REDESIGNING SCIENCE TEACHER EDUCATION TO REFLECT THE NATURE OF CONTEMPORARY SCIENCE

Abstract

Evidence that many students are not being captivated by school science has led to advocacy of revising the science curriculum. However, there need to be accompanying changes in science teacher education. This study is designed to lay foundations for innovation in the pre-service education of secondary science teachers, involving a reconceptualisation of the nature of contemporary science and a course structure that links science teaching with broader science public reform initiatives. We held a series of Focus Groups, built around Government Research Priority areas, which brought together people from industry, government, research organisations, and community groups involved in science and its applications. In the groups the participants discussed how science currently operates in their area, ways in which the area will develop in the coming decade, and what implications there are for the nation and its citizens and for science education. What emerged was a concern for public responses to science at a range of levels, and a very different view of science practice and community involvement with science to that represented in current university and school science courses. This was confirmed in interviews with science graduates working in disparate fields, and also focus groups of school students. The paper will report on the insights generated, and explore the implications for redesigning the pre-service education of science teachers.

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Objectives and significance

It is generally recognised that in many countries school science is in difficulty. One indicator is that there are fewer students enrolling in post compulsory science courses. There is more direct evidence of the failure of school science to capture the interest of students. In a recent review of international research, including some from Australia, Lyons (2005) claims that students perceive science as a subject where knowledge content is transmitted to passive recipients, where the content is irrelevant, decontextualised, boring, and difficult.

To respond to such a situation requires radical surgery performed on the school science curriculum. But that alone will not be sufficient. There needs to be significant innovation in the education of teachers of science. While teacher educators traditionally contribute to discussion and activity related to the curriculum, we argue that their greatest contribution to improving the situation is through innovation in teacher education.

Lawrance and Palmer (2003), in a study of the preparation of teachers for the challenge of teaching science, mathematics and technology in the 21st century, present a picture of heroic activity by a few committed individuals rather than significant national or even institutional response to a crisis in science education. Yet all the evidence suggests there is a crisis in science education the solution to which is likely to require innovative approaches to science teacher education at the program level. The report of an enquiry into teaching and teacher education (Committee for the Review of Teaching and Teacher Education, 2003) points to the decreasing proportion of teacher education students with the intention of teaching science and mathematics. The challenge presented in that report is to create a program which will attract quality science students into teacher education.

This paper will describe a study undertaken at Deakin University, Australia, aimed at developing an innovative program for the pre-service education of secondary school science teachers.

Theoretical background

In the science education literature there are a number of intersecting foci relevant to this study, concerning the purposes of school science, the content of the curriculum, teacher pedagogies required to address new content and approaches, the relationship between the way teachers are educated and the way they teach, and innovations in pre-service science teacher education. Indicative studies are described below.

A number of authors (de Boer, 2000; Symington & Tytler, 2004) have revisited the question of the purposes of school science. Their findings highlight the need to reconsider the curriculum in the light of the changing world in which tomorrow's students will find themselves. Further argument for reconsideration of the curriculum comes from studies such as that of Duggan and Gott (2002) who investigated the science required by employees in a number of science based industries and by people in everyday life, and Tytler, Duggan and Gott (2002) who investigated the science needed by the public to understand and pursue an environmental dispute. Emerging from such studies is the necessity for students to understand the way contemporary science operates and to develop the ability to analyse science based issues as they confront these in their lives. This includes developing an understanding of the way evidence is gathered and used in science, and its limitations.

It is recognised that a significant change in curriculum designed to address contemporary issues will make new demands on teachers. For example, a number of authors (eg. Brice & Gray, 2004; Oulton., Dillon, & Grace, 2004; Sadler, 2004) have been exploring pedagogies which will enable teachers and students to engage in science classes with controversial issues such as the development and use of genetically modified organisms or ways of responding to climate change. Other researchers (see Linn, 2003; Hee-Sun Lee & Songer, 2003) have been studying the use of modeling in school programs, reflecting the important role that modeling plays in contemporary science. It is clear from such work that science teachers will need a greater repertoire of strategies if they are to engage students in issues associated with the development and use of modern science.

Where are they to learn such strategies? Pre-service teacher education programs are one obvious starting place. Pre-service programs for secondary school teachers normally comprises two parts, one in which the students study science and a second in which the students are prepared for teaching. Most often these two parts are treated quite separately, usually within separate faculties, with the assumption that it will be in the education studies that the students will develop their repertoire of teaching strategies (see Lawrance & Palmer (2003).

Yet research (Veal, 2004; Adamson et al, 2003) suggests that the students are likely to base their own teaching of science on the way they themselves have learnt science. This means that attention needs to be given to the way in which the prospective teachers themselves are taught science. The literature (eg. Pedrosa de Jesus & Watts, 2003; Harper, Etkina, & Lin, 2003; Kelly, Chen & Prothero, 2000) provides useful insights into strategies that are being successfully employed in the teaching of science at tertiary level which provide appropriate models for those preparing to become teachers.

In summary, the literature presents a picture in which science educators are seeking ways to make science more relevant and interesting to students. There are a number of established reference points including the way in which contemporary science operates and the social and ethical considerations which are presented by developments in science. It is clearly recognised that the necessary changes will not only relate to the content of the curriculum but also to the way in which science is taught. This suggests an important role for those involved in teacher education. It is within this context that the study to be reported here was conceived and executed.

Design and procedure

This study concerns the development of an innovative program for the pre-service education of secondary school science teachers. It was decided, as a first step in this process, to address the issue of contemporary relevance since this was a key reason for student dissatisfaction with science curricula. We determined to explore with people in the community involved with contemporary science, how science is operating within their experience, what they see as the key future issues in their particular domain, and how science is impacting on the lives of individuals and communities.

The data was gathered by means of a series of focus group discussions around significant science based issues of contemporary relevance. The use of focus groups, rather than interviews with individuals, was seen to increase the number of people whose ideas could be explored, and allowed the possibility for a consensus to emerge, or at least for the testing of different perspectives against each other. To identify 'big issues' that might inform science education we worked from a list of Australia's research priority areas, choosing one or two areas from each of the four major categories:

- An environmentally sustainable Australia: *Water – a critical resource* and *Responding to climate change and variability*
- Promoting and maintaining good health: *Preventative healthcare*
- Frontier technologies for building and transforming Australian industry: *Frontier technologies* and *Advanced materials*
- Safeguarding Australia: *Protecting Australia from diseases and pests*

The focus groups dealt with six of a total of twenty areas and represented a variety of emphases, dealing with economic, personal, and public sustainability issues, and intersecting to various extents with contemporary technologies. The decision to sample six areas was not made from the outset, but having completed these six we felt confident that there would be diminishing returns from conducting further Focus Group discussions, since our analyses were beginning to confirm previous insights rather than open up new ones.

For each Focus Group we identified a person who was a key player in the area and asked that person to suggest who should be invited to participate and to act as host for the Focus Group. There was discussion in each case about the type of people to be included and in some cases the researchers added names to the list to broaden the representation. Our criteria for who might be included were based on our wish to identify big picture issues rather than to focus on details of science knowledge and skills, and to allow the possibility of stepping outside the prevailing orthodoxy concerning what counts as science and how it should be transmitted. This process had the advantage that the project team was not primarily responsible for selecting appropriate participants in areas where they have no expertise. A disadvantage was that there was significant variation in group membership. Almost all of the participants had science qualifications and expertise in the topic addressed and had responsibility for the application of science to particular community activities.

A set of questions (Table 1) were designed as a framework to lead the discussion through a series of foci; the major future issues related to science, the implications of this for public knowledge and perspectives, and lastly what this implies for science education.

Table 1

Questions used as the framework for the focus group discussions

1. In what way will your industry / community of interest develop over the next 10 years?
2. What are the issues for Australia and its citizens arising from these developments?
3. What are the skills and understandings that potential workers will need to be able to contribute effectively to the industry / community of interest in the future?
4. What are the skills and understandings that you would like Australian citizens to have to contribute to a climate which will allow your industry / community of interest to develop productively?
5. From the perspective of your industry / community of interest, what are the skills and understandings that the average citizen should have to be able to operate effectively in the future?
6. What are the implications of all of these considerations for schooling?

A sound recording was made of each of the discussions, and used to prepare a report which was circulated for comment to the group participants. The reports set out the key ideas emerging from the discussion and a Researchers' Comment section. In the Researchers' Comment the team indicated their response to the ideas generated in the forum discussion and identified ideas which they believed require further exploration. The responses of the Focus Group participants were incorporated as appropriate into the document and circulated to participants again if necessary. The status of the final document for each Focus Group is that it is agreed as a valid record of the meeting. It could not be claimed to represent an agreed position by the group members or to fully reflect the views of all of the participants.

Each of the key researchers (authors) independently analysed the Focus Group reports seeking common themes emerging from them. These analyses were then shared and a common understanding developed through discussion. Significant common themes emerged, but there were different meanings attached to the themes in each of the groups as will emerge in the findings section

This variability is not surprising as the Focus Groups differed from one another in a number of respects. First, there was significant variation in the extent to which the field impacts directly on all citizens. For example, *Responding to climate change and variability* and *Water – a critical resource* are topics where it can be expected that all citizens will be aware to some extent of the issues and expect community action to impact directly on their lives. In some of the other topics the public are less aware of the possible impact upon themselves and their communities. For example, many citizens are unlikely to recognize a community role in the advancement of fields such as *Advanced materials* or *Frontier technologies*.

Second, the composition of the Focus Groups was decided jointly by the researchers and the host for that group and by the availability of invitees. Thus there was considerable variation in the composition of the groups. For example, in the *Water – a critical resource* group the majority of participants are employed by public bodies whilst in the *Frontier technologies* group about half are employed in private enterprise. Table 2 shows the composition of two of these two Groups to illustrate this variation.

Table 3

Composition of two of the Focus Groups

Water – A critical resource	**Frontier technologies**
Technical director of water industry association	New technologies manager in instrument company
University lecturer who consults to the water industry	Program director, Bio Micro Nano Technology in consulting company
Education manager for rural water authority	Director of technology company
Strategic manager for urban water supply authority	Instrument and designer expert in technology company
Strategic water services planner for urban water authority	Manager for new manufacturing in university
Manager in Department of Sustainability and Environment	Professor of Nanotechnology
Cleaner production consultant for urban water authority	Social scientist investigating public response to nanotechnology
Engineering manager for rural water authority	Manager of major scientific infrastructure program in Department of Industry, Infrastructure and Rural Development
Research scientist in water treatment area	Scientific and commercial director of organisation for the commercialisation of nanotechnology
Science co-ordinator in Department of Sustainability and Environment	Manager of a technology company
Manager in Environment Protection Agency	

Finally, although there was an agreed framework for the discussion, the predetermined questions were not strictly followed, and groups were allowed to explore the issues of greatest interest to them while keeping the overall purpose in mind.

Findings and Implications

While recognising these qualifications and the impact they have on the interpretation of the data, it is claimed that these focus groups, based as they are around Australia's research priority areas, represent a significant voice of science in relation to contemporary society. As such, they are an authoritative voice to speak to science education in schools and universities, if we are to pursue a version of science that is relevant to people's lives, to community interest and concern and to the future of the country. Overall, they paint a different view of the practice of science to that represented in most school science curricula, and in university science courses. Three broad categories of themes emerged: the relation of science to the public, expectations of citizens, the nature of science and expectations of scientists, and views regarding science education.

<u>The relation of science to the public</u>

There were compelling arguments for the importance of science to the country's future, in so many ways. Concern with public understanding of, and response to, science and to the particular issues was universal. This took various forms from a concern with personal responses to science and decision making to government policy making. The concerns were of two broad types:

- The need to develop a culture of innovation and willingness to engage with new technologies. For example:

  > The public must be engaged with science if we are to implement technologies which can save humanity and the planet (*Protecting Australia from invasive pests and diseases)*
  >
  > There is a lack of awareness at community level with the consequent danger of the nation being left behind in manufacturing (*Advanced materials)*
  >
  > There are many opportunities for new science-based technologies and we need the attitude and the dream to be able to grasp some of these (*Frontier technologies)*

- The need to develop a better understanding of science and technology to promote reasoned debate concerning impacts on individuals and communities. For example:

  > It is imperative that individuals understand what the changes will mean for their area and what the impact will be (*Responding to climate change and variability)*
  >
  > Community attitudes are important as professionals will not recommend the use of technologies if there is likely to be community concern with the outcomes (*Water – a critical resource*)

There was a variety of reasons proposed for lack of public engagement with and understanding of science. First, it was acknowledged that it is not always easy for the issues to be understood and conveyed simply to the public. For example, in the *Water –a critical resource* group it was pointed out that often decisions about water usage involve both social engineering, economic and energy considerations. Second, there is a mistrust of science and technology amongst many members of the public that did not exist in earlier times, and it was suggested that the media contribute to this by lack of balance in reporting. Finally, some groups proposed that lack of political leadership was an issue influencing public opinion. The *Advanced materials* group suggested "there is no national focus which brings science to the forefront”, and the *Climate change* group suggested that government policy directions had tended to promote critical perspectives on the reality of climate change rather than provide leadership on this issue.

Participants proposed a number of ways in which the issues needed to be addressed: through public policy and promotion, through formal programs in school and university and through a more enlightened media. For example, in the *Advanced materials* group it was suggested that scientists need to be able to enter the public debate about contentious issues which have a scientific basis.

<u>Expectations of citizens</u>

All of the Groups discussed what understandings and skills would enable citizens to operate effectively in the coming decades. In this context effectiveness is referring to both their role as individuals coping with innovation in an increasingly scientific and technological society, and as enlightened citizens in a democratic society.

By far the most commonly promoted view was that the critical attribute needed by citizens was that of analytical thinking, to enable critical appraisal of information and policy, and contribution to democratic processes. This was raised in nearly all of the groups. For example, in the *Water – a critical resource* group it was suggested that “a certain level of information is necessary before people know the sort of questions that they should be asking. Further there is a need for citizens to have highly developed analytical skills to enable them to understand and contribute to addressing water issues”. In the *Preventative healthcare* group it was proposed that what is needed is “a community which does not accept the status quo but will challenge and enquire. Critical thinking is a crucial element in the operation of an effective democracy”.

Various aspects of knowledge of science and how it operates were raised in all groups. Mention was made of understanding specific ideas, such as uncertainty, understanding how scientists work, understanding the impact of science on people’s lives, and knowing who to trust in relation to the science behind controversial issues. There was little mention of specific conceptual areas.

<u>The nature of science and expectations of scientists</u>

The greatest degree of commonality across the Focus Groups related to the nature of science as it is practised, and the implications for those who work as scientists.

The view of science that emerged was one where:

- Science is constantly evolving. In the *Responding to climate change and variability* group it was noted that ‘science knowledge grows rapidly and so it is important that science graduates are committed to life-long learning and have the skills to be life-long learners’.
- Science is practised in multidisciplinary teams. In the *Preventative healthcare* group it was observed that ‘there is a blurring in the boundaries between the traditional sciences. It is inappropriate to prepare people in the traditional way when the workplace requires people to work across the discipline boundaries’.
- All major areas of science are bound up with social and ethical issues and hence public policy. Science is never seen as providing all the answers for public or personal decision making. In the *Responding to climate change and variability* group it was noted that ‘It is inappropriate for scientists to be trained only in a narrow specialization. While expert knowledge is required, it is important that scientists understand the social context and ethical climate in which they work’.

- Science and technology are inextricably linked. In the *Protecting Australia from invasive pests and diseases* group it was stated that ‘emerging technologies are having a significant impact on the way in which science is being done. There will be increasing focus on systems which allow the manipulation of large amounts of data’.
- Science often deals with complex systems which involve system level thinking, and balancing of interconnected effects when framing policy direction (such as the economic, social, energy and environmental implications of climate change, or deciding the balance of interests in dealing with water policy, or attending to features of uncertainty and risk analysis in providing the science on which health policy is based).

In the light of this scientists were seen to need an ability to communicate effectively to multiple audiences, to be able to work in multidisciplinary teams, to have well developed analytical thinking skills, to understand the social and ethical context in which they work; and to need the desire and ability to be lifelong learners. In a follow up study briefly reported below, interviews with science graduates working in disparate fields broadly confirmed these assertions.

In none of the groups was there specific discussion of the requirement for scientists to have particular knowledge. This does not mean that such expertise is unimportant. The issue was not pursued by the researchers and its significance was most likely assumed by the group participants.

<u>Views regarding science education</u>

The Focus Group participants were invited for their expertise in their field and no assumption was made about their knowledge or experience with education. However, it was found that they had a great deal to say about science education. There were frequent expressions of concern that at present school science represented an outdated and discipline-bound view of science. All groups argued that a primary focus on developing knowledge structures was misconceived. There was no suggestion that the main focus of school science should be to select future scientists. Rather, there was an overriding concern with future public attitudes and a community climate that was science friendly, as the best way forward. There was general agreement that the focus of school science should be to capture students’ interest in science and engage them in science such that they develop a life-long interest and the skills to pursue that interest.

The various groups placed different emphases on what should be focused on, in place of knowledge structures. However common foci emerged from the groups, stressing a focus on:

- the processes and skills and habits of mind of science (problem solving — which referred to developing innovative techniques or technologies or investigative designs, and analytical thinking — which was variously described as reasoning with evidence, or thinking clearly about how to represent and interpret data mathematically — were most frequently the focus, but also communication, team work, and lateral thinking. Problem solving was seen in a multi disciplinary context);
- the need to focus on relevance, engagement, enjoyment;
- the need to teach science in a multidisciplinary framework within strong social contexts that allows discussion of ethical and social issues;
- the need to appreciate the way sciences and scientists really work.

Thus, the views of these focus groups based around Australian’s research priorities are strongly aligned with contemporary thinking on scientific capability or literacy. They also align with the views of community leaders concerning the purposes of school science (Symington & Tytler, 2004).

Further findings and implications for science teacher education

Those aspects of the findings that touch on the nature of contemporary science and the work of scientists is consistent with the advocacy of scientific literacy perspectives on the purposes of school science, yet inconsistent with the ways in which either school or university science is generally framed and taught. The findings concerning the capabilities identified as important for scientists are consistent with general thinking on graduate outcomes (eg. Australian Council of Education Research, 2001; Australian Chamber of Commerce and Industry & Business Council of Australia, 2002) and echoes some attempts at re designing university science education to emphasise generic skills (Peat, Taylor & Franklin, 2005). The views of these focus groups concerning public knowledge and attitudes are consistent with the literature on public understanding of science. What is new is the way the commentary pulls these themes together in a way that clarifies the imperative of addressing, in a coherent way, the significant issues in tertiary science education concerning graduate outcomes, school science education, public understanding of science and the scientific and technological future of the country.

For our purposes, the findings provide confirmation from a high status group of recent advocacy of school science more closely reflecting contemporary science practices, community science, and incorporating higher order thinking especially in relation to reasoning with evidence and acknowledgment of societal implications (Tytler, 2003; Tytler & Nakos, 2003, Victorian Curriculum and Assessment Authority, 2005). Thes groups of science professionals are constituted rather differently to those who influence science curricula through membership of government boards, and who tend to represent more tightly defined disciplinary knowledge structures than was evidenced by the conversations reported in this paper. Thus these focus groups constitute a significant but hitherto under represented voice in science curriculum conceptualization.

The findings from the focus groups have implications for school and university science education, and also for teacher education and teacher professional learning. Teachers will need support to develop skills and pedagogies and understandings that will enable realization of this vision of a curriculum that better reflects contemporary science. It is our strong conviction that the capabilities and perspectives required of science teachers are the same as those described for science graduates who will be working in contemporary science settings. It was also our suspicion that the significant minority of science graduates who work in areas not directly related to their disciplines would also utilize such capabilities and perspectives. To test this, we undertook a second investigation (to be reported in a separate publication) to explore with science graduates (n=17) who are working outside their area of discipline expertise the skills they utilise in their work and how they see these in relation to undergraduate science education. What has emerged from these interviews is a list of skills which match to a significant extent lists of generic skills, and which in turn match the capabilities and skills described by the science focus groups as important for people working in science research and development. This is both significant, and encouraging, since it implies the possibility of a science degree that meets the needs of graduates who are going into mainstream science areas, and non-science areas.

At this stage, our thinking was to work with the science faculty at Deakin to design a generic science degree which while retaining a commitment to a major-sub major structure would contain sequences of units focused on the capabilities identified in this study, and an overall commitment to these in all units, and use this as a springboard for the education of teachers. To complete the cycle of investigations we explored, in focus groups of senior secondary students, (n= 149) who have undertaken or are about to undertake science studies at year 11, what factors would influence their decision to enrol in a tertiary science program and their attitudes to science teaching as an employment option. The data indicated that, while only a minority would consider a science course directed toward employment in laboratories or the field, and very few would consider science teaching as an option, the majority would consider a course which offered broad employment prospects and involved interaction with others, including science teaching. Thus, the focus of the degree is on flexibility, and an interweaving of content that addresses the needs of future scientists, professionals in areas loosely or not related to science, and science teachers.

Thus, in reflecting on the findings from these focus groups and the further investigations we are working on a combined B.Sc./B.Teach (Science) degree program with the following characteristics. The program:

- defers students having to make premature decisions which would restrict their career choices;
- offers teaching as one of a number of career options;
- provides explicitly for students who, while being interested in science, are not interested in laboratory/field work type positions;
- gives insight into the contemporary practice of science and in particular produces teacher education graduates capable of and disposed to significant innovation in school science;
- provides skills which are valuable in the workplace and ensures that students have both a full understanding and documentary evidence of their capabilities in these skill areas;
- is managed jointly by the Faculties of Education and Science and Technology rather than the traditional arrangement where the two faculties have responsibility for individual units within either a combined degree or an end on program for secondary science teachers.

A significant feature of the program is a sequence of Professional Practice units which deal explicitly with the nature of contemporary science and the capabilities identified in this research, aimed at the needs of both B.Sc. graduates and science teachers. For the latter, this sequence incorporates content traditionally associated with education, such as knowledge and learning and communication, but these are supported by field experience in non school settings such as museums, community science resources, industry and government departments. Once they have taken the combined (B.Sc./B.Teach (Science)) option, this strand continues into an education discipline major sequence that increasingly focuses on school science. Thus, the aim is to provide science graduates generally with capabilities and dispositions that will fit them for a variety of workplaces, and science teachers with a wider conception of contemporary science, its interactions with the public, and experience of learning science in a variety of settings. We thus hope to prepare them for the critical task of taking school science in productive directions.

References

Adamson, S.L. et al (2003) Reformed undergraduate instruction and its subsequent impact on school teaching practice and student achievement. *Journal of Research in Science Teaching*, 40, 10, 939-957.

Australian Chamber of Commerce and Industry & the Business Council of Australia (2002). *Employability skills for the future*. Canberra: Department of Education, Science and Training.

Australian Council for Education Research (2001) *Graduate Skills Assessment Summary Report*. Canberra: Department of Education, Training and Youth Affairs.

Brice, T. & Gray, D. (2004). Tough acts to follow: the challenges to science teachers presented by biotechnological progress. *International Journal of Science Education*, 26, 6, 717-733.

Committee for the Review of Teaching and Teacher Education (2003) *Australia's teachers: Australia's future – Advancing innovation, science, technology and mathematics*. Canberra: Department of Education, Science, and Training.

DeBoer, G.E. (2000) Scientific literacy: Another look at its historical and contemporary meanings and its relationship to a science education reform. *Journal of Research in Science Teaching,* 37, 6, 582-601.

Duggan, S. & Gott, R. (2002) What sort of science education do we really need? *International Journal of Science Education*, 24, 7, 661 –679.

Harper, K.A., Etkina, E. & Lin, Y. (2003) Encouraging and analysing student questions in a large physics course: Meaningful patterns for instructors. *Journal of Research in Science Teaching*. 40, 8, 776 –791.

Hee-Sun Lee & Songer, N.B. (2003) Making authentic science accessible to students. *International Journal of Science Education*, 25, 8, 923-948.

Kelly,G.J., Chen,C & Prothero,W. (2000) The epistemological framing of a discipline: writing science in university oceanography. *Journal of Research in Science Teaching*, 37, 7 691-718.

Lawrance, G.A. & Palmer, D.H. (2003) *Clever teachers, clever sciences: Preparing teachers for the challenge of teaching science, mathematics and technology in 21st century Australia*. Canberra: Department of Education, Science and Training.

Linn, M.C. (2003) Technology and science education: starting points, research programs and trends. *International Journal of Science Education*, 25, 6, 727-758.

Lyons, T. (accepted). Different countries, same science classes. *International Journal of Science Education.*

Osborne, J., Collins, S., Ratcliffe, M. Millar, R. & Duschl, R. (2003) What "Ideas-about Science" should be taught in school science? A delphi study of the expert community. *Journal of Research in Science Teaching*. 40, 7, 692-720.

Oulton, C., Dillon, J. & Grace, M.M. (2004) Reconceptualizing the teaching of controversial issues. *International Journal of Science Education*, 26, 9, 4, 411-423.

Peat, M., Taylor, C. and Franklin, S. (2005). Re-engineering of undergraduate science curricula to emphasise development of lifelong learning skills. *Innovation in Education and teaching International, 425*(2), 135-146.

Pedrosa de Jesus, H. & Watts, M. (2003) Questions of chemistry. *International Journal of Science Education*, 25, 8, 1015-1034.

Sadler, T.D. (2004) Informal reasoning regarding socioscientific issues: A critical review of the research. *Journal of Research in Science Teaching*, 41, 5, 513-536

Symington, D. & Tytler, R. (2004) Community leaders' views of the purposes of science in the compulsory years of schooling. *International Journal of Science Education*, 26, 11, 1403-1418.

Tytler, R., Duggan, S. & Gott, R. (2001). Dimensions of evidence, the public understanding of science and science education. *International Journal of Science Education,* 23(8), 815-832.

Tytler, R. (2003). A window for a purpose: Developing a framework for describing effective science teaching and learning. *Research in Science Education*, 30(3), 273-298.

Tytler, R. & Nakos, S. (2003). School Innovation in Science: Transformative initiatives in Victorian secondary schools. *Australian Science Teachers' Journal*, 49(4), 18-27.

Veal, W.R. (2004) Beliefs and knowledge in chemistry teacher development. *International Journal of Science Education*, 25, 8, 923-948.

Victorian Curriculum and Assessment Authority (2005). The Victorian Essential Learning Standards. http://vels.vcaa.vic.edu.au/essential/index.html (Accessed Feb 2006)