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Authors' Biography

Mark Hackling, Denis Goodrum and Léonie Rennie have recently completed a national review of the status and quality of science teaching and learning in Australian schools for the Commonwealth Government. Mark Hackling and Denis Goodrum are Associate Professors of Science Education at Edith Cowan University. Léonie Rennie is a Professor of Science and Technology Education at Curtin University of Technology. Mark and Denis are currently working on a DETYA funded national professional development program for secondary science teachers. Léonie is currently working on a DETYA funded national project with ASTA to raise awareness of the nature and importance of scientific literacy.

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INTRODUCTION

This study was commissioned by the Commonwealth Department of Education, Training and Youth Affairs (DETYA) and investigated the status and quality of teaching and learning of science in Australian primary and secondary schools. This paper draws heavily on the research report by Goodrum, Hackling and Rennie (2001) published by DETYA. Goodrum et al's report on the status of science education in Australia complements the review of Australia's science capability conducted by the Chief Scientist (Batterham, 2000) and the review of Australia's capacity for innovation and commercialisation of research findings (Miles, 2000).

The research design, which is outlined more fully in Goodrum et al (2001), set out to establish two pictures: one of the ideal regarding the teaching and learning of science, the other of the reality of what is actually happening in Australian schools. Data collected from reviewing reports and research literature, analysing Australian science syllabuses and curriculum frameworks, two rounds of focus group meetings with teachers and other stakeholders, surveys of students and telephone interviews with teachers provide triangulation of perspectives and findings.

This paper will briefly outline key features of the ideal picture, discuss some aspects of the actual picture that are particularly relevant to the teaching of secondary science in the compulsory years of schooling, and then identify some issues and implications for science teachers and the profession.

THE IDEAL PICTURE

Fundamental to the ideal picture is the belief that developing scientific literacy should be the focus of science education in the compulsory years of schooling. Scientific literacy is a high priority for all citizens, helping them to be interested in and understand the world around them, to engage in the discourses of and about science, to be sceptical and questioning of claims made by others about scientific matters, to be able to identify questions, investigate and draw evidence-based conclusions, and to make informed decisions about the environment and their own health and well-being.

Based on the literature review, document analysis, work on professional standards, case studies, submissions and the first round of focus group meetings, a picture of ideal science education was drafted around a series of themes. The ideal picture is characterised by the following nine themes.

(1) The science curriculum is relevant to the needs, concerns and personal experiences of students.

(2) Teaching and learning of science is centred on inquiry. Students investigate, construct and test ideas and explanations about the natural world.

(3) Assessment serves the purpose of learning and is consistent with and complementary to good teaching.

(4) The teaching-learning environment is characterised by enjoyment, fulfilment, ownership of and engagement in learning, and mutual respect between the teacher and students.

(5) Teachers are life-long learners who are supported, nurtured and resourced to build the understandings and competencies required of contemporary best practice.

(6) Teachers of science have a recognised career path based on sound professional standards endorsed by the profession.

(7) Excellent facilities, equipment and resources support teaching and learning.

(8) Class sizes make it possible to employ a range of teaching strategies and provide opportunities for the teacher to get to know each child as a learner and give feedback to individuals.

(9) Science and science education are valued by the community, have high priority in the school curriculum, and science teaching is perceived as exciting and valuable, contributing significantly to the development of persons and to the economic and social well-being of the nation.

THE ACTUAL PICTURE

Data from previous research reports, submissions from stakeholder groups, focus group meetings, telephone surveys of 296 secondary teachers and surveys of 2802 secondary students were analysed to determine the picture of what is actually happening in school science. When all data are considered together, the emergent picture of what is happening in secondary school science is complex, however, there are a number of aspects or themes regarding the actual picture that will be considered in turn. These are: curriculum, the nature of the science being taught and the types of learning outcomes being developed; science teaching, learning and assessment practices; student participation in science; level of student achievement; factors limiting the quality of science teaching; teachers' knowledge, skills and perceptions of status; initial teacher education; and lack of national focus for science teaching and learning.

SCHOOL SCIENCE CURRICULUM

The development of Australian national curriculum and assessment frameworks for each learning area, between 1989 and 1993, has had a profound effect on science curriculums. An analysis of the science syllabuses and curriculum frameworks developed by the States and Territories following the collapse of national curriculum initiatives in 1993 reveals a number of important characteristics. Some jurisdictions adopted the national curriculum framework (Curriculum Corporation, 1994a) and assessment framework (Curriculum Corporation, 1994b) with little change whilst others have completed various stages of curriculum redevelopment and implementation. However, there remain features from the national frameworks in all new syllabuses, curriculum and assessment frameworks. These include a rationale for school science based on scientific literacy for all students, a focus on learning outcomes rather than on what should be taught, a link between outcomes and making improvements to students' existing understandings and skills so that learning is seen as progressive and developmental. The focus on content to be covered has been replaced with a focus on development of broad conceptual understandings that help students understand the world around them and become informed and responsible members of society. Concepts are broadly representative of the four conceptual strands from the national curriculum framework; *Earth and Beyond, Energy and Change, Life and Living,* and *Natural and Processed Materials.* The processes, skills and attitudes associated with the scientific endeavour, which were part of the Working Scientifically strand of the national frameworks, are currently described in the essential learnings for all students. All syllabuses and frameworks either embed these processes into the conceptual outcomes or emphasise that they should be integrated in teaching and learning. On the whole, the current science syllabuses and curriculum frameworks provide an appropriate, modern and progressive vision of the intended science curriculum.

This research reveals a gap between the intended curriculum as described in the States' and Territories' science curriculum frameworks, and the implemented curriculum. At the secondary level, in particular, science is often traditional, discipline-based and dominated by content. There is concern that, in some schools, the type of science being taught and the learning outcomes being achieved are not those that prepare students for the future world in which they will work and live. Most lower secondary students believe that the science they are taught lacks relevance to their needs and interests, and fails to develop key aspects of scientific literacy. Only about one-fifth of lower secondary students report that science lessons are relevant or useful for them, very often or almost always. About one-third of these students indicate that science never deals with things they are concerned about or helps them make decisions about their health, which raises questions about the appropriateness of the selected content and learning contexts (see Table 1).

Data from the Third International Mathematics and Science Study collected in 1994, reveal that Australian students' attitudes towards science deteriorate markedly between primary and secondary education. When responding to the item "I enjoy learning science" the frequency of disagree and strongly disagree responses increased from 22% male and 19% of female middle primary students, to 32% male and 37% of female lower secondary students (Lokan et al, 1996, 1997). Data from the 1999 repeat of the TIMSS study (Martin et al, 2001) which collected data from 13 and 14-year-olds, show that Australia was ranked 19 out of 23 countries for positive attitude towards science, which was the lowest of all English speaking countries.

Almost 40% of secondary students surveyed in this study reported that they never got excited about what they do in science and 22% indicated that they were almost always bored in science.

Teacher focus group discussions confirmed the heavy content burden at the secondary level, with teachers and students rushing superficially through content so that it is covered for the test. Forty percent of students indicate they never or only sometimes have time to think about what they are doing in science. Teacher survey data reveal that the broad content areas of biological, physical and earth sciences are all substantially represented in the curriculum.

The student questionnaire data give some small insight into the curriculum emphasis on the nature of science presented in schools. Students' responses indicate that students learn about scientists and what they do quite infrequently.

TABLE 1.

PERCEIVED RELEVANCE OF SCIENCE IN THE SECONDARY SCHOOL (n = 2802)

		% Response				
Item		Almost never	Sometimes	Often	Very often	Almost always
The science we learn at school:						
21.	Is relevant to my future.	19	36	23	13	9
22.	Is useful in every day life.	18	40	24	12	6
23.	Deals with things I am concerned about.	31	36	19	10	4
24.	Helps me make decisions about my health.	35	35	17	9	4
25.	Helps me understand environmental issues.	12	31	28	19	10

SCIENCE TEACHING, LEARNING AND ASSESSMENT PRACTICES

For many secondary students, the teaching–learning process is teacher directed and lessons are of two main types: practical activities where students follow the directions of the teacher to complete an experiment, and the chalk and talk lesson in which learning is centred on teacher explanation, copying notes and working from an expository text. The extent of teacher-centeredness is revealed by the 61% of secondary students who indicated that they copy notes from the teacher nearly every lesson; the 59% who indicated that the teacher never allows students to choose their own topics to investigate; and the 33% who are never allowed to plan and do their own experiments (Table 2).

These data are supported by the teacher interview data. Teachers themselves indicated that practical exercises and chalk and talk are common approaches to teaching secondary science. Current emphases on *Working Scientifically* and open investigations (eg, Curriculum Council, 1998; Hackling, 1998; NSW Board of Studies, 1998) that engage students in planning and conducting investigations so that they are both minds-on and hands-on, as well as learning skills at the heart of scientific literacy, have not penetrated the traditional implemented curriculums of many schools. The dominance of traditional closed laboratory exercises in the early 1990s, as reported by Staer, Goodrum and Hackling (1998), appears to be common in many secondary schools, whilst other schools have enthusiastically adopted more student-centred and investigative approaches to practical work. The student survey data also revealed that excursions, visiting speakers and computers are infrequently used approaches to learning secondary science.

TABLE 2. PRACTICAL WORK IN SECONDARY SCIENCE (n = 2802)

	% Response				
Item	Never	Once a term or less	About once a month	About once a week	Nearly every lesson
In my science class:					
5. I watch the teacher do an experiment.	10	17	32	27	14
6. We do experiments by following instructions.	3	7	20	37	33
7. We plan and do our own experiments.	33	25	22	13	7

TABLE 3. PERCENTAGES OF SECONDARY TEACHERS WHO MENTIONED VARIOUS APPROACHES TO REPORTING (n = 296)

Approach	Percent
Grades	64
Marks or percentage	22
Rank/position in class	5
Written comments	63
Criteria rated as satisfactory/unsatisfactory or as tick boxes	31
Outcomes reported in levels	8

Traditional assessment practices remain as one of the most significant barriers to educational reform in secondary schools where teachers are required to cover too much content to prepare students for 'the test'. Teachers indicate that tests are the most common form of assessment and, on average, represent 55% of the weighting of assessment. Students indicate they are required to remember lots of facts. Assignments and reports of practical work are also commonly assessed. Reporting is normally based on marks, grades or percentages in combination with comments (Table 3).

Assessment is therefore typically summative, norm-referenced and focused on content. Students indicate that quizzes are frequently used to provide feedback to students, however one-third of students indicate that their teacher never spoke to them about how they were going in science.

None of the data gathered in this study indicates that there has been a marked shift from the dominance of summative assessment methods used in secondary schools to provide information for reporting, towards greater use of formative assessments for improving teaching and learning. There does appear to have been a shift towards a more outcomes-based approach to assessment and to a much lesser extent towards reporting achievement in terms of outcome levels. Using outcome levels to locate students on a learning continuum provides a framework to guide the provision of feedback to learners. It is the provision of meaningful feedback to learners that can help them to achieve improvements in learning outcomes (Black & Wiliam, 1998; Sadler, 1989). These changes in assessment practices require significant shifts in teachers' beliefs and pedagogy, and will require considerable support in terms of resources and professional development activities.

STUDENT ACHIEVEMENT IN SCIENCE

The Third International Mathematics and Science Study, conducted in 1994, assessed students' achievement in science using fairly traditional pencil and paper tests comprising multiple-choice and short answer questions, many of which were of low cognitive level. A small sample of Australian students completed performance tests.

At the lower secondary level, only students from Singapore, the Czech Republic, Japan and Korea performed significantly better than Australian students. However, there was considerable variation in students' performances between Australian States and Territories. The performance of students from four jurisdictions was below that achieved by the top third of the 37 participating countries, and the performance of one jurisdiction was within that of the bottom third of participating countries (Lokan, Ford & Greenwood, 1996). The limited data from the TIMSS performance tasks, in which students completed experimental work, adds to these concerns about the standards in lower secondary science learning outcomes. On two of five tasks, the performance of Australian students was ranked eighth out of 12 countries (Harmon et al, 1997). The TIMSS study was repeated in 1999, collecting data about 13 and 14-year-olds' science achievement (Martin et al, 2001). Based on these assessments, Australia was ranked 7/38 and was ranked highest of the English speaking countries. It should be noted that many of the countries that ranked higher than Australia on achievement are our Asian neighbours who compete with us in trade and commerce.

It is important to emphasise that the traditional, low cognitive level, norm-referenced measures of achievement used by TIMSS do not provide information about students' levels of understandings, skills and competencies benchmarked against absolute standards. To adequately monitor performance within Australia to see the impact of changing curriculums and levels of resourcing, it is necessary to collect standards-referenced data linked to science learning outcomes that contribute to the scientific literacy of citizens. The OECD/PISA (1999) study will collect data that are more informative about the scientific literacy of Australian students than the TIMSS series of assessments.

STUDENT PARTICIPATION IN SCIENCE

Secondary teachers, in the telephone survey, indicated that on average, across jurisdictions, science is taught for 200 minutes per week in the compulsory years of secondary schooling. The variation in modal science teaching times between jurisdictions was extraordinary, ranging from a high of 240 minutes per week in one State to a low of 150 minutes in another State. Time on task has long been recognised as a significant variable influencing learning, and this was borne out in the relative performance of these two States on the TIMSS science tests (Lokan et al, 1996). The State providing 240 minutes of science per week was at the top of the TIMSS state rankings and the State providing only 150 minutes of science per week was at the bottom of the state rankings.

There has been concern for some years that fewer students are studying science in the non-compulsory years of secondary schooling. Professors John Dekkers and John De Laeter have systematically compiled the relevant official data from State and Territory Boards of Study for the past 18 years. They have published a series of papers (eg, Dekkers & De Laeter, 1997, 2001) chronicling changing enrolment patterns in science, which includes the diversification of subject offerings beyond the traditional discipline-based Public Examination Subjects (PESs) to include Alternative PESs and School Assessed Subjects in the 1980s. Teachers surveyed by telephone estimated that on average, across jurisdictions, 32% of upper secondary students study no science. Our analyses of the data kindly provided to us by Dekkers and De Laeter indicate that between 1980 and 1998 the Year 12 cohort has increased in size by 99%; however, science subject enrolments have only increased by 31%. There is now a lower percentage of the cohort taking traditional discipline-based public examination subjects than in 1980. Indeed, in 1980 students enrolled in an average of 1.3 science subjects but by 1998 this had reduced to an average of 0.86.

A number of factors are likely to be impacting negatively on upper secondary students' science enrolments. These may include negative experiences of science in the lower secondary years, changing requirements for matriculation and admission to university courses and the widening range of abilities and interests represented in the 1998 Year 12 cohort compared to 1980. Schools will need to carefully evaluate the science education needs of upper secondary students and ensure that an appropriate range of science subject choices is available for these students.

On a positive note, the differential rates of enrolment in Biology, Chemistry, Physics and Geology by male and female students has been reduced so that under-representation of males in Biology and the under-representation of females in Chemistry, Physics and Geology have been reduced.

TEACHERS' PERCEPTION OF THE FACTORS LIMITING THE QUALITY OF SCHOOL SCIENCE

In the telephone interviews, teachers were asked to identify the factors that limited the quality of science teaching in their schools. The percentages of teachers mentioning each factor are listed in Table 4. The factors most frequently mentioned by secondary teachers were inadequate resources and budget, insufficient time for preparation, collaboration and reflection, and large class sizes.

RESOURCES AVAILABLE TO SUPPORT SCIENCE TEACHING

There is considerable variation in access to resources amongst schools in terms of availability of teachers with specialist knowledge of science, teaching space, science consumables, equipment, curriculum resources and information technology. Teacher focus group and telephone survey data clearly indicate that resource limitations are a significant constraint on the quality of teaching and learning.

CURRICULUM RESOURCES

Curriculum resources provide materials and dictate approaches for implementing syllabuses and curriculum frameworks. Whilst we have modern and innovative curriculum frameworks many of the curriculum resources are traditional in approach thus constraining the implemented curriculum. Secondary teachers' responses to the telephone survey indicate that the use of textbooks supplemented by school-developed curriculum materials is the almost universal approach to curriculum implementation. The concern here is that many of these texts embody traditional pedagogy, content and contexts, limiting teachers' ability to implement curriculum frameworks as intended by their writers. To implement outcomes-based approaches to teaching, learning and assessment, teachers must reconstruct existing curriculum and assessment resources, a task for which teachers lack preparation time and the sophisticated curriculum development skills that are needed to produce quality materials.

TABLE 4. FACTORS LIMITING THE QUALITY OF SECONDARY SCIENCE TEACHING (N = 296)

Factor	Percent
Resources:	
Inadequate resources	24
Inadequate science budget	19
Poor access to a laboratory for teaching science	13
Inadequate equipment	12
Poor access to computers	9
School and Syllabus Constraints:	
Class size is too large	19
Student Factors:	
Poor student behaviour, attitude or welfare problems	16
Teacher Factors:	
Teachers have inadequate time for preparation, reflection and collaboration	21
Teachers lack the knowledge and skills to teach science or there is a lack of professional development	15
There is inadequate time for teaching science and/or too much content to cover in the available time	8

SCIENCE BUDGETS, CONSUMABLES, EQUIPMENT AND FACILITIES

Focus group meetings and teacher telephone surveys revealed that limitations in science budgets, consumables, equipment and facilities are a significant constraint on the quality of science teaching. A quarter of secondary teachers surveyed indicated that inadequate resources were a major limiting factor inadequate science budget (19%), poor access to laboratories (13%), inadequate equipment (12%) and poor access to computers (9%) were other limiting factors cited by teachers.

TEACHER STATUS AND ONGOING PROFESSIONAL GROWTH OF TEACHERS

The education systems are experiencing constant change, reflecting changes in society. Most teachers are open to changes that they believe will benefit students. However, many teachers lack the time, resources and professional development opportunities for change to be a positive period of personal growth, rather it becomes a time of stress and feelings of inadequacy. Teachers need support to maintain an ongoing commitment to personal professional development. One of the focus group teachers explained, "There is an attitude that once trained, the teacher has the skills and knowledge to cope. There is no nurturing of teachers or encouragement of life-long learning."

Most teachers feel they have low status. As one focus group teacher explained:

> *The profession itself believes that it is underpaid for what it does. Many teachers would not encourage their students to become teachers. There may be various reasons for this: poor pay, low morale, little public recognition, work imposing itself on family life, preparation, school sport and increased administrative duties.*

Many teachers feel undervalued, under-resourced and overloaded with non-teaching duties. This was a consistent theme emerging from the focus group meetings. One of the most startling aspects of the 1994 TIMSS data was the proportion of Australian teachers who indicated that they would prefer to change career. Forty-five percent of Australian primary and 50% of Australian secondary teachers sampled indicated they would like to change career and get out of teaching. Both of these figures were the worst of all participating countries, except for New Zealand (Lokan et al, 1996; 1997). There has been devolution of policy and administrative tasks from the system to schools and from the school administration to teachers. Teachers report that they do not have sufficient time for core professional responsibilities such as preparation of teaching materials and lessons.

Limited professional or monetary recognition is given to teachers who upgrade their knowledge and skills through professional development or further studies. In the last few years there has been an abrupt decline in the number of teachers upgrading their professional knowledge and skills through coursework master degrees as a consequence of policy decisions made in 1989 by the Federal Government and universities to make students pay up-front fees for coursework master degrees rather than having access to a no interest loan scheme.

The ongoing professional growth of teachers needs to be supported by a framework of professional standards for certification, registration following a period of induction and mentoring, and to recognise and reward teachers with advanced levels of professional knowledge and skills. Fortunately the profession itself has accepted the responsibility for providing strong leadership in this area and has initiated the development of professional standards for science teaching (Ingvarson & Wright, 1999).

As the international research demonstrates (eg, Darling-Hammond, 2000) and the daily experience of students and parents confirms, there is a significant relationship between the quality of teachers and the quality of student learning outcomes. However, the profession is in urgent need of renewal as there is an ageing population of teachers and fewer outstanding people entering the profession. In the telephone survey, a large number of teachers indicated that there is a need to upgrade existing teachers' skills, and attract more, younger and better teachers into the profession if science education is to be revitalised.

INITIAL TEACHER EDUCATION

Initial teacher education is under-resourced and close to crisis. There has been a progressive running down of funding and staffing within university education faculties (Dobson & Calderon, 1999) to the point that a great deal of teaching fails to model best professional practice. Reduced budgets and staffing levels have forced education faculties to reduce the hours of class contact provided to students, adopt low cost, mass lecture and tutorial methods which are failing to produce the much higher standards of professional knowledge and skills, and capacity for educational leadership, that are required by modern innovative schools. Research in Australia and the United Kingdom (Dillon et al, 2000; Osborne & Simon, 1996; Yates & Goodrum, 1990) indicates that primary teachers are emerging from initial teacher education programs lacking confidence in their knowledge of science and competence to teach science. Student survey data collected in this study indicate that many secondary science teachers lack the knowledge and skills to use relevant content and contexts, and teaching-learning strategies that effectively engage students in learning science that deals with their interests, needs and concerns.

Currently there are few effective incentives being employed to attract school leavers into teacher education. The prospect of completing a minimum four-year teacher education program and attracting a high fees debt for science-based courses to ultimately emerge into a profession with low community standing and relatively poor remuneration places limits on the number and calibre of students prepared to commit themselves to teaching. However, the current age profile of the secondary teacher population indicates that the impact of retirements over the next few years will be greater for secondary science teaching than for any other professional occupation (ACDE, 2000). The combination of these two factors points to an impending crisis in teacher supply relative to demand.

If the quality and number of graduate teachers of science are to be improved, there needs to be greater investment in teacher education and appropriate incentives to attract young people into teacher education programs.

NATIONAL FOCUS ON SCHOOL SCIENCE EDUCATION

While there is some cooperation between stakeholders in science education, there is no strong national focus. There is a spirit of cooperation between the Australian Science Teachers Association, the Australian Academy of Science, university science educators and system science curriculum officers who share a commitment to working together to improve science education in Australia. However, there is a lack of national focus in science education, with States and Territories having developed their own syllabuses and curriculum frameworks and embarking on few collaborative innovations that have the potential to develop world class curriculum resources or professional development programs. On-line technology provides a delivery mechanism that now makes possible the national dissemination of resource materials for science education.

CLOSING THE GAP BETWEEN THE ACTUAL AND THE IDEAL

The curriculum statements in the Australian States and Territories generally provide a framework for a contemporary and well-structured science curriculum, with a focus on developing scientific literacy and continuous development of students towards achieving the stated outcomes. However, the actual curriculum implemented in most schools is different from the intended curriculum. For many secondary students, the science they are taught is neither relevant nor interesting. Traditional chalk-and-talk teaching, copying notes, and cookbook practical lessons offer little challenge or excitement to students. Disenchantment with science is reflected in the decline in science subjects taken by students in upper secondary school. When students move from primary to secondary schools many experience disappointment, and it is here that students' interests wane markedly. Science at school is engaging and challenging when it connects with students' contemporary interests and experiences, but often this is not the case. Our findings agree with Osborne and Collins' (2000) assertion that a vital component of any science course is to allow

> *exploration of aspects of contemporary science … such an element is essential to providing a connecting thread between school science and the 'real' world of adults, endowing the subject with a relevance that no other mechanism can. Whilst pupils will accept a curriculum diet that consists largely of the received wisdom of uncontested and pre-established knowledge, contemporary science offers a glimpse into the world of here and now, not the world of yesteryear. This is a world of science-in-the-making, of future possibility and uncertainty where their views can begin to matter, providing an essential dose of salience and significance. (pp 191–192)*

Considerable effort is required to assist teachers to replace traditional content with relevant, contemporary material.

Closing the content gap is only part of the solution however; the teaching and learning must also change. Australia's *first* National goal of schooling states that "when students leave school they have the capacity for, and skills in, analysis and problem solving, and the ability to communicate ideas and information, to plan and organise activities and to collaborate with others" (MCEETYA, 1999). Traditional teaching methods that emphasise learning as comprehension and factual recall cannot contribute to this goal. Teaching for scientific literacy requires an approach that is more student-centred and inquiry-based. Students need opportunities to plan and carryout worthwhile, extended and meaningful investigations through which they can develop understanding of science and scientific ways of thinking. Engaging in relevant and meaningful science is enriching for students, including those who may wish to pursue a scientific career, and this approach is likely to increase the number of students who consider scientific or technological vocations.

When introducing science that promotes the development of scientific literacy one would expect to see changes to teaching and learning strategies in our classrooms. These changes should not be seen in terms of what is right and what is wrong but rather in terms of emphasis. An approach to teaching and learning science that provides opportunities for the development of scientific literacy would encompass the changes in emphasis described in Figure 1. Clearly, some of these changes in emphasis will require significant and sometimes fundamental changes in teachers' practices, and their beliefs; it is not a simple matter of 'fine tuning'.

TEACHERS ARE THE KEY TO CHANGE

Teacher change is the basis of educational innovation, reform and improvement. The research findings presented in this report emphasise repeatedly that the most important factor in improving learning is the teacher. Efforts to close the gap must focus on helping teachers recognise the gap between students' real needs in science and what is offered in the actual curriculum. Teachers also need support to develop the understandings and skills needed to make the changes possible. Leadership in schools and systems is also important, but it must be balanced by teacher input. Research has continually shown that imposed change without teacher engagement and ownership of the change brings little effective improvement in the longer term. The power for improvement lies in the collegial efforts of teachers and their profession.

CHANGE TAKES TIME AND RESOURCES

Changes to teachers' professional practice involve significant shifts in beliefs and professional knowledge, and consequently, take considerable time, resources and effort. A teaching style that emphasises an inquiry-oriented, student-centred, outcomes-focused approach requires more sophisticated teaching skills than those associated with traditional didactic methods. To do this with large classes, poor resources and potentially disruptive

FIGURE 1.

Changes in emphasis required to teach for scientific literacy. (This format and some parts of the figure are derived from the *National Science Education Standards*, National Science Council, 1996, pp 52, 100, 113.)

Teaching for scientific literacy requires:

Less emphasis on	*More emphasis on*
memorising the name and definitions of scientific terms	learning broader concepts than can be applied in new situations
covering many science topics	studying a few fundamental concepts
theoretical, abstract topics	content that is meaningful to the student's experience and interest
presenting science by talk, text and demonstration	guiding students in active and extended student inquiry
asking for recitation of acquired knowledge	providing opportunities for scientific discussion among students
individuals completing routine assignments	groups working cooperatively to investigate problems or issues
activities that demonstrate and verify science content	open-ended activities that investigate relevant science questions
providing answers to teacher's questions about content	communicating the findings of student investigations
science being interesting for only some students	science being interesting for all students
assessing what is easily measured	assessing learning outcomes that are most valued
assessing recall of scientific terms and facts	assessing understanding and its application to new situations, and skills of investigation, data analysis and communication
end-of-topic multiple-choice tests for grading and reporting	ongoing assessment of work and the provision of feedback that assists learning
learning science mainly from textbooks provided to students	learning science actively by seeking understanding from multiple sources of information, including books, Internet, media reports, discussion, and hands-on investigations

students presents problems that many teachers find too difficult to overcome. It is easier to maintain the status quo. If change is to occur, there is a need to develop realistic curriculum and professional development resources that show teachers how to translate the intended curriculum into classroom action and to demonstrate that an outcomes-focused curriculum can really work and benefit students.

COLLABORATION IS ESSENTIAL FOR QUALITY

Teachers working alone in their classroom can make small steps towards change. Teachers working together can make larger strides. Schools collaborating make a greater impact still. But quality science education curriculum and professional development resources are very expensive and require the very best expertise to develop. Collaborative ventures that pool the financial and human resources from a number of jurisdictions have the potential to produce the world-class materials that are required for a contemporary, relevant and engaging science education for all students.

CONCLUSIONS

The actual picture of science teaching and learning in Australian schools is one of great variability but, on average, the picture is disappointing. Although the States and Territories' curriculum statements generally provide a framework for a science curriculum focused on developing scientific literacy and helping students progress toward achieving the stated outcomes, the actual curriculum implemented in most schools is different from the intended curriculum. When students move from primary to high school, many experience disappointment, because the science they are taught is rarely relevant and engaging and does not connect with their interests and experiences. Traditional chalk-and-talk teaching, copying notes, and 'cookbook' practical lessons offer little challenge or excitement for students. Disenchantment with science is reflected in the declining numbers of students who take science subjects in the post-compulsory years of schooling.

Many science teachers feel undervalued, under-resourced and overloaded with non-teaching duties. Education systems are experiencing constant change as they attempt to respond to the changing needs of society. Many teachers lack the resources and professional development support needed for this time of change to be a period of personal growth; rather, it becomes a time of stress and feelings of inadequacy. It is, therefore, not surprising that up to half of our teachers of science would like a career change out of teaching.

Despite a spirit of cooperation among States and Territories, there is wasteful duplication of effort in preparing curriculum resources and resources for the professional development of teachers. University science teacher education is under-resourced and close to crisis, with faculty staffing profiles much smaller and older than 10 years ago. The profile of science teachers is also aging, with expected shortages in the near future due to retirements and the recruitment of younger teachers by overseas countries.

Reform of science education in Australia must focus on attracting capable young people into the teaching profession, supporting teachers to develop teaching, learning and assessment practices that engage students and enhance students' development of scientific literacy, and national collaboration in the development of world-class curriculum resources.

As we commence the third millennium, a greater priority must be given to building the scientific literacy of our people if Australia is to experience social and economic well being. At this time, the greatest priority is to improve the quality of school science in the compulsory years of secondary schooling so that **all** students can experience a science education that will make a difference in their lives, and attract our best young minds into science research and careers to make Australian industry internationally competitive.

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