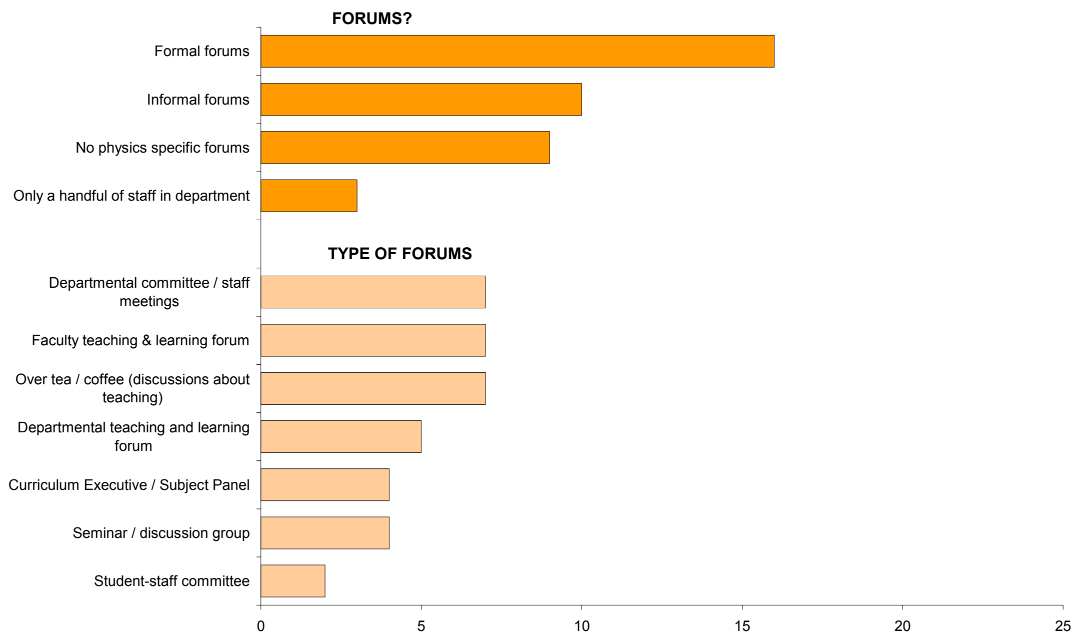

Figure 7.1: Categorised and quantified questionnaire responses to main questionnaire item "H1. Are there any forums for discussion of physics education (teaching innovation) within the department? If so, please provide examples of some of the forums."

In 13 of the 34 departments there are active departmental committees addressing teaching issues such as subject structure, teaching methodology and assessment. Additional discussion occurred in forums with students, such as Staff-Student Liaison Committees. Nine departments reported that there were no forums available, but in many of these groups the small number of staff meant that informal processes still ensured that these issues were being considered actively in corridor and tearoom discussions. Responses from small departments included:

"Not applicable. There are only 3 physics staff and one of them is heavily involved in university administration."

"Only over coffee/lunch or planning days. There are only 8 of us!"

Within many departments there are processes for the review of physics subjects using a formal committee structure of the department. Such venues can provide a forum for a more broad-ranging discussion of teaching and learning issues or a springboard for development of new strategies.

7.4.2 Support for Teaching Development

Responses to the main questionnaire item *H2. How does your department (or faculty) support staff interested in curriculum enhancement and investigating issues related to teaching and learning of physics? Are staff who employ innovations in teaching and learning valued? Please provide example(s)* included the following:

"*Curriculum issues (like motherhood) are recognised as important, but are also recognised to take time, and do not bring in money in an identifiable way. This is a problem…*"
"*There is a perception that research innovations are still valued considerably higher than teaching innovation. This may be because research innovations bring in funds and people that can indirectly support teaching, whereas the converse is not the case.*"
"*The [department] has recently invited applications for School funding of teaching initiatives, having approved up to $20,000 to be allocated for this purpose.*"

Responses from 34 departments, summarised in Figure 7.2, show that physics teaching staff in more than 90% of departments have opportunities to pursue teaching initiatives through leave from other responsibilities, funding support for projects or award courses.

Several responses recounted the support given to members of staff who took the lead in curriculum development during recent significant change in departmental subject offerings. These staff were encouraged to visit other departments to discuss the approaches being taken elsewhere.

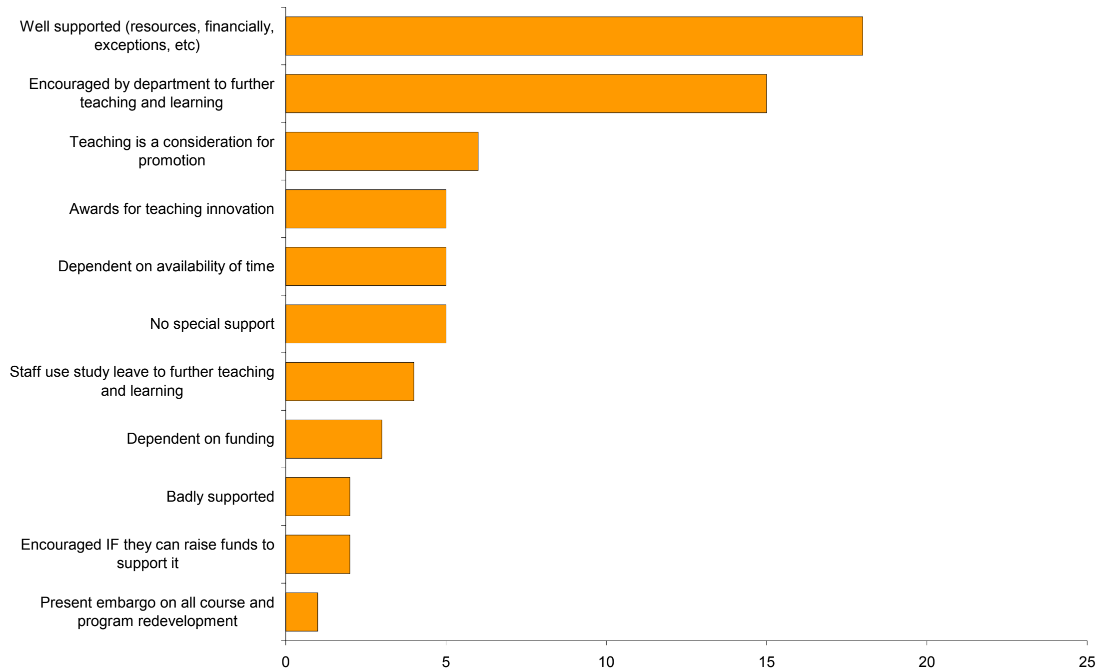

Figure 7.2: Categorised and quantified questionnaire responses to "H2. How does your department (or faculty) support staff interested in curriculum enhancement and investigating issues related to teaching and learning of physics? Are staff who employ innovations in teaching and learning valued?"

Ongoing supportive measures described by departments included development leave being available for enhancement of teaching skills, as an alternative to research (six departments), financial support at departmental, faculty or university level for development, implementation and evaluation of teaching strategies (fifteen departments) and the encouragement of, or requirement for, staff to undertake formal study such as a Graduate Certificate in Tertiary Teaching (four departments). This encouragement has included time relief, mentoring and financial support for enrolment in these courses.

Several departments, however, described the absence of time relief for teaching development, with staff needing to contribute additional time and an entrepreneurial spirit to obtain external funding support for teaching development.

Visits to other universities at times of specific needs in curriculum development were mentioned within the main questionnaire but there was limited mention of regular meetings such as the forums provided by the Australian Universities Computers in University Physics Education conferences (OzCUPE) and their successor, the Physics Education Group meetings within the AIP congress. There was no specific question about such meetings so it is not clear whether their low profile in this study is of significance.

7.4.3 Recognition of Teaching Achievements

Responses to the main questionnaire item *H2. How does your department (or faculty) support staff interested in curriculum enhancement and investigating issues related to teaching and learning of physics? Are staff who employ innovations in teaching and learning valued? Please provide example(s)* included the following which relate to recognition of good teaching:

"*Promotion to Ass. Professor can be made on the basis of a very strong teaching commitment.*"
"*Teaching is now given more weight in promotions…*"
"*Innovation in teaching is one important aspect of gaining promotion. Sabbatical programs which concentrate on teaching development are also encouraged. If staff wish to undertake major changes to the way physics subjects are taught they will in general need to find external funding.*"
"*New staff must complete a Graduate Certificate in Higher Education which includes developing a teaching portfolio. A teaching portfolio is also considered for promotion, etc.*"
"*… recognition that quality teaching has built up student numbers.*"

Responses from 34 departments suggest that promotion criteria and teaching awards are increasing in importance as avenues for the recognition of the teaching achievements of physics academic staff. Both can be viewed as part of a systemic change in the value placed on quality teaching in the university sector.

Six departments referred to changes in the criteria for promotion that placed greater value on documented excellence in teaching as a component in cases for promotion.

Awards for excellence in teaching provide prestigious recognition at both faculty and university level, through Deans' awards, Teaching fellowships and Vice-Chancellors' awards. Seven departments discussed the encouragement their departments provided through the nomination of staff for these awards.

7.4.4 Sustaining Good Teaching Practices

Heads of Department responses to the interview question *How have you been able to ensure that good practices are sustained?* included the following:

"[We've been able to ensure good practices are maintained] mainly by encouraging people involved in such practices to continue doing them."
"[We have] set up teams of teacher + tutor, in order to instruct tutors in teaching practice, what the lecturer want to achieve in the subject."

"All new staff get a mentor, who counsels them in their teaching or in both teaching and research; mentor is encouraged to go to the lectures of the new staff member, evaluate them, etc.; the mentor relationship remains for a long period of time, not just a month or two."
"Ultimately, sustainability is linked to demand…"

A major difficulty in sustaining innovation is staffing levels. A great deal of knowledge and expertise has been lost with the departure of many older, highly experienced staff as physics departments have 'downsized' across the nation over the past decade. When academic staff numbers are at an all-time low in many departments (a trend that is unlikely to be reversed in the foreseeable future) it is harder to give time-relief to academic staff to implement new teaching and learning, to update notes or teaching materials or to set up entirely new teaching arrangements.

7.5 Recommendations

Several departments reported increased use of sessional staff to deliver lectures. Though they may deliver quality lectures, the associated administrative tasks and out-of-class support for their students falls on other staff. Sessional lecturing staff are cheap, but at a cost.

In many institutions new academic appointments are required to demonstrate their teaching abilities during the selection process and to complete a formal teaching qualification following appointment. This good practice augurs well for the quality of physics teaching in the future. Such staff should be given relief from other duties to undertake the teaching qualification.

Training of casual staff – tutors and laboratory demonstrators – is very limited. This is both a university-wide and nationwide issue when the major contacts our first year students have in transition are with tutors and demonstrators. Training of these sessional staff should be seen as an investment leading to better retention of students into second year studies in physics. Providing good-practice case studies and resources will clearly be of value.

Physics teaching is increasingly demanding as we teach outside our areas of expertise into multidisciplinary areas. We need more people to teach the diverse range of topics undertaken, or more time for staff to acquire new skills, or both.

People in physics work well together, in cooperative and supportive environments. There is real potential for significant joint teaching developments within the physics community.

Recommendation 7.1:
That departments provide time, and resources for staff who contribute substantially to innovative and quality teaching, recognise their contribution to retaining students, and support their promotion based on their teaching.

Recommendation 7.2:
That Heads of departments and institutions ensure academic staff appointments address teaching capabilities alongside research, that new appointees have a good induction to teaching and learning, and that ongoing support is provided for physics-specific teaching and learning practices.

Recommendation 7.3:
That departments value the contribution that demonstrating, tutoring and sessional staff have on students and should ensure adequate training and support, both in terms of physics content and teaching and learning issues.

Recommendation 7.4:
That the AUTC project team in Stage 2 highlight and disseminate good practices and available resources for demonstrator and tutor training.

Chapter 8: Future Directions

8.1 Introduction

Tertiary physics education in Australia has faced a multitude of challenges over the past decade. The future of learning and teaching in physics requires wise and bold academic leadership in departments and a collective Australia-wide effort to ensure that best use can be made of effective learning resources and approaches. The International Year of Physics in 2005 is a good time for reflection and constructive planning.

The following points summarise findings of earlier chapters, which suggest that Australian tertiary physics departments are poised to improve the outcomes for their graduates and the overall profile of tertiary physics.

- There are many good practices in learning and teaching at individual institutions, which would be of benefit to physics at other departments.
- Departments are capable of creative change, as indicated by the number of successful initiatives to develop new programs in photonics, nanotechnology, space science, security technology, scientific imaging, and biomedical physics.
- Other disciplines such as biomedical, environmental, and biological sciences, have an increased awareness that their students need some relevant physics. This is coupled with recognition that physics departments are increasingly able to undertake relevant and inspiring teaching.
- There is an increase in higher year physics student numbers in many institutions in parallel with increased media publicity of the contributions of physics.
- There is an opportunity to raise the profile of teaching experience in appointing staff as a number of institutions face replacements of retiring staff.
- Departments are responsive to collaboration and to adopting viable and successful practices as a result of financial and staffing pressure.
- A collaborating network has been formed through this project, directly involving about 50 physics academics, who have influential roles in their departments.

From this we see that the second year of the AUTC project starts in 2005 with good prospects. In this chapter we first identify the areas in which departments see particular possibilities of working together, then we describe a number of processes and strategies which we believe will enable physics departments to make better use of available resources and collective wisdom.

8.2 Departments' Requests for Collective Resources

Heads of departments or their nominated representative were asked, in the main questionnaire, (item B.6) *Can you identify resources that could be developed cooperatively by the physics education community that could support the teaching and learning of physics in your department? Please provide a brief description.*

In the overall response to this question as well as some in-depth interviews, several Heads expressed their hope for better cooperation and sharing of resources. Staff time, expertise, and financial resources are required to maintain the quality of learning. These requirements now present a challenge with reduced staff numbers. In these circumstances, developing one's own resources may not be a viable, or the best, option. Cooperative endeavour between departments, and across the whole tertiary physics sector, is something we can no longer consider too hard. A past President of the Australian Institute of Physics has commented that this had been a topic for discussion at one Heads of Physics departments meetings in the mid 1990s, which was greeted warmly but lapsed due to lack of follow up and initiatives (Pilbrow, 2004).

No simple solution has emerged to the challenge of improving learning and teaching in physics: heads of departments have not said 'if only we had X or could do Y then our physics learning and teaching would be top-rate'. This reflects the fact that a 'one-size fits all' approach is not appropriate, due to the wide spread of characteristics such as the local department-university environment, degrees offered and students' preparation and directions in Australian physics departments. Suggestions made in this Chapter for the pooling of effort for efficiency and for quality, would allow **some** materials to be used in common where departments choose, but would not significantly alter the distinctiveness of each department's offerings.

The most common responses to item B.6 included requests covering the **availability of shared physics teaching resources** (**14** - this number does not include other specific resources noted below) including a database for ready access, on-line quiz materials, simulation applets, and physics demonstrations, particularly for first year subjects, specialised areas such as quantum mechanics, medical imaging, and astrophysics in the Australian context were each mentioned by one institution.

Shared laboratory experiments and equipment (6) was sought by some departments, either the design and laboratory script, or the actual experiment by students or equipment moving between institutions. Experiments for bio-science and biomedical physics were mentioned by one department. **Shared subjects, on-line or otherwise (5)** were particular requested by smaller and isolated institutions, with reference being made to **specialised and honours/higher year topics**, in some cases stating the need to maintain breadth in their course.

One head found **evaluating** existing approaches and resources to be a challenge: *"My biggest problem is finding time to find (and familiarise myself with) those resources which are out there!"* and another noted the need for appropriate professional development for tertiary physics teaching.

Four departments provided no suggestions for this question, although in some responses there was a hint of not having time to think about the issue; another department doubted that resources could be developed and shared effectively. Some departments were looking outward: one department was keen to explore the sharing of an on-line tutorial system developed in their department; training for secondary teachers by another, and promotion of physics in secondary schools by two.

If a cooperative effort is to be conducted in any networked or organised fashion with some central resources or funding, then the effort must be coordinated, and tasks prioritised. The best way to foster sustainable cooperation would be for participating departments to discuss and decide.

8.3 Sustaining Good Tertiary Physics Education

This section describes the key goals and proposed actions for Stage 2 of the project in 2005. Consultation with departments will take place prior to detailed planning.

8.3.1 The Key Players

The future of tertiary physics is in the hands of physics academics. Heads of departments and chairs of academic programmes have a pivotal role, but no less important are those younger members of staff who may have had valuable experiences in other institutions, together with sessional postgraduate tutors and demonstrators who are much closer in experience and outlook to students.

We note the value of networks and a range of learning and teaching forums, formal and informal, involving physics academics and others from the sciences, engineering, education and other disciplines.

We recognise the potential of The Australian Institute of Physics, and the Physics Education Group, to play a bigger role in bringing in fostering and helping resource our efforts in tertiary physics education. Uniserve Science and the Carrick Institute for Learning and Teaching in Higher Education are two bodies which can make a significant contribution.

8.3.2 Further Research into Course Design and Outcomes

The Stage 2 Project brief specifies that the project should undertake analysis of the relationship between course design and indicators such as enrolment and employment trends, graduate satisfaction and graduate employability. This will expand the preliminary investigation into graduate and employer satisfaction in Stage 1.

8.3.3 Priorities and Good Practices

The project has identified several areas in which physics departments could draw on the collective knowledge and experiences of tertiary physics educators. Ones which stand out include IT and learning, effective teaching of concepts, incorporating better generic skills, relating physics to bio- and biomedical sciences, careers in relation to physics, good learning-teaching approaches for the Generation Y. Resources which could be of assistance have been noted above.

As specified in the Project Brief, Stage 2 will prepare case studies of good practices. Where possible, these will be presented by the originators of the good practice. An opportunity for presentation to a wide audience is tentatively planned at the end of September 2005.

8.3.4 Strategies for Sharing Key Findings and Good Practices

Stage 2 moves the focus from researching the state of physics teaching in Australian universities to improving the quality of physics teaching and learning. This can only be achieved to the extent that departments are able to both participate in decisions about the directions to be taken and to cooperate in bringing making them happen. Six strategies are proposed for sharing the good practice materials and key findings of this project, which will be refined early in Stage 2.

- Meeting with Heads of Physics Departments, anticipated to take place in conjunction with the AIP Congress in Canberra late January 2005, as a way of further deepening their sense of ownership and inviting input in the ongoing process of reinvigorating our discipline.
- A summary in The Physicist (magazine of the AIP) which reaches most physics academics.
- An attractive catalogue as a way of providing academics with ready access to good-practice examples.
- Presenting colloquia by a project leader at departments or at local AIP meetings as a direct method of engaging physics academics in a situation where there can be questions relating to implications for their own institution(s).
- Opportunity for further discussion with key staff in departments following a colloquium, to helping relate the project outcomes to their situation.
- Maintaining an on-going project website, as a readily accessible host for various resources, ideally in co-operation with the well-established UniServe Science clearing-house website and/or the Australian Institute of Physics.

We now expand our description of these activities.

8.3.5 Workshops

Workshops are effective means of equipping academic staff. A suitable model is the successful 'Chautaqua' workshops which were offered in various centres in Australia in 1996 and 1998. These would involve about 20 physics educators in hands-on and small group interactive learning. The project team has experience in running such workshops, for example, on Workshop Tutorials in Physics (Sharma, Wilson, Newbury).

Workshops could be run in major centres in various states, with funds for subsidising attendance by participants from regional universities. Topics offered would be drawn from areas identified in Stage 1, including good practice case-studies, physics resources accessible via the Uniserve Science clearing-house, and effective use of teaching resources (doing more with less), and the local departments would decide on the particular workshop topics.

Workshops would ideally have about 30% of participants as active contributors, and draw together teaching staff responsible for the areas identified above. The workshop aims are to:

- enable teaching staff to discover elements that enhance learning, and analyse the fundamental reasons for their success (not just show and tell of what has worked in different places)
- assist staff embarking on teaching and learning development to identify the opportunities which could lead to research publications
- to synthesise the elements which suit the unique features and meet the individual needs of each department
- discuss the challenges likely to arise during implementation and explore the role of evaluation in sustaining and further developing good practice

8.3.6 Capacity-Building: A Physics Education Network

Developing the capacity of a network of experienced and inspiring physics educators is essential to the long-term future of good physics learning and teaching in Australia.

The project team asserts that the current Physics Education Group of the AIP must become, or be part of, a national entity to promote and resource Australian physics education. This would be a desirable effect of Stage 2 of the Project, and provide for ongoing equipping and provision of resources. Early in 2005 we will seek discussions with The Carrick Institute as to how they may be involved in the long term. This concept has been informally endorsed by present and incoming President of the AIP and all of 8 heads who were contacted in a straw-poll.

There are some 80 current members of the Physics Education Group of the AIP, about 50 of whom are active tertiary physics academics (others are secondary teachers and active retirees). This group has provided helpful interactions for over a decade, starting from OzCupe (Computers in Physics Education - Australia). The project would see as an achievable target, expanding the network to at least 110 tertiary academics (more than that number would be currently involved in some teaching innovations or have major learning and teaching oversight in a department). Recruitment strategies will target younger academics. Having three or four participants from medium sized departments would mean that materials from workshops and the resources described above are likely to be adopted.

8.3.7 Resources Clearing-House

Section 8.2 above has presented the range of requests by Heads of departments for collective resources. This section considers how this may be achieved.

The Accreditation process of the Australian Institute of Physics (AIP) currently gathers together laboratory experiment scripts and manuals with the purpose of making them available to departments, but there is no mechanism for informing potential users (departments) of their availability or contents. Uniserve Science clearing-house, hosted by the University of Sydney, provides a suitable platform for indexing resources; the AIP website is an option for large volume storage.

Our strategy in this area is first to catalogue the available resources identified in Stage 1, and second, for the project officer to work with the source department or academic to document the resources in a suitable format (issues of whether directly downloadable, or whether available by negotiation with the author). Finally, we aim to publicise the resources at several levels (including the AIP Congress and other means mentioned above) so that there would be a strong association between the 'Physics Education Network' and physics teaching resources.

8.4 Fostering Learning and Teaching Excellence

The study on undergraduate physics in the USA (AAPT 2003), mentioned in Chapter 1, has identified essential elements in all thriving physics departments: a well-designed and resourced curriculum, good staff-student interactions fostering a strong sense of community and providing mentoring, commitment to this program by all staff, and strong and sustained departmental leadership.

In interviews with selected Heads of Departments, a sense of belonging to a physics community has been identified as an important need in Australia. The project will also look at the affective factors in this regard, and endeavour to assist departments and the AIP in matters where the image of physics needs updating, such as promoting physics at secondary school, giving a lead on graduate employability in particular the multidisciplinary opportunities and student satisfaction.

The AIP itself would undoubtedly benefit from more active involvement by Physics Education Group members in general, and the younger members in particular. As part of sociological and generational changes, it appears that the traditional monthly lecture format will no longer attract most time-pressured academics. Involvement with worth-while action-groups may be more likely to succeed.

8.5 Recommendations

Recommendations in this chapter are primarily intended to help facilitate the implementation of earlier recommendations with regard to specific learning-teaching practices.

Recommendation 8.1:
That the Heads of departments and the AIP consider means by which they can more effectively support tertiary physics education in Australia, including obtaining strategic government funding and strengthening the AIP Accreditation guidelines.

Recommendation 8.2:
That the Physics Education Group of the AIP play a more prominent role as a network which provides effective mechanisms for promoting and sharing good practice. To achieve this, it should invite a wider membership, have representatives from all departments and support for its activities from Heads of physics departments and the Australian Institute of Physics.

Recommendation 8.3:
That the AUTC project team, Heads of departments, and the AIP cooperate in establishing an effective means of sharing teaching resources and providing a database containing evaluations of and advice regarding resources.

Recommendation 8.4:
That the AUTC project team and Heads of departments to work together to prioritise areas for evaluation or provision of teaching resources, with special attention to resources adapted to an Australian context.

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