The role of inquiry in senior secondary science

March 2010

This article was first published in the journal of the Science Teachers Association of Queensland (STAQ), *The Queensland Science Teacher*, Volume 36, No 1, 2010, pp. 2–8.

Contents

Abstract 3

Introduction 4

Stage 1. Identify the desired results: What are the objectives of science education? 4

Stage 2. Determine acceptable evidence: Assessment of inquiry in senior science 7

Stage 3. Plan learning experiences and instruction: Building student and teacher capacity 9

Works cited and further reading 12

Abstract

Producing a scientifically literate citizen is an important purpose of science education. As such, it is argued that more authentic, inquiry-based investigations in science are needed. In the Queensland Studies Authority (QSA) secondary science syllabuses, this means the use of extended experimental investigations and extended responses. These are challenging categories of assessment that require associated learning experiences and instruction for students.

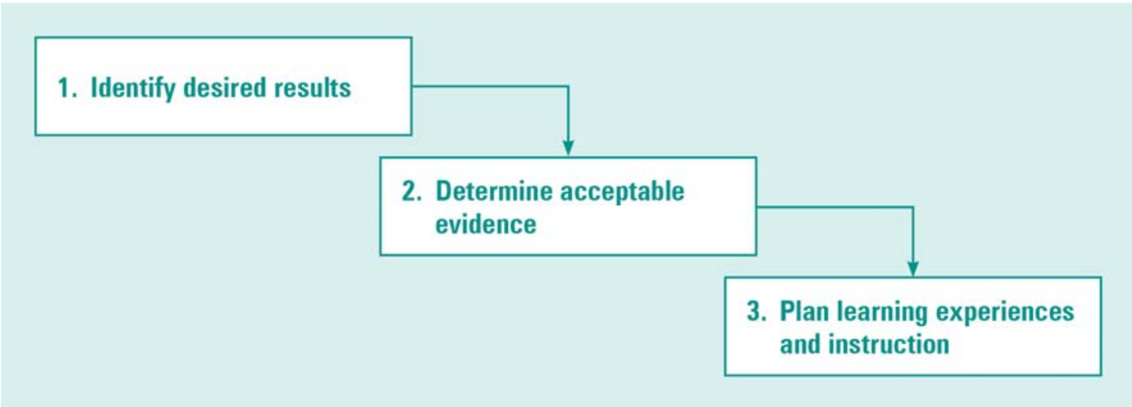
For teachers there is a corresponding need for a range of support. Using the curriculum planning framework *Understanding by Design* (Wiggins & McTighe 2005), this paper asks: What do we value in senior secondary science education in Queensland? How do we achieve it?

This paper also provides an overview of some capacity building strategies, resources and sources of professional development for secondary science teachers.

Introduction

Understanding by Design (Wiggins & McTighe 2005) presents a "backward design" approach to curriculum planning.[1] The three-staged approach asks us to 1) identify the desired results, 2) determine acceptable evidence and 3) plan learning experiences and instruction (see Figure 1). Its purpose is to develop and deepen understanding of important ideas.

Figure 1. The three stages of backward design (Wiggins & McTighe 2005, p. 18)



The backward design approach fits well with Queensland's system of school-based assessment, which is based on the premises that assessment is an integral part of the teaching and learning process, and that the most valid and informed judgments about a student's achievement are made by the student's teachers (Pitman & Dudley 1985).

Stage 1. Identify the desired results: What are the objectives of science education?

When asked about the purpose and nature of school science, Dr Jim Peacock (Chief Scientist of Australia 2006–08) made the following three points:

- Science education shouldn't be prescriptive — it is about the 'spark of excitement' that stems from discovery
- Open-ended tasks and relevance are vital — students need to understand the world around them and make rational decisions on important issues
- Teacher confidence and professional development is just as important as the students' learning materials.

Tytler 2007, p. iii

Peacock is not alone in his view. Tytler and Symington (2006) interrogated the nature of contemporary science relevant to major societal issues using focus groups of community

[1] This approach to aligning curriculum, assessment and instruction is the one cited in the *Shape of the Australian Curriculum: Science* (National Curriculum Board 2009).

representatives from government, university, industry and education. These focus groups were assembled and led by key scientists in relevant fields.

A consistent pattern of values emerged (Tytler 2007, pp. 26–27). Participants felt that Australian citizens[2] needed to be able to:

- respond critically and analytically to new technologies and associated issues
- understand uncertainty and risk, how scientists work, the impact of science on people's lives, and who to trust when it comes to the science behind controversial issues
- understand the evolving and inter-disciplinary nature of science, the links with technology, and the complexity of systems with many interconnected effects (such as balancing economic, social, energy and environmental factors).

Participants also felt that school science, as currently practised, represented an outdated and discipline-bound view of science, and that it should instead focus on:

- lifelong learning aimed at future public attitudes through engaging students' interest, rather than on knowledge structures aimed at the selection of future scientists
- the processes, skills and habits of mind of science (problem solving, reasoning with evidence, representing and interpreting data mathematically), on personal relevance and engagement, and on science within social and ethical contexts.

Goodrum and Rennie (2007) in the *Australian School Science Education National Action Plan 2008–2012* argue that the fundamental purpose of school science education is promoting scientific literacy.[3] This view, based on a significant body of research, argues that the development of scientifically literate citizens is fundamental to Australia's future and, as such, ought to be given primacy in science education. Science curriculums in Australia and internationally increasingly reflect this view.[4]

Scientific literacy and the skills of science are the focus of the Australian science curriculum, whose central aims are to:

- provide students with a solid foundation in science knowledge, understanding, skills and values

---

[2] When such questions are put to scientists internationally, similar values emerge. Fensham (2004) discusses a study he undertook in China, in which 11 directors of Beijing's leading research institutions, covering a wide range of scientific fields, were asked: "Are there qualities about science that are important for future scientists beyond a great deal of knowledge?" Ten qualities were identified by at least half of the respondents as important. Creativity was listed by ten of the 11. Personal interest in science, perseverance, willingness and desire to inquire, the ability to communicate, social concern and team spirit were all listed by half the respondents.

[3] The *Action Plan* adds that science not only prepares students for citizenship but "provides firm basis for more specialised, discipline-based subjects in upper secondary school that lead to science courses at university, and prepares students for technical education courses that lead to science-related careers" (p. 3), thus bringing together both sides of the debate. Arguably the focus on scientific literacy will further the goal of developing future scientists, rather than hinder it.

[4] For example, in the United States, the American Association for the Advancement of Science produced *Inquiry into Inquiry Learning and Teaching in Science* (Minstrell & van Zee 2000) and the National Research Council produced *Inquiry and the National Science Education Standards* (2000). In the United Kingdom, key stage 4 science now includes the organiser "how science works", which incorporates the dimensions "data, evidence, theories and explanations", "practical and enquiry skills" and "communication skills" (Qualifications and Curriculum Authority 2007).

- foster an interest in science and a curiosity and willingness to speculate about and explore the world
- teach students how to communicate about science, value evidence and scepticism, and question claims made by others in which science can be brought to bear
- develop in students the ability to identify and investigate scientific questions, draw evidence-based conclusions and make informed decisions about their own health and wellbeing (adapted from National Curriculum Board 2009, p. 5).

None of these purposes for science education undermine the status of disciplinary knowledge. The suggestion that disciplinary knowledge ought to be rejected in school science and replaced solely with, for example, problem solving, reasoning and interpreting data is a false dichotomy. *Problem solving, reasoning and interpreting data require disciplinary knowledge*.

Contemporary science education aims to use knowledge in authentic contexts. Osborne (2007) argues that a focus on examining ideas, evidence and argumentation in science classes has the potential to improve conceptual understanding, enhance critical thinking and reasoning, develop a deeper understanding of the nature of science, and make learning science more enjoyable. This offers an education that is more appropriate to the needs of future citizens.

These changes to the purpose of science education — and the corresponding focus on students learning science through inquiry, and on teaching science as contextualised and interdisciplinary (Tytler 2007) — require an associated change in pedagogy and assessment. This is a challenge for all science teachers, including Queensland science teachers.

As science educators we should ask ourselves similar questions to those that were asked of Dr Peacock:

- What *are* the purposes of science education?
- What *should be* the nature of science education?
- What *do we value* in science education?
- What do we value and find interesting about *science itself?*

How we answer these questions should inform and guide enthusiasm in teaching science and be the framework around which curriculum is built (Clark 2009).

If we accept that our “desired result” — the objectives of science education — is to develop scientific literacy in students, using backward design we must now identify the types of assessment that will provide the “acceptable evidence”.[5]

[5] Even though this paper limits itself to discussing formal assessment, in the *Understanding by Design* framework, assessment is both formal and informal, and ongoing (Wiggins & McTighe 2005, p. 19).

Stage 2. Determine acceptable evidence: Assessment of inquiry in senior science

Inquiry, especially in the form of hands-on investigations, best describes the way of thinking and methods of investigation that will achieve the “desired result” of a science education. Inquiry needs to be at the centre of science lessons.

Hackling (2005, p. 4) contends that in science education there is a strong need for inquiry in the form of open investigations:

> Open investigations are activities in which students take the initiative in finding answers to problems (Jones, Simon, Fairbrother, Watson, & Black, 1992). The problems require some kind of investigation in order to generate information that will give answers. Garnett, Garnett, & Hackling (1995) describe a science investigation as ‘a scientific problem which requires the student to plan a course of action, carry out the activity and collect the necessary data, organise and interpret the data, and reach a conclusion which is communicated in some form’ (p. 27). The planning component and the problem-solving nature of the task distinguish investigations from other types of practical work.

Queensland science syllabuses have always included the assessment of experimental work. However, secondary school science has often been dominated by recipe-style, worksheet-based laboratory exercises that provide little chance for students to formulate a researchable question or hypothesis, or plan and conduct their own experiment (Hackling 2005, p. 3).

In recent Queensland Studies Authority (QSA) science syllabuses, there has been a shift. Students are required to undertake extended experimental investigations and may also be required to undertake extended responses.[6] These assessment techniques apply the principles of inquiry authentically and are not unique to Queensland syllabuses.[7]

There are different levels of inquiry, ranging from verification (where the problem, equipment, procedure and answer are given) to open inquiry, where all of the steps are open or negotiated. The level of openness of an activity can be categorised as shown in Table 1.

Table 1: Levels of openness of inquiry (adapted from Hackling 2005, p. 2)

Level	Problem	Equipment	Procedure	Answer	Common Name
0	Given	Given	Given	Given	Verification
1	Given	Given	Given	Open	Guided inquiry
2a	Given	Given	Open/Negotiated	Open	Open guided inquiry
2b	Given	Open/Negotiated	Open/Negotiated	Open	Open guided inquiry
3	Open/Negotiated	Open/Negotiated	Open/Negotiated	Open	Open inquiry

[6] This paper limits itself to discussing the inquiry-based categories of assessment of the QSA’s Biology (2006), Chemistry (2007a), Physics (2007b) and Science21 (2007c) senior syllabuses. These categories are, broadly speaking, extended experimental investigations and extended responses (although each syllabus has slightly different nomenclature and requirements). This does not imply that inquiry is not assessed in other categories.

[7] In New South Wales, students are required to undertake an open-ended investigation in senior Physics (Board of Studies NSW 2007). Similarly, in Victoria there is a requirement for a student-designed extended practical investigation (Victorian Curriculum and Assessment Authority 2008).

Both extended experimental investigations and extended responses are types of inquiry-based assessment techniques where the level of openness would depend on the nature of the task and the context in which it is being undertaken.

Open investigations should not be equated with minimal guidance, where learners are expected to discover or construct essential information for themselves, such as the procedures they would need to use to conduct a rigorous investigation (Krischner, Sweller & Clark 2006). Such an attitude towards investigations would be detrimental to science education. There needs to be a "clear distinction between learning a discipline and practicing a discipline" (Krischner, Sweller & Clark 2006, p. 78). This is especially important when inquiry-based investigations are a component of summative assessment — assessment must provide students with the opportunity to succeed.

In this paper, Table 1 has been adapted to include "negotiated", because it is recognised that teachers will always play a key role in student investigations.[8]

We cannot afford to confuse "the teaching of a discipline as inquiry (i.e., a curricular emphasis on the research processes within a science) with the teaching of the discipline by inquiry (i.e., using the research process of the discipline as a pedagogy or for learning)" (Krischner, Sweller & Clark 2006, p. 78).

Teachers need to plan learning experiences and provide appropriate scaffolding for inquiry-based investigations. According to the *Physics Senior Syllabus 2007* (QSA, 2007b):

> Teachers **can provide the research question** or it may be **instigated** by the student. In those instances **teachers should negotiate** with students to ensure safety and the possibility of success. It is more likely that students will be able to generate their own research questions the further they progress in the course of study.
>
> …
>
> **Scaffolding must be provided**. When an extended experimental investigation [or extended response] is undertaken for the first time, the scaffolding should help students complete the assessment by **modelling the extended experimental investigation** [or extended response] process and familiarising students with the expectations for the written scientific report. However, the scaffolding provided should not specify the physics, or lead the student through a series of steps dictating a solution.
>
> Queensland Studies Authority 2007, p. 22. Emphasis added.

Two further points with regard to these assessment types need to be highlighted.

First, when choosing a question to investigate, difficulty should not be confused with rigour. Writing for the American Physical Society, Professor of Physics Joseph Ganem makes the following points:

> Rigor is critical to math and science because it allows practitioners to navigate novel problems and still arrive at a correct answer. But if the novel problems are so difficult that a higher authority must always be consulted, rigorous thinking will never develop.
>
> …
>
> Rigor … is best obtained by learning age-appropriate concepts and techniques. Attempting difficult problems without the proper foundation is actually an impediment to developing rigor.
>
> Ganem 2009.

While Ganem is referring to solving mathematical problems, the same idea applies to choosing a problem to investigate in an extended experimental investigation or extended response. When we consider that some of the standards in the senior science syllabuses use the descriptions "complex" and "challenging" as discriminating qualities in student work,

[8] Even PhDs are to a great extent "negotiated".

we need to be especially mindful of Ganem's point.[9] What is considered complex and challenging must be developmentally appropriate within the context of a course. The level of complexity and challenge must not defeat the purpose of students developing scientific rigour in their thinking.

Second, the purpose and intent of inquiry-based assessments is for students to gain a deeper knowledge and understanding of the relevant processes and concepts of science. Though the assessments produced are in written formats, such as scientific reports, articles or assignments (or oral/multimodal presentations), they are still required to be about *the science*. The general objectives, dimensions and associated standards make this clear.

To further illustrate this point, consider setting as an extended response in physics a persuasive argument assignment. Let us define this as "one that seeks to argue or persuade and is intended to convince readers to accept particular perspectives or points of view" (QSA 2008c, p. 26). Would this work? Absolutely. A student could argue the proposition "that the Tower of Terror is a better amusement park thrill ride than the Giant Drop".[10] We would expect them to persuade us, to justify this proposition by using ideas, evidence and argumentation based on science. They would need to define what they meant by "better". Faster? Greater accelerations? Longer periods of time? Expectation versus experience? All of the above? They would need to compare and contrast the rides using scientific evidence. This would include secondary data from the amusement park (in this case Dreamworld), and some kind of primary data from accelerometers, altimeters, heart-rate monitors and direct measurement. In turn, this data could be related to key physical concepts and the first-person experience of being on the ride. Such an assessment instrument would be dominated by annotated diagrams, graphs and equations. This is what would make it a persuasive physics text.

Inquiry-based investigations for assessment and learning in science lead to an understanding of the methods by which science comes to build up a body of knowledge, a deeper understanding of that knowledge, and the ability to apply knowledge to new or novel situations. Undertaking such investigations requires the development of higher-order thinking processes and associated skills. Consequently there is a need to teach these thinking processes and skills by embedding inquiry-based investigations into the curriculum.

Stage 3. Plan learning experiences and instruction: Building student and teacher capacity

The final stage of the backward design process is to plan for learning and instruction. There is a limit to the detail this paper can go into, but there are some general things to consider and points to be made.

[9] Complexity may relate to the number of steps involved in applying knowledge to the situation or task, and/or the level of scaffolding given. The level of challenge in a task may relate to familiarity, synthesis of several concepts and/or the level of abstraction. What is complex or challenging in the early part of a course of study may not be complex or challenging in the latter part (QSA 2008b).

[10] An admittedly nonsensical example — the Claw is obviously the best ride at Dreamworld.

Students do not begin their senior science studies with the understanding and skills required to perform open inquiries. This capacity needs to be built over time. Students need to be familiar with the processes and skills required *for* senior science *before they begin* senior science. The challenge for secondary science departments is to build inquiry into the curriculum from Year 8 through to Year 12. This needs to be well thought out and planned, and take into account the levels of openness as described in Table 1.[11]

Science teachers' required pedagogies are also affected by these changes. At the senior secondary level, teachers still need to be content area experts. However, they are also "expert guides". Teachers need to introduce students to the concepts and skills of inquiry relevant to their content area, such as heuristics for generating questions and interpreting data (Krajcik, Blumenfeld, Marx & Soloway 2000, p. 286).

With a greater focus on inquiry, on teaching "science by doing", students should soon see that science is not simply a body of "immutable facts". They will see that science "is a way of knowing". However, we need to make clear to students that it is not *just* a way of knowing (Ellerton 2009).[12]

Building an inquiry focus into a science curriculum is not a challenge to be faced unsupported or alone. Designing valid assessment instruments is not simple and involves many hours of work (Matters 2006). There are many resources and sources of professional development that teachers can use to build their own and their students' capacities in inquiry-based science. Some general examples are listed below:

- *Working Scientifically* (Hackling 2005) gives an excellent overview of inquiry-based investigations in science and includes student planning and reflection worksheets and checklists, <www.det.wa.edu.au/education/science/Teach/workingscientificallyrevised.pdf>.
- The American Association for the Advancement of Science's *Inquiry into Inquiry Learning and Teaching in Science* (Minstrell & van Zee 2000) is framed around the three questions: Why inquiry?, What does inquiry look like?, What are some of the issues associated with shifting toward inquiry-based practices? It includes papers from academics and practising teachers with real examples of inquiry in science classes, <www.aaas.org/programs/education/about_ehr/pubs/inquiry.shtml>.
- Professional associations such as the Science Teachers Association of Queensland (STAQ) and the Australian Science Teachers Association (ASTA) provide excellent professional development opportunities, with associated science education journals and links to resources and networks, < www.staq.qld.edu.au> and <www.asta.edu.au>.
- The Australian Academy of Science is developing Science by Doing, a national initiative aimed at actively engaging junior secondary school students in learning science through an inquiry-based approach, <www.science.org.au/sciencebydoing/>.
- The CSIRO offers a range of resources for teachers and students, such as the highly successful Scientists in Schools, < www.csiro.au/resources/ScientistsInSchools.html>.

---

[11] The *Year 10 Guidelines* (QSA, 2010) provide further advice about inquiry in the science learning area.

[12] When pop singer Katie Melua sang: "We are 12 billion light-years from the edge, That's a guess, No one can ever say it's true" on what basis did science writer Simon Singh correct her with the alternate lyrics: "We are 13.7 billion light-years from the edge of the observable universe, That's a good estimate with well-defined error bars, Scientists say it's true, but acknowledge that it may be refined" (Singh 2005)? Why should one believe Singh rather than Melua? The basis on which a science teacher can answer this cuts to the heart of the deeper understanding of science we now expect teachers to have.

Queensland-based examples include:

- The QSA has assessment samples and other resources for teachers of senior secondary science. These can be located by browsing from the relevant subject area in the Years 10–12 section of the website, <www.qsa.qld.edu.au>.
- Teachers are able to join subject moderation review panels. Teachers who are not panellists are able to observe at monitoring. This is an excellent professional development and networking opportunity. See the QSA website <www.qsa.qld.edu.au> under Years 10–12 > Moderation and quality assurance.
- The QSA's Assessment Bank has many sample assessment packages for science up to Year 9. It is an ongoing project and more science packages will be added in 2010. See the QSA website <www.qsa.qld.edu.au>.
- The Queensland Department of Education hosts discussion lists for staff to communicate and share ideas. There are separate lists set up for senior physics and chemisty, as well as other topics that would be of interest to teachers. This is an excellent resource for communicating with other teachers across the state. See < http://discussions.eq.edu.au/listserv/index.html>.
- Teachers can subscribe to *QSA Connect*, a fortnightly email update on the Queensland Studies Authority's initiatives, professional development activities and events. See <www.qsa.qld.edu.au> under Publications > Newsletters.

When considering the challenge of inquiry-based science education and the associated changes in curriculum and assessment, we must continually remind ourselves that these changes are processes, not events. By looking at the curriculum within a framework of backward design, it is possible to understand where these changes have come from and what is required to enact them.

Queensland teachers have been successful in delivering such curriculum changes. Since 1972 a system of school-based assessment has operated in secondary education in Queensland. This system has two premises at its core — that assessment is an integral part of the teaching and learning process, and that teachers, as informed professionals, are best placed to make valid and informed judgments about their students' achievement (Pitman & Dudley, 1985).

School-based assessment is a system that gives all Queensland teachers the flexibility to engage with, and implement, a curriculum that best suits their context and circumstances. It is a system that puts Queensland science teachers in a strong position to deliver an inquiry-based science education and to develop students' scientific literacy. The challenge this presents should not be understated, but when considering it we should go back to the initial questions posed, and ask: "What do I, as a science teacher, value and find interesting about science?"

Works cited and further reading

Board of Studies NSW 2007, *Science Stage 6: Revised support document,* State of New South Wales, accessed 16 Dec 2009, <www.boardofstudies.nsw.edu.au/ syllabus_hsc/pdf_doc/science_revised_support.pdf>.

Clark, T 2009, “Using Year 10 science guidelines to audit and reboot an assessment — Galileo's inclined plane”, *The Queensland Science Teacher,* 35 (3), pp. 42–43.

Ellerton, P 2009, “Innovation in senior sciences”, paper presented to the Science Teachers Association of Queensland’s Senior Sciences Workshop 2009, 27th Nov 2009, Brisbane.

Fensham, P 2004, “Engagement with science: An international issue that goes beyond knowledge”, paper presented to the Science and Mathematics Education Conference, 23–24 Sep, Dublin.

Ganem, J 2009, “A math paradox: The widening gap between high school and college math”, *APS News*, Oct 2009, accessed 14 Dec 2009, <www.aps.org/publications/apsnews/200910/backpage.cfm>.

Garnett, PJ, Garnett, PJ & Hackling, MW 1995, “Refocussing the chemistry lab: A case for laboratory-based investigations”, *Australian Science Teachers Journal ,* 42 (2), pp. 26-32.

Goodrum, D & Rennie, L 2007, *Australian School Science Education National Action Plan 2008 –2012*, Department of Education, Science and Training, Commonwealth of Australia.

Hackling, M 2005, *Working Scientifically: Implementing and assessing open investigation work in science,* Western Australia Department of Education and Training.

Jones, A, Simon, S, Fairbrother, R, Watson, R & Black, PJ 1992, *Development of Open Work in School Science*, Association for Science Education, Hatfield, UK.

Krajcik, J, Blumenfeld, P, Marx, R & Soloway, E 2000, “Instructional, curricular, and technological supports for inquiry in science classrooms”, in Minstrell, J & van Zee, E 2000, *Inquiring into Inquiry Learning and Teaching in Science*, American Association for the Advancement of Science, accessed 14 Dec 2009, <www.aaas.org/programs/education/about_ehr/pubs/inquiry.shtml>.

Krischner, P, Sweller, J & Clark, R 2006, “Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experimental, and inquiry-based teaching”, *Educational Psychologist ,* 41 (2), pp. 75-86.

Luke, A, Weir, K & Woods, A 2008, *Development of a Set of Principles to Guide a P–12 Syllabus Framework*, Queensland Studies Authority, accessed 12 Dec 2009, < <www.qsa.qld.edu.au/downloads/publications/qsa_p-12_principles_dev_ppr.pdf>.

Matters, G 2006, *Assessment Approaches in Queensland Senior Science Syllabuses,* Australian Council for Educational Research.

Minstrell, J & van Zee, E 2000, *Inquiring into Inquiry Learning and Teaching in Science*, American Association for the Advancement of Science, accessed 14 Dec 2009, <www.aaas.org/programs/education/about_ehr/pubs/inquiry.shtml>.

National Curriculum Board 2009, *Shape of the Australian Curriculum: Science*, Commonwealth of Australia, accessed 14 Dec 2009, <www.acara.edu.au/verve/_resources/Australian_Curriculum_-_Science.pdf>.

National Research Council 2000, *Inquiry and the National Science Education Standards: A guide for teaching and learning*, The National Academies Press, accesssed 14 Dec 2009, <www.nap.edu/openbook.php?record_id=9596&page=R1>.

Osborne, J 2007, “Towards a science education for all: The role of ideas, evidence and argument”, in *Boosting Science Learning — What will it take?*, Australian Council for Educational Research, pp. 2–5.

Pitman, J & Dudley, R 1985, "Criteria-based assessment: the Queensland experience", paper presented to the 11th International Conference of the International Association for Educational Assessment, Oxford, England.

Qualifications and Curriculum Authority 2007, *Science: Programme of study for key stage 4*, accesssed 14 Dec 2009, <http://curriculum.qcda.gov.uk/uploads/QCA-07-3345-p_Science_KS4_tcm8-1799.pdf>.

QSA (Queensland Studies Authority) 2006, *Biology Senior Syllabus 2004*, amended 2006, State of Queensland, accessed 14 Dec 2009, <www.qsa.qld.edu.au/downloads/10-12/snr_biology_04_syll.pdf>.

—— 2007a, *Chemistry Senior Syllabus 2007*, State of Queensland, accessed 14 Dec 2009, <www.qsa.qld.edu.au/downloads/10-12/snr_chemistry_07_syll.pdf>.

—— 2007b, *Physics Senior Syllabus 2007*, State of Queensland, accessed 14 Dec 2009, <www.qsa.qld.edu.au/downloads/10-12/snr_physics_07_syll.pdf>.

—— 2007c, *Science21 Pilot Senior Syllabus 2007*, State of Queensland, accessed 14 Dec 2009, <www.qsa.qld.edu.au/downloads/10-12/snr_science21_07_syll_pilot.pdf>.

—— 2008a, *Building Student Success: A guide to the Queensland Curriculum and Reporting Framework*, State of Queensland.

—— 2008b, *Interpreting "Complex" and "Challenging": Biology, Chemistry and Physics advice for teachers*, State of Queensland, accessed 14 Dec 2009, <www.qsa.qld.edu.au/downloads/10-12/snr_bio04_chem_phys07_complex_challenge.pdf>.

—— 2008c, *English Senior Syllabus 2008*, open implementation trial, State of Queensland, accessed 14 Dec 2009, <www.qsa.qld.edu.au/downloads/10-12/snr_english_08_syll_trial.pdf>.

—— 2009a, *Learning P–12,* State of Queensland, accessed 14 Dec 2009 <www.qsa.qld.edu.au/downloads/approach/learning_p-12_int_approach.pdf>.

—— 2009b, *Student Assessment Regimes: Getting the balance right for Australia,* State of Queensland, accessed 14 Dec 2009 <www.qsa.qld.edu.au/downloads/publications/qsa_paper_assess_balance_aust.pdf>.

—— 2010, *Year 10 Guidelines*, 2nd ed., State of Queensland, accessed 14 Dec 2009, <www.qsa.qld.edu.au/downloads/10-12/yr10_guide.pdf>.

Singh, S 2005, "Katie Melua's bad science",*The Guardian,* 30 Sep 2005, accessed 15 Dec 2009, <www.guardian.co.uk/education/2005/sep/30/highereducation.uk>.

Thomson, S & De Bortoli, L 2008, *Exploring Scientific Literacy: How Australia measures up,* Australian Council for Educational Research.

Tytler, R 2007, *Re-imagining Science Education: Engaging students in science for Australia's future,* Australian Council for Educational Research, accessed 12 Dec 2009, <www.acer.edu.au/documents/AER51_ReimaginingSciEdu.pdf>.

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

Tytler, R & Symington, D (2006), "Science in school and society", *Teaching Science, the Journal of the Australian Science Teachers Association,* 52(3), pp. 10–15.

Victorian Curriculum and Assessment Authority 2008, *VCE Physics Assessment Handbook 2009–2012,* State of Victoria, accessed 16 Dec 2009, <www.vcaa.vic.edu.au/vce/studies/physics/physics_hb.doc>.

Wiggins, G & McTighe, J 2005, *Understanding by Design*, expanded 2nd ed., Association for Supervision and Curriculum Development, Alexandria, Va.

Queensland Studies Authority
295 Ann Street, Brisbane
PO Box 307 Spring Hill
QLD 4004 Australia
T +61 7 3864 0299
F +61 7 3221 2553
www.qsa.qld.edu.au