Education

and the

Ideal

EDITED BY Naomi Smith

FOREWORD BY Christopher Koch

NEW FRONTIER PUBLISHING

7

Science Education for the Twenty-First Century

NEVILLE H. FLETCHER

With the twentieth century now safely in the past, it is appropriate to look back at what we seem to have done right in the field of science education, and also at the mistakes that we made, and to try to chart a better path for the future. Because education as a whole is divided into primary, secondary, and tertiary (or 'post-secondary' in some terminology), and because developments have been rather different in each of these three areas, it is appropriate to divide up my discussion in the same way. Within these three main divisions, other relevant topics will be covered, such as the relationship between the sciences and the social sciences, the proper use of information technology, the future of school syllabuses, teacher preparation, and university education.

Because my background is in physics, I hope I may be forgiven for concentrating on that subject. My additional excuse is that the problems I want to discuss are generally more severe for physics than for the other sciences.

Primary School Science

While some sort of science has always been a part of primary school education, a Federal Government inquiry in 1989 reported that this teaching was then in a 'state of crisis'; the Australian Schools Council reported in 1992 and 1993 that little had changed, and there is still concern today.[1] This reminds one of the passage from Shakespeare's *Henry V*, when the Duke of Burgundy laments:

> *Even so our houses and ourselves and children*
> *Have lost, or do not learn for want of time,*
> *The sciences that should become our country.*[2]

It was not until the mid-1990s that an Australia-wide meeting of education ministers through the Australian Schools Council formulated a common set of agreed curriculum priority areas, of which science was one. This decision did not imply a common curriculum, but it did provide a stimulus for the development of teaching materials in science that could be used on an Australia-wide basis. The major outcome was the primary school science, technology and environment project *Primary Investigations*, developed by the Australian Academy of Science with the support of the Commonwealth and of State education departments, CSIRO and CRA (Conzinc RioTinto Australia). The aim of this project was to produce teaching materials to cover the primary school kindergarten to Year 6 range on a whole-school basis and, most importantly, to provide introductory training and continuing guidance for teachers in schools throughout Australia. Because this project has been so important, it will be discussed in some detail.

The Academy, established in 1954 under Royal Charter, has many roles. Perhaps the chief one is to honour outstanding Australian scientists by electing them to Fellowship, along the same lines and with the same criteria as the Royal Society of London. But the role set out in the Charter includes the statement that the Academy shall 'declare, promote and disseminate' scientific knowledge, and education at all levels is a major element of this activity. The Academy had been active in education at upper high-school level, as we shall see presently, but this was the first venture into primary school teaching.

Fortunately, a study in the United States – the Biological Sciences Curriculum Study – had developed a science program for primary schools that was not limited to biology, and they agreed to make this available to the Academy as a basis upon which to build a rather broader program for use here. A great deal of modification was required, and indeed the course materials were completely rewritten under the leadership of Denis Goodrum from Edith Cowan University, and involving many other teachers and Fellows of the Academy. The major successful element was the '5Es' approach in which children first became *Engaged* by the intrinsic interest of a topic, then *Explored* it through guided experiments, had the underlying principles *Explained* by the teacher, *Elaborated* the topic to more diverse experiments based upon this understanding, and finally *Evaluated* what they had learnt. This approach mirrors the real way in which science develops – though of course there is no one to 'explain' what is going on, and the researcher must work this out for him or herself!

In 1993 the draft materials were subjected to a full-year trial in forty schools from different backgrounds around Australia, the trial involving some 600 teachers and 12,000 children. All teachers involved were given special preparatory courses, and consultants were available throughout the year. The materials were revised on the basis of feedback from these schools, and the final sets of teaching materials, involving seven teacher manuals, five student workbooks for Years 2 to 6, and access to those items of experimental equipment not readily available from a local hardware store, were distributed to schools at the beginning of 1995. Since it was widely known that most primary school teachers, despite their training in teachers colleges or universities, did not know enough about science to be able to teach the course confidently, some 600 experienced teachers were given special training and visited all schools adopting the materials to give special training sessions to teachers. Special training videos and a website were also developed by the Academy to support teachers using the program.[3]

Over the intervening years *Primary Investigations* has continued to be very successful and has been widely adopted in all states except Victoria and New South Wales. The reason for the limited adoption in these two states was partly the more rigid structure of the state syllabuses. An investigation completed in 2002 for the Academy and the Commonwealth Department of Education, Science and Training by Peter Aubusson documented the successes of the project and made suggestions for its future development. A particular need is to present the material in such a way that its use can be more readily adapted to meet the requirements of the New South Wales and Victorian syllabuses, perhaps using digital media.

The Australian Academy of Technological Sciences and Engineering (ATSE) has recently carried out its own study of technology education in primary schools, and it is likely that some new initiatives will arise out of this. The report tends to emphasise a perceived dichotomy between science and technology:

> *Science and technology are based on different approaches to learning and emphasise different approaches to knowledge and its use*[4]

... with which one may or may not agree. Their definition of 'technology' adopts the 'Design, Make, Appraise' philosophy that also characterises the approach to technology projects within the Academy of Science *Primary Investigations* course, so there is no disagreement here, but I would maintain that 'design' in the absence of knowledge and understanding is a dangerous thing. More widespread adoption of the *Primary Investigations* course in primary schools in Victoria and New South Wales would therefore go a long way towards satisfying their wishes. There is to my mind, however, one thing missing from the ATSE proposals, and that is something about the teaching of practical skills in technology, and here the tradition has always been one of apprenticeship. 'Creativity' is all very well, but it does not progress far if accompanied by technical incompetence! I would therefore like to see a renewed emphasis on practical subjects such as woodwork, metalwork, bookbinding, painting, weaving and cookery in both primary and secondary schools for the benefit of those who want to pursue careers in these directions. I never regretted the I time spent learning bookbinding and watercolour painting in primary school, or technical drawing in high school!

Most importantly, and this remark applies at all levels of education, it is almost impossible for a teacher to teach a subject with the infectious enthusiasm that is necessary for real student learning unless that teacher has a confident knowledge and understanding of the subject matter and, in the case of science and technology subjects, a mastery of the practical procedures involved. Even at primary school level this requires substantial education and training during the course of basic teacher preparation. Of course this is not all, but one has only to look at students' perceptions of teachers to be convinced of its truth.

Secondary Schools

The aims of science teaching in secondary schools, and particularly in the final two years, are two-fold. In the first place it should prepare the general student, who will go into business or law or politics, with a modest understanding of scientific principles and scientific understanding of the world around us. Secondly, however, it must attract and provide a thorough preparation in basic science for those who aim to become engineers or health professionals or agriculturalists, so that they can build upon this as they progress in their professional training. (The small number who will become scientists is also included.) The future health and prosperity of Australia depends to a large degree upon the abilities of these people.

In most states the secondary school syllabuses in science are much more closely defined than in primary schools, and the level of this prescription increases for the final two years of post-compulsory schooling. The first four years of secondary schooling attempt to cover many subjects at a rather broad and not very deep level – the Wyndham Scheme in New South Wales that added an extra year to compulsory schooling could almost be said to have added this year to the end of primary school, even though it features as the first year of high school!

From the viewpoint of science education, these four years have been in something like limbo, although there are some signs now that this may be remedied. Students who experienced the whole-school version of *Primary Investigations* find they have already gained much of the understanding that teachers try to impart at this level, and this is disappointing and even off-putting. Many teachers, too, are ill-prepared to teach science at this level because of lack of appropriate education and training, a point to which I return later.

There are also problems with some state syllabus documents for Years 7 to 10, which have been overly simplified to match either the knowledge of those writing them or perhaps their perception of the abilities of those who must teach the syllabus. A prime example from a Year 10 science syllabus prescribes 'Newton's laws of motion (qualitative only)'. It is not clear why one needs to be 'qualitative' about the fact that undisturbed bodies move with uniform speed in a straight line, or that to every action there is an equal and opposite reaction! Doubtless the prescription refers to the second law, but by eliminating quantitative thinking it destroys the very essence of science, particularly physical science. Students following such a 'qualitative only' syllabus will not come to realise that science is opposed to the sort of woolly thinking and vague generalities that characterise certain aspects of the social sciences. Certainly there is nothing really wrong with students learning about the 'big bang' and the expansion of the universe, or other equivalently general matters, at about the level of a television program, but they should learn more than that.

On the other hand, there are some good points about the new, rather general, science courses. If taught properly by a teacher who understands the basic science involved, a broad course that covers many issues of practical interest or importance provides valuable background for later life to those who study no science after the end of Year 10 and are unlikely to ever read a science book afterwards. Even so, it is difficult to present such a course without being quantitative. Some obvious 'practical' and 'socially relevant' things that should be included in the course are renewable energy (solar-electric, wind-power, etc) and also nuclear energy, but to assess these properly one needs to know some figures about energy requirements, power outputs, etc, and realistic facts rather than emotional opinions on the risks involved. Even pictorial theories such as the expansion of the universe lack real meaning unless they are somehow quantified with numbers and (dare I say it?) equations – and students must understand just where the equations come from and what they mean.

Science is, above all, about understanding, and not just the acquisition of facts. A pertinent quotation comes from the French philosopher-scientist Henri Poincaré:

> *Science is built up with facts, as a house is with stones. But a collection of facts is no more a science than a heap of stones is a house.*[5]

Equally, a house of the classical type built without stones is just an illusion, as is a science without factual backing! Let me also quote Leonardo da Vinci:

> *No human investigation can be called real science if it cannot be demonstrated mathematically.*[6]

A well-balanced science course should pay attention to all these precepts.

Upper High School

It is in the final two years of high school education that subjects become more clearly differentiated and science splits into physics, chemistry, biology and geology. I omit psychology from this list because, though some parts of it are definitely science, much fits more readily within the social sciences. The Academy of Science has had a long association with this level of high-school science, dating back to the publication of the biology text *The Web of Life* in the 1970s. Biology, of course, benefits greatly from reference to the life forms that the student sees around, and biology texts are therefore often somewhat geographically regional in nature, so that 'international' texts in anything other than basic cellular biology are at a disadvantage. *The Web of Life* was adopted so widely in Australian high schools that it became one of the country's major book publishing activities every year. CSIRO had a major input to the development of the book, and it was at a time when CSIRO Science Centres were also expanding and having increasing impact. Even a major success such as this, however, has a limited lifespan, and by the 1990s the emphasis in biology had shifted towards DNA and gene technology, resulting in the publication by the Academy of a replacement two-volume set – *Biology: The Common Threads* – in 1990.

Books were also published by the Academy dealing with chemistry and with geology at this level, though they made less impact. Physics, being a universal rather than a regional subject, was adequately served by books from overseas so that no attempt was made in this area. There were, of course, also texts published by Australian authors and some by the Science Teachers Associations in the various states. They were widely used in their areas since they were able to adhere closely to the current state syllabus requirements and structure.

The science syllabuses for some states are readily available on the internet, and it is instructive to look at them in some detail, as I have done with physics. These courses are designed for students with a real interest in the subject and, somewhat surprisingly, are split into two separate sections for Years 11 and 12. From all I had heard, I expected to find a 'dumbed down' syllabus with much concentration on description and social issues, but to my surprise the syllabuses in New South Wales and Victoria, and to a less extent in Queensland, have almost moved in the opposite direction. Certainly there are remnants of 'deconstructive' or 'postmodern' philosophy in the NSW syllabus, for example:

> *Students develop knowledge of how our understanding of energy, matter and their interrelationships is influenced by society.*

If one adopts this philosophy in a holistic manner, however, it is clear that this view itself is 'socially constructed' by a school of philosophers suffering an extreme form of what has been called 'physics envy'. It therefore has no necessary validity outside that philosophical school and so can safely be disregarded!

On the other hand, perhaps teachers are meant to take a historical view, and discuss the way in which the Catholic Church suppressed the views of Galileo that the Earth actually revolves around the sun (the Queensland Science syllabus does actually mention this), the way in which the Russian Stalinist government imposed the genetic theories of Lysenko, and the way in which religious fundamentalists today wish to suppress the teaching of evolution in schools in favour of 'creation science'. One might even discuss the 'envy' of postmodern philosophers!

Fortunately these are isolated points in the syllabus, and it certainly makes good sense for teachers to mention the historical development of scientific ideas and to stress the philosophical position that scientific theories do not pretend to be 'true' but only to be 'reliable' within defined fields. Despite quantum mechanics and relativity, Newton's laws of motion (in the form of equations) still give reliable predictions of the behaviour of physical systems provided they are not too small (atoms) or too large (galaxies) and that they move slowly compared with the speed of light.

The problems with the current syllabus are, however, rather different: some of the learning tasks are well beyond the abilities of most students (and most teachers!) at this level. Two examples are:

Analyse and interpret some of Einstein's thought experiments involving mirrors and trains and discuss the relationship between thought and reality

or

Discuss the BCS theory (of superconductivity).

It is true that, according to the syllabus, students are supposed to make use of significant equations such as Einstein's equations of Special Relativity, but will they know how these arise or what their implications are? Simply substituting some numbers in an equation is not enough to give understanding.

There are also some cases in which the writers of the syllabus have failed to consider its implications. The New South Wales physics syllabus, for example, contains the item:

> *Perform a first-hand investigation to gather information to compare the penetrating power of alpha, beta and gamma radiation in a range of materials.*

This raises real safety issues in an environment in which Bunsen burners were banished from the laboratory on the grounds that they are dangerous. But perhaps a 'first-hand investigation' only means looking the data up on the internet for yourself!

When all the options are taken into account, the NSW HSC physics course can be regarded as modern and exciting, with attention devoted to relativity theory, astrophysics, electronic circuitry, and much more. But there are several problems. In the first place, physics preparation at honours degree level is about what is required of a teacher to present these courses and answer questions about them, and I suspect that many nominal physics teachers do not possess this knowledge – I return to this point later. Secondly, the range of subjects to be treated is also so large that each will receive very little detailed attention, and the understanding imparted is likely to be very superficial. Thirdly, textbooks and equations are not everything:

> *Of making many books there is no end; and much study is a weariness of the flesh.* [7]

It is important in all branches of science to have hands-on experience in the laboratory for interest, for training and for learning. Here things seem to be lagging, although practice varies greatly from school to school. Fifty years ago the equipment even for senior-level science was simple, durable, and not particularly expensive, whereas now it is often thought necessary to have sophisticated electronics and computer control. Another problem is that the amount of hands-on laboratory work, specified as thirty-five hours in Year 12, is inadequate. Some people see a way around this using computer simulation instead of real experiments, and this often counts as 'laboratory work'. Certainly some very impressive effects can be achieved, and it is possible to change any aspect of a simulated experiment by simply typing in a new number instead of buying a new piece of equipment or even going to the moon, but I believe it is necessary for a student to have a firm grasp of reality in the laboratory, to feel things with the hands, to look through lenses, to make measurements. Without this grip on reality one can be easily misled.

A quick glance at other HSC science syllabuses suggests that they are generally much less adventurous than is the physics syllabus, though they usually do have optional courses that become much more specialised. Just how much understanding is expected of students could only be assessed by looking at exam papers, the answers given by students, and the unscaled marks awarded by examiners.

It is worth noting that Australia is not alone in facing these problems in school science education – the state of science education in Britain and the US is not very different, as is shown by a recently published forum on physics education in the UK.[8] The worldwide academic education community tends to read the same books and follow the same fashion trends.

Sciences and Social Sciences

Science and technology, it can be convincingly argued, have had more effect on the life of the average human over the last 500 years than have all the wars, political upheavals, and social reforms. Science and technology are both advancing at an increasing rate today, so that it is to be expected that they will have even more effect upon us all in the future. It would be reasonable to expect, therefore, that courses in history and the social sciences generally would devote a great deal of their attention to the history of science and its current social implications. But is this so? I fear not. The social sciences are generally completely focused on 'social' issues, and history courses, understandably, examine topics such as the politics underlying the rise and fall of the Roman Empire, but give little or no attention to the great developments in technology that occurred in that empire.

Is it too much to hope that those constructing the syllabus statements for both the sciences and the social sciences might collaborate on this matter? Social science and history teachers would, of course, need to know a good deal more about science, technology, and their history and implications than they do now, and perhaps that is too much to expect. The alternative would perhaps be to reduce the time spent in school on these subjects and expand that devoted to science, if science teachers are expected to teach a major part of history and social science as well as their own subjects. Of course, a certain amount of historical and social perspective is valuable in the teaching of science, and I would not wish to eliminate this, but it is a means to an end as far as science teaching is concerned, not an end in itself.

Computer and Information Technologies

It is reasonable that young people at school should acquire a familiarity with computer technology, since it will have such a large influence on their later lives. Those of us who have lived and worked with computers since the 1950s have a great respect for what they can now achieve, but we lack the almost superstitious worship of computers that seems to be growing everywhere now. Surprisingly, this worship of computers seems to be more strongly developed in the social sciences and even the humanities than in the 'hard' sciences such as physics and mathematics, even though these sciences make much greater use of computational techniques. There is, perhaps, a significant difference in that workers in the hard sciences use computers to actually compute things, while in the social sciences they are thought of more as sources of information – 'data mining' is a popular term.

I have always been struck by the insight that some short poetic utterances are able to convey, and in this connection I can do no better than to quote T. S. Eliot:

Where is the wisdom we have lost in knowledge?
Where is the knowledge we have lost in information?[9]

Equally appropriate is the view expressed by P. M. S. Hacker in an essay on the writings of the philosopher Ludwig Wittgenstein:

We need not fear that our machines will out-think us – though we might well fear that they will lead us to cease to think for ourselves.[10]

Being realistic, most occupations these days do require knowledge of how to operate a computer, though not of how to carry out computations. Many children learn these skills at home with little or no teaching, but they can certainly benefit from more formal instruction. The internet is also an excellent source of information, but simply knowing how to access scientific information on the web and copy it into a homework document is not science, and may impart no understanding whatever. In addition, of course, not all of the 'information' on the web, particularly that relating to controversial subjects, is correct! It is important that any education on use of web-based resources should instill in the student an appropriate level of scepticism – there are websites that can be trusted, but many that cannot.

A very good example of the productive use of the web for science education is the Academy of Science website *NOVA: Science in the News.*[11] This site provides reliable information for secondary science teachers, senior students, and the general public, on topics in science and technology that have, for one reason or another, attracted recent media attention. In addition to concise discussion of the topic concerned, NOVA also provides links to other sources of information around the world that have been examined and found to be reliable. Another Academy web-based project documents the historical development of Australian science by providing transcripts of interviews with major

Australian scientists such as Sir Mark Oliphant and also includes notable women scientists.[12] Video recordings of the original interviews are also available.

At another level, it would probably be very helpful if computer courses at school did actually teach something about computation – perhaps some of them do. Ideally a student should be able to observe a physical phenomenon, such as the collision of two billiard balls, and then be able to write a computer program to calculate the paths of the balls after the collision. Similar tasks could be devised in biology. This is real computer science and reinforces understanding of physics, mathematics, and computation!

Other Major Science Education Activities

Back in the 1980s, Dr Michael Gore, then a Senior Lecturer in physics at the Australian National University, began a project that was to have a superb outcome and to influence science teaching around Australia. This was the Questacon science centre in Canberra, designed to display and explain interesting scientific phenomena and experiments to a school audience. The Questacon initially concentrated on physics, and recruited a panel of mostly-retired 'explainers' to demonstrate the displays – mostly with interactive features – to groups of visiting school students. It was very successful and was funded to become the Questacon National Science Centre in Canberra in 1988, with the aid of a Bicentennial gift from Japan.

This immensely impressive centre has many 'hands-on' exhibits and a large team of explainers, many of them now young people studying for a Science Communication qualification at ANU. Bus-loads of school students come to Canberra to visit the Centre, and travelling exhibitions are also sent to other parts of the country. It continues to have a great influence on science learning for young people.

CSIRO also has a long history of science education activities for young people through science centres located in all capital cities. Recently a major centre, the CSIRO Discovery Centre, has been opened in Canberra. Botanic gardens around Australia also provide pleasant and informative information centres for school groups.

Another organisation that has had a huge impact on high school students is the National Science Summer Schools which have been held in Canberra for the past twenty or more years under the direction of Professor Rod Jory and with the sponsorship of Rotary, which provides funds to bring Year 11 students from round Australia to the two schools held in January each year. During the school, which covers all branches of science, students hear guest lectures and visit research facilities around Canberra such as ANU and CSIRO.

The impact on school students of a visit to one of these centres, and more particularly of participation in one of the two-week summer schools, is immense. From conversation with some of the summer school students it is also clear that they will go back to their schools, in areas remote from Canberra, carrying to their friends a message about the excitement and importance of science.

A School Syllabus for the Future

Looking forward, then, what sort of science syllabus would I like to see for schools in the future? Clearly a great deal of detailed consideration is required, and this should involve scientists as well as education professionals, but some general objectives seem clear.

At primary school level, I think that the approach and content of *Primary Investigations* is about right. It introduces children to the methods of science – observation to collect facts, ordering these facts coherently, developing an explanation, and then testing this explanation by further experiments. It also introduces various aspects of technology – armed with the understanding from scientific investigation, how do you go about designing something useful, and how do you test what you have designed?

The course demonstrates that science is based upon experiment but that the underlying explanation is the real science, and it can be put to practical use. It covers a good range of science, from astronomy to biology, and introduces practical skills in measurement, analysis and presentation.

Lower secondary level may be the last many students see of science, so the aim should be to cover a good range of topics in physics, chemistry, biology and geology that will impact on their later lives. They should understand the basics in some quantitative detail and have considerable first-hand experience with simple experiments – self-designed investigations are a good idea in moderation, but should not dominate the limited time available. To add interest, some mention of historical developments is a good idea, as also is a sketch of current science and future possibilities. Finally, the application of scientific discoveries and their impact on society should be discussed. At this level I would also like to see every student having some first-hand experience of practical technology, but this is rather a different topic.

At upper secondary level the courses have a rather different purpose, since a moderate fraction of the students should regard this as direct preparation for some sort of post-secondary specialised education involving science or technology. It is therefore important to give a thorough grounding in the less esoteric but more generally applicable branches of the subject at a good quantitative level, and in most sciences this will require a companion study in upper level mathematics. Despite this orientation, the courses should also be generally interesting and attractive and should make mention of current research interests and practical applications, and a little historical background would add perspective. They should not, however, try to cover the complete gamut of modern research at a shallow level – students should be encouraged to read books to find out about this, and perhaps to then tell their fellow students.

Teacher Preparation

It is, of course, all very well to have a good syllabus, but its impact on the students will depend very greatly upon the competence and enthusiasm of the teacher. At one time, primary school teachers were trained (not 'educated') in teachers' colleges and spent a significant part of their two years learning about the subjects they were going to teach. With the so-called 'Dawkins Reforms' of higher education in the mid-1980s, all these institutions were amalgamated with universities, or became universities in their own right, and the situation changed. Students who were going to become primary teachers spent most of their time in the education faculty and largely studied subjects relating to the history, philosophy and comparative practice of education, mixed in with some sociology and psychology. While many of these subjects are of some assistance to trainee teachers, there are some notable omissions from the curriculum dealing with the practical aspects of teaching, and particularly with the subject matter that is to be taught. Surveys of primary teacher competence and confidence show a disturbing lack of knowledge of science and of mathematics.

Statements on teacher education do, of course, recognise that, to be competent, a teacher needs to have a good command of the subject matter to be taught, though some individuals in education faculties still appear to adhere to the hoary old adage

We are not teaching (science), we are teaching children!

A policy statement by the Deans of Education certainly lists subject competence near the top in specifying competence qualities for teachers, but states simply that

It is assumed that students have a good competency in the subjects to be taught[13]

... and makes no provision to ensure that this is true – how many Bachelor of Education programs for primary teachers have compulsory courses of reasonable length in general science (physics, chemistry, biology, geology, astronomy) and mathematics (arithmetic, geometry, algebra)? Very few, I fear. Even English grammar seems to be overlooked. It might be objected that students already know these things from high school – in which case it would be informative to subject all final year BEd students to an appropriate test, set and marked by scientists rather than education lecturers, to confirm this claim. Do I have any takers among education faculties?

When it comes to secondary school teaching, the situation is rather different, and it is most encouraging to see the development of the Victorian Institute of Teaching and the corresponding organisation in New South Wales, together with the new National Institute for Quality Teaching and School Leadership which is in the process of establishment in Canberra. These organisations will, it is hoped, establish and maintain adequately high standards of professional competence for teachers. Basically these standards will require at least the equivalent of a two-year university course (a 'sub-major') in the subject being taught at secondary-school level. While it would be good to see a full three-year degree requirement, this is presumably precluded by the fact that the education faculty generally insists on a full two years of courses in education itself. A similar statement by the Australian Science Teachers Association specifies subject competence as a major requirement for a good science teacher, but actually gives more attention to attributes that apply to teachers generally, rather than specifically to science teachers.[14]

There is, of course, the problem of the significant fraction of present teachers who do not meet these requirements, and also all the teachers who are teaching a science subject different from those in which they are qualified. Physics appears to be particularly badly off in both these ways, but state education authorities decline to release figures on the actual qualifications of their teachers related to the subjects that they are teaching. Clearly a major program of qualifications upgrading is really required. Some such programs are in existence, but for the most part they deal not with upgrading qualifications in the subject being taught, but rather with more peripheral studies in education disciplines. The matter is certainly attracting some attention at Commonwealth Government level[15] but it is not clear that anything much has been done apart from easing HECS contributions for education degrees. In the Australian education system it is probably the states that must collaborate to get something done.

The Commonwealth Government, it should be recognised, actually has legislation that discriminates against the preparation of science teachers, compared with all other subjects, by imposing a higher HECS levy for science. It would be good to see a return to the old system of 'Teachers College Scholarships' in which intending high-school teachers with a sufficiently good HSC pass were awarded a fee-free place in a university plus a small but adequate living allowance to cover a full three-year or even four-year university degree plus a one-year Diploma in Education, in return for entering into a five-year bond to teach their major subject in a state high school in any part of the state. Similar places were available within the teachers' colleges for a two-year qualification in primary teaching. Reintroducing some teacher preparation scheme such as this might be a good solution.

Obviously there are many things that need to be improved before Australia can claim to have a really good teacher preparation system in the sciences. There are some moves in the right direction, but there is still a long way to go.

University Education

Over the past twenty years or so there have been many major changes that have affected Australian tertiary education. From an organisational point of view the major change was that inflicted by the 'Dawkins Reforms', under which the 'tertiary divide' between universities and colleges of advanced education (CAEs), which provided training for many professions including primary school teaching, was abolished. This provided much wider access to 'university education', simply by changing the meaning of the words! More recently, and under a different government, the universities and research organisations such as CSIRO have all been pressured into an operational philosophy dominated by financial outcomes and crude performance measures. Much could be written about the effects of these changes on the nature of universities and on the culture of Australian science generally, but here my concern is just with education.

While my own first-hand involvement with undergraduate teaching in physics ended in 1983, I have been able to observe at first hand the accomplishment levels of recent graduates, and I am of course aware of the general state of physics departments around Australia.

Physics departments in universities have two major roles relating to undergraduate teaching – nearly all of them are, of course, also concerned with post-graduates and with research. In the first place, they educate to a high level the best students in the subject who want to go on and take an honours or post-graduate qualification in physics or mathematics. From all I have heard, the academic level of these students has not declined severely as a result of the changes that have taken place in school science education. This may be partly due to their own enthusiasm for the subject and partly due to the fact that only students who have had good teachers at school consider a career based upon physics. The number of these students has declined somewhat over the years, but not too seriously.

It is in so-called 'service courses' for students concentrating on engineering, medicine, agriculture and the like that a major decline in student numbers has been experienced. My conclusion is that this has occurred, not so much because of any dissatisfaction with the physics teaching or its relevance, but simply because, by teaching a smaller amount of clearly relevant physics within their own faculties, these disciplines can gain a significant amount of basic funding for themselves under the formula by which these things are determined. The effect of this on student numbers, and therefore funding, in physics departments, and to a less extent on chemistry and mathematics, has been very bad.

Looking around the Australian university scene today, we observe that many formerly flourishing physics departments are now skeletons of their former selves, and sometime even corpses. The same is happening, though less severely, in chemistry and mathematics. Much of the decline has been caused by the reduction or elimination of service courses, and the rest by declining numbers of physics majors. There were, it is true, probably too many groups in the former CAEs that thought of themselves as physics departments when all they had done was to teach service courses at CAE level, and a reasonable concentration of both staff and students into a smaller number of institutions would probably be a good idea. In fact, this almost amounts to a return to the 'tertiary divide'. It is probably not possible to remove the title 'university' from that set of institutions specialising in subjects such as tourism, leisure studies, real-estate management and sports studies, so here too Australia has followed the US pattern, and it seems inevitable that two different classes of universities will emerge. Indeed the title of 'Research Universities' has already been adopted for the upper stratum. A worry, however, is that many of these lower-level courses may remain with the research universities, simply because they are such good money-spinners in times when the Government's 'quality audits' focus largely upon 'student throughput' and the financial 'bottom-line'.

So what will this do for science education at university level? In the long run things might well settle down to a fairly satisfactory state, provided the Federal Government recognises that there are two classes of institutions and weights the funding levels appropriately. Once this has been done, those school students, particularly in the sciences, who aim to make their career in science, engineering, medicine, or related fields, will move preferentially to the research universities and restore the balance there.

Finally, I should emphasise that science activities in universities do not end with the production of students with a bachelor's degree, though the counting of degrees granted now appears to be a major feature of the Federal Government approach to education – even the vaunted 'quality audits' tend to simply count quantity of student outputs with little or no regard to the quality of teaching or accomplishment. But for many students in the sciences or engineering, a first degree is simply a preparation for entry into an apprenticeship, either with an experienced researcher in the university or with an experienced engineer in industry. Learning, and thus education, never ends.

But let me finally give a little consideration to post-secondary education and training that is not at universities, for this is very important for a large fraction of young people. There are many who want training in particular areas of the arts, of musical performance, of business, and of information technology and who are interested in the acquisition of practical skills rather than in academic discourses. In some areas the institutes of technology provide what is desired, while for others the colleges of advanced education used to do so but no longer exist. I see a strong role for revitalising this sector, and a reinstatement of the 'tertiary divide' might accomplish this.

Conclusions

It is difficult to avoid the conclusion that science education at all levels in Australia is under threat and has been for some time. This is not a set of problems that is easy to solve. It will take a long time to overcome the lack of appropriately qualified teachers of science, and particularly in physics. Even when university teacher education courses are restructured appropriately, there are all those teachers already in the schools who need to be given adequate knowledge of the subjects that they are currently teaching.

There is a major task ahead for education authorities around Australia, and a major change of attitude required in university education faculties. It can only be hoped that they have the courage to carry out these necessary reforms.

Neville Fletcher spent twenty years as Professor of Physics at the University of New England, including terms as Dean of Science, Chairman of the Professorial Board, and Pro-Vice Chancellor. He was then Director of the Institute of Physical Sciences in CSIRO for five years and is now a Visiting Fellow at the Australian National University and an Adjunct Professor at the University of New South Wales. He is a Fellow of both the Academy of Science and the Academy of Technological Sciences and Engineering, and was chairman of the Academy of Science *Primary Investigations* project.

NOTES

1. D. Goodrum, M. Hackling and L. Rennie, *The State and Quality of Teaching and Learning of Science in Australian Schools,* Dept. of Education, Training and Youth Affairs, Canberra, 2001.

2. William Shakespeare, *Henry V,* act V, scene 2.

3. <www.science.org.au/pi/index>

4. *The Teaching of Science and Technology in Australian Primary Schools: A Cause for Concern,* Australian Academy of Technological Sciences and Engineering, Melbourne, 2002.

5. Henri Poincaré, *La Science et l'Hypothèse,* Flammarion, Paris, 1902.

6. Quoted in A. L. Mackay, *The Harvest of a Quiet Eye,* The Institute of Physics, Bristol, 1977.

7. Ecclesiastes 12:12.

8. 'New Dimensions in Education', *Physics World,* vol. 17(1): 27–41 (Jan. 2004).

9. T. S. Eliot, *The Rock,* chorus 1.

10. P. M. S. Hacker, 'Wittgenstein on human nature', in *The Great Philosophers,* R. Monk and F. Raphael (eds), Phoenix, London, 2000.

11. <www.science.org.au/nova>

12. <www.science.org.au/scientists/index>

13. *Preparing a Profession,* Australian Council of Deans of Education, 1998.

14. *Professional Standards for Highly Accomplished Teachers of Science,* Australian Science Teachers Association, Canberra, 2002.

15. Kwong Lee Dow, *Attracting and Retaining Teachers of Mathematics, Science and Technology,* Dept. of Education, Science and Training, Canberra, 2003.