# Science literature review

Senior syllabus redevelopment

Prepared for Queensland Curriculum and Assessment Authority by:

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# Executive summary

**Syllabuses comprising the Science subject group**

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| **Authority-registered syllabuses** | • Agricultural Practices 2014<br>• Aquatic Practices 2014<br>• Science in Practice 2015 |
| **VET qualifications** | • MSL20109 Certificate II in Sampling and Measurement<br>• AHC10210 Certificate I in AgriFood Operations<br>• AHC21210 Certificate II in Rural Operations<br>• AHC32810 Certificate III in Rural Operations<br>• AHC20110 Certificate II in Agriculture<br>• UEE10111 Certificate I in ElectroComms Skills<br>• UEE22011 Certificate II in Electrotechnology (Career Start) |

# Overview of methodology and findings

This literature review identifies significant emerging trends and compares curriculum, pedagogy, assessment and structure of senior science syllabuses from three domestic jurisdictions: New South Wales, Western Australia and Victoria, and three international jurisdictions: United Kingdom (specifically Assessment and Qualifications Alliance (AQA)), Ontario, Canada, and New York State, USA. The three domestic jurisdictions were selected by the QCAA, and the three international jurisdictions were selected because of the similarities between these regions economically, socially and culturally to Queensland. Despite these similarities, Ontario and New York State have taken different approaches to science education in the senior years than most Australian states and the AQA, by affording more flexibility for schools and teachers. The AQA and several Australian states have more rigid regulatory approaches to learning in the sciences; therefore, these Australian and international jurisdictions make for informative and diverse comparisons of curriculum, pedagogy, assessment and structure of senior science syllabuses.

The AQA provides the most prescriptive central regulations on learning in senior science subjects, while New South Wales, Western Australia and Victoria are less imperative in terms of external exams and explicit stipulations of course structure, assessment criteria and standards, and time allocations. Ontario and New York State provide guidelines, big/key ideas concerning knowledge and understanding, and standards that fully integrate mathematics, technology (use of sensors, data-loggers and relevant scientific software packages) and science. At present, Queensland senior science syllabuses sit in the middle of what could be called two extremes with a system of school-based assessment that is moderated using a social system approach. Queensland's system of social moderation will soon be changed, with both a review into senior assessment and tertiary entrance, and a parliamentary inquiry into physics, chemistry and maths, recommending that senior science courses include both school-based assessment and external assessment (Department of Education, Training and Employment (DETE) 2014, Education and Innovation Committee 2013). External assessment will consist of up to 50% of the valuation, and will be set and marked by the QCAA. These recent recommendations within Queensland could be considered at odds with other jurisdictions like New South Wales where recent consultations (Board of Studies Teaching and Educational Standards (BOSTES) 2014) make recommendations to consider the nature and emphasis of external examinations, including significantly reducing content to provide more opportunities to students for project-based learning and science, technology, engineering and mathematics (STEM) learning experiences (Tytler 2007, Chubb 2013). Queensland's move towards external assessment for moderation may present challenges, as it may necessitate an increased focus on content, which would then detract from the quality and diversity of learning experiences provided to students in school-based assessment.

Twelve recommendations have been suggested for consideration arising from this literature review that include providing longer time periods for students to develop, lead and accomplish scientific discovery through project-based learning, and opportunities to work on complex multidisciplinary problems. This literature review found significant overlap between Science21 (Authority) and Science in Practice (Authority-registered), and Agricultural Sciences (Authority) and Agricultural Practices (Authority-registered). There are opportunities to integrate practical elements from Science in Practice into all senior science subjects particularly if greater emphasis is placed on opportunities for students to conduct project-based learning (Barron 1998). Inquiry-based learning is prevalent within the curriculum across all jurisdictions, and fits naturally within the constructs of scientific inquiry (Schwartz, Lederman & Crawford 2003). However, project-based learning has the potential to provide a richer and more in-depth insight into scientific discovery (Blumenford et al. 1991), and ultimately a more authentic experience for students (Herrington & Herrington 2006). In the United Kingdom and New York State practical skills are assessed through competency checklists. The explicit identification of desirable skills may assist with enhancing student perceptions of science as a profession and career; and assist students to grasp the challenging theoretical aspects of science (Goodrum, Druhan & Abbs 2012).

Science is no longer a field that operates in a silo, but is instead highly integrated with clear connections and impacts on society, technology (how science is translated into applications), the environment and culture (Goodrum, Druhan & Abbs 2012, Chubb 2014). There are also opportunities to broaden the science curriculum offered, in accordance with the Australian Curriculum, so that students can incorporate cross-curriculum priorities into senior science courses such as an appreciation of Aboriginal and Torres Strait Islander peoples' knowledge; Asia and Australia's engagement with Asia; and exploring and investigating sustainability. Students should have more opportunities to reflect on the complex role science plays in world affairs.

Recommendations are made to incorporate the list of 21st century skills into senior science subjects but not to incorporate them as a checklist of general capabilities. Many of these skills are already present within Queensland senior science syllabuses. These skills could be more explicitly identified in a new section that provides information for schools and teachers on where to incorporate these skills into course and learning experiences. Finally, a recommendation is made to incorporate tasks that assist students more explicitly with becoming meaningful life-long learners, and this could come with the use of learning journals in both Year 11 and 12 senior science subjects.

Overall, Queensland's senior science subjects are providing meaningful, cutting-edge, and varied learning experiences for students. A key recommendation from this literature review is to maintain the flexibility and creativity afforded to science teachers in Queensland.

# Summary of recommendations

**Recommendation 1:** To incorporate longer, more involved opportunities for students to develop, lead and complete scientific discovery through project-based learning (Bell 2010); and to provide increased support for project-based learning to schools and teachers, including access to paraprofessionals (Goodrum, Druhan & Abbs 2012), and collaborations with tertiary and other research institutions. This would mean taking into consideration the proportion of course time in which students conduct extended experiment investigations.

**Recommendation 2:** To incorporate more opportunities in senior science subjects to work on complicated multidisciplinary projects in groups where students are assessed as a member of a collaboration. Multidisciplinary group projects (incorporating science, technology, engineering and mathematics) are more in line with how the profession of science operates and are becoming an growing focus in tertiary institutions in undergraduate science degrees (Tytler 2007, Chubb 2013, BOSTES 2014).

**Recommendation 3:** To incorporate into all senior science subject syllabuses, elements of the practical focus from Authority-registered subjects on how students work safely and effectively in a science workplace. The achievement of competency in practical scientific skills could be assessed separately as part of a checklist in a similar manner to the United Kingdom and New York State.

**Recommendation 4:** To provide students completing the Authority-registered subjects Science in Practice 2015 and Agricultural Sciences 2014 with the option to be credited towards the calculation of Overall Positions (Ops) and Field Positions (FPs) because of the significant overlap between these subjects and the Authority subjects Science21 and Agricultural Sciences; this may involve additional assessment focused on knowledge and theoretical constructs.

**Recommendation 5:** To research the benefits of diversifying approaches to teaching, learning and assessment outlined in the syllabuses, depending on the specific characteristics of science subjects. This includes taking into consideration the recommendations from the Education and Innovation Committee 2013 report, e.g. numeric marking against standards, and focusing more on ensuring students understand and can apply the basic content of subjects like chemistry and physics.

**Recommendation 6:** To consider how to maintain the flexibility Queensland senior science syllabuses offer schools and teachers in terms of the design of teaching, learning experiences and school-based assessment with the introduction of significantly weighted external assessment (up to 50% depending on the subject).

**Recommendation 7:** To trial a longstanding practice in New York State and invite select groups of teachers from subject areas to participate in the preparation of external assessment for Queensland senior science subjects; and to prepare external assessment two to three years in advance to allow time for testing and research.

**Recommendation 8:** To facilitate opportunities for schools and teachers to incorporate cross-curriculum priorities into senior science courses such as an appreciation of Aboriginal and Torres Strait Islander peoples' knowledge; Asia and Australia's engagement with Asia; and exploring and investigating sustainability.

**Recommendation 9:** To incorporate within the general objectives of science subjects a more explicit consideration of the role science plays in society, technology and the environment, which is the approach taken by Ontario and New York State. This may assist students to appreciate science as a career path, and scientific literacy as useful in decision-making within other careers and modern society (Tytler 2007, Goodrum, Druhan & Abbs 2012).

**Recommendation 10:** To trial the approach taken by the AQA and New York State and more explicitly integrate mathematical and technological (use of sensors, data-loggers, modern scientific equipment, relevant software) learning experiences and skill development into Queensland senior science subject key ideas and standards.

**Recommendation 11:** To build opportunities within the curriculum for students to develop the skills of meaningful independent learners that may involve the use of learning journals as formative or summative assessment. Learning journals may also help to address concerns expressed by teachers that during inquiry-based group learning activities it can be difficult to distinguish individual student contributions (Education and Innovation Committee 2013).

**Recommendation 12:** To avoid adding 21st century skills as an additional set of general capabilities for schools and teachers, but to embed more explicit reference to these skills throughout the syllabus, including an additional section within senior science syllabuses that explicitly detail where these skills could be developed within courses. Western Australia senior science syllabuses have adopted this model including describing learning as the attainment of a set of seven general capabilities.

# 1 Subject group: Significant emerging trends

## 1.1 Assessment

The significant emerging trends in assessment for the subject group include project- and research-based assessment that provides opportunities for students to experience what it is like to work as a scientist — to create new knowledge through scientific discovery — and multidisciplinary projects that integrate knowledge and skills across STEM studies (Tytler 2007, Chubb 2013, BOSTES 2014). There is also a move in some jurisdictions, including New South Wales, Victoria, Western Australia, and the Australian Curriculum, focusing away from assessing the specific attainment of content, and towards assessing understanding of how a scientist asks questions and solves problems, including the opportunity to practice and develop skills in creativity, critical thinking, researching and reflection (Goodrum, Druhan & Abbs 2012). Assessment items in Ontario and New York State already have a focus on scientific process and discovery. Other emerging trends include student self-monitoring and goal-setting, assessment of learning processes, attitudes, values, and assessment of practical skills in science.In most jurisdictions, final assessment items (leaving assessment) are supervised exams that are most often external and regulated by the relevant curriculum and assessment authority. The exception is Ontario, where although a final evaluation is prescribed to be weighted 30%, this does not have to be a supervised exam but can instead be an ‘examination, performance, essay, and/or other method of evaluation suitable to the course content and administered towards the end’ (Ministry of Education 2008, p. 30).

In the United Kingdom and New York State students are assessed on their attainment of practical scientific skills with competencies evaluated and reported separately.

## 1.2 Pedagogical approaches

In the Australian and international syllabuses the following are a focus: inquiry and problem-based learning; active learning; increased emphasis on embedding mathematics explicitly into science curriculum (particularly in higher order skills and in the United Kingdom); and pedagogy that encourages students to understand the bigger picture connections science makes with other disciplines and societal issues.

Within Australia, New South Wales, Western Australia and Victoria senior science syllabuses are highly detailed in their requirements, with more emphasis on the activities and students’ experience, as opposed to detailed content directives. The AQA provides detailed prescriptions on content within science subjects. In New York State and Ontario senior science syllabuses are less prescriptive of content.

## 1.3 Implications for the redevelopment of Queensland syllabuses in the subject group

Scientific knowledge, understanding and technology are arguably advancing at a faster pace than ever before in history (Edwards et al. 2013). Big ideas and theories in science will likely hold into the future but the advancement in knowledge and methods is changing rapidly. With these changes, what were once highly advanced and expensive scientific processes and methods, such as genomics, are becoming increasingly cheaper and easier to use. Scientists of the future, and arguably of today, need to be adaptable and prepared to be life-long learners (Chubb 2013). This is the impetus for many of the emerging trends found in this study and described above. Many students studying senior science subjects will not end up working as scientists. Because of the rapidly changing nature of science and technology and its significant impact on the lives of individuals, neighbours, cities, regions and countries, contributing citizens of the future should have a base set of scientific literacies to help them understand, and take a stand for or against, scientific and technological discoveries.

In five out of the six jurisdictions reviewed a leaving authority-approved or monitored exam is prescribed by the syllabus, and recent recommendations mean Queensland will adopt a version of this approach (Education and Innovation Committee 2013, DETE 2014). This approach arguably provides a clear and transparent way for regional bodies to moderate standards across school students and graduates. There is also an emerging trend towards developing more opportunities for students to work in collaborative groups, but without assessing the role or contribution of a student within the group. Working in a group is potentially vital for future student development; therefore, consideration could be given to provide students with opportunities to experience and practice collaboration, and experience what it is like to have a stake in the functioning of a group (Bell 2010).The process of scientific discovery, the seamless incorporation of mathematical skills including statistics within curriculum and assessment, multidisciplinary project-based learning and ethical practice are emerging trends that are not easy to assess using standardised testing.

## 1.4 Recommendations

### Recommendation 1

To incorporate longer, more involved opportunities for students to develop, lead and complete scientific discovery through project-base d learning (Bell 2010); and to provide increased support for project-based learning to schools and teachers, including access to paraprofessionals (Goodrum, Druhan & Abbs 2012), and collaborations with tertiary and other research institutions. This would mean taking into consideration the proportion of course time in which students conduct extended experiment investigations.

### Recommendation 2

To incorporate more opportunities in senior science subjects to work on complicated multidisciplinary projects in groups where students are assessed as a member of a collaboration. Multidisciplinary group projects (incorporating science, technology, engineering and mathematics) are more in line with how the profession of science operates and are becoming an growing focus in tertiary institutions in undergraduate science degrees (Tytler 2007, Chubb 2013, BOSTES 2014).

# 2 Subjects in the group: Overview, comparison and connections

## 2.1 Queensland syllabuses and VET qualifications

Queensland science syllabuses align strongly in their focus on teaching, learning and assessment. All syllabuses organise student learning into knowledge and understanding, investigation and analysis, evaluation and communication. The Queensland syllabuses also share much in common in terms of assessment, including extended experimental investigations as well as other extended responses, examinations and extended response tests. In a recent assessment of Queensland senior Mathematics, Chemistry and Physics subjects, issues were raised by teachers across the state concerning the ambiguity in the standards described in the syllabuses and recommendations for an alternative approach of numeric marking against standards were made (Education and Innovation Committee 2013). Other recommendations in this report included a reduction in emphasis on inquiry-based learning and an increased focus on basic content (Education and Innovation Committee 2013). The Authority syllabuses in science are set out almost identically and it may be that subjects should be diversified so that discipline-specific characteristics can be better captured in teaching, learning and assessment. Biology, as an example, is a very broad field that is multidisciplinary (Martin, Mintzes & Clavijo 2000); therefore, there could be benefits in diversifying the teaching, learning and assessment approaches between science subjects.

There are significant overlaps between the Authority syllabus Agricultural Science 2013 and the Authority-registered syllabus Agricultural Practices 2014. Both syllabuses are focused on studying plant science and animal science with key differences in the level of practical activities. Agricultural Practices, as the name suggests, places a stronger emphasis on practice knowledge and affords choice by schools to focus on one of either animal or plant studies as units of work that are set within context, e.g. poultry, vegetables or conservation areas. The learning and teaching focus of both syllabuses is on three core areas that are common across the science subject group and assessment items are similar (see table below), although the Authority syllabus Agricultural Science is less prescriptive with four broad categories of assessment items as opposed to five within the Authority-registered syllabus Agricultural Practices.

### Comparison of syllabuses Agricultural Science and Agricultural Practices

| Agricultural Science 2013 | Agricultural Practices 2014 |
|---|---|
| **Learning and teaching focus** | |
| • *Knowledge and understanding*<br>• *Investigation and analysis*<br>• *Evaluation and communication* | • *Knowledge and understanding*<br>• *Analysing and applying*<br>• *Planning and evaluating* |
| **Assessment** | |
| • Extended response<br>• Examination<br>• Short response<br>• Extended response test | • Project<br>• Collection of work: a series of tasks related to a single topic<br>• Investigations<br>• Extended response to stimulus<br>• Examination |

Both of these syllabuses have some overlap with the vocational education and training (VET) qualification AHC10210 Certificate I in AgriFood Operations, which is an entry-level qualification for students interested in entering into agriculture, horticulture and conservation and land management. This qualification is more practical than the Authority-registered syllabus Agricultural Practices (2014), being focused on basic knowledge and preparation for work including the completion of a range of simple tasks under close supervision. The AgriFood Operations VET qualification is made up of six units: two core units and four electives. Core units are Occupational Health and Safety and Work. Elective units are within plant and animal studies, as well as agribusinesses. Some examples are broadacre cropping, chemicals, horse breeding, irrigation, landscape, turf, and wool.

There are also significant overlaps between the Authority syllabus Science21 2010 and the Authority-registered syllabus Science in Practice 2015 (see table below). Both of these syllabuses focus on interdisciplinary learning experiences about working as a scientist. Science21 is aimed at complementing students taking Physics, Chemistry, Biology and Earth Sciences, whereas Science in Practice stipulates that learning experiences should incorporate at least two of the following: Biology, Chemistry, Earth Science, Environmental Science and Physics. The main focus of Science21 is to provide students with a broad scientific understanding that will allow them to comprehend and participate in a society where scientific and technological innovation is ever present. Again, the Authority-registered syllabus Science in Practice 2015 is more practically focused. Both subjects share assessment items, including collections of work, investigations and supervised exam-like pieces. Because of the strong focus in the subject Science in Practice on interdisciplinary projects and practical hands-on investigations, this unit also overlaps with all the other Authority syllabuses in science that include extended experimental investigations.

### Comparison of syllabuses Science21 and Science in Practice

| Science21 2010 | Science in Practice 2015 |
|---|---|
| **Dimensions** | |
| • *Knowledge and conceptual understanding*<br>• *Investigative processes*<br>• *Issues and impacts*<br>• *Attitudes and values* | • *Knowing and understanding*<br>• *Analysing and applying*<br>• *Planning and evaluating* |
| **Course organisation** | |
| Five focus areas:<br>• Structure and properties of matter<br>• Living systems<br>• Earth and space<br>• Energy<br>• Information and communication<br>Four scientific priorities from which contexts must be drawn over the course of study. These are:<br>• Technology<br>• Health and wellbeing<br>• Catalysts for discovery<br>• Environment | Three core topics:<br>• Scientific literacy and working scientifically<br>• Workplace health and safety<br>• Communication and self-management<br>The core topics are learned through the electives (that are used to develop contextual units of work). These are:<br>• Science for the workplace<br>• Resources, energy and sustainability<br>• Health and lifestyles<br>• Environments<br>• Discovery and change |
| **Assessment** | |
| • Supervised written assessment<br>• Extended experimental investigation<br>• Extended response task<br>• Collection of work | • Project: authentic and/or real-world opportunities to demonstrate learning<br>• Collection of work: at least three assessable components that relate to the same topic<br>• Investigation: which involves locating data beyond a student's own knowledge and inquiry-based learning opportunities<br>• Extended responses to stimulus<br>• Examinations |

With an increased focus internationally and within Australia on teaching science the way that the profession of science is conducted including extended student-led investigations (Tytler 2007, Chubb 2013), the practical nature of Science in Practice is directly relevant to other Queensland Authority science subjects. Practical skills related to working safely and independently, and science in the workplace, may be beneficial requirements to integrate within Agricultural Science, Biology, Chemistry, Earth Science, Physics, and Marine Science. In the Science21 syllabus there is mention that this subject complements the other Authority science subjects. Because Science in Practice is more focused on the specific considerations of how science is conducted in the workplace than Science21, elements of this subject could also be incorporated into other Authority science subjects.

In a review of the status and quality of Year 11 and 12 science in Australian schools for the Office of the Chief Scientist, Goodrum, Druhan & Abbs (2012) found curriculum was heavy in content, and because of this there was little room for flexibility in teaching and learning practices. Given the practical focus of Science21 consideration should also be given to recommending or even requiring this subject for any students taking senior science. The teaching and practice of the core elements of scientific discovery in Science21 could then reduce the scope of learning experiences within senior science subjects, and free time for other experiences. Exposure to Science21 along with another senior science subject may then assist with increasing the skill and confidence of students undertaking extended investigations.

Both the Authority syllabus Science21 (2010) and the Authority-registered syllabus Science in Practice 2015 hold some similarity to the VET qualifications MSL20109 Certificate II in Sampling and Measurement; although the differences are substantial given the additional knowledge and theoretical concepts embedded within Science21 and Science in Practice. This VET qualification covers the skills and knowledge needed in ‘scientific’ workplaces such as laboratories, production or field operations in the construction, manufacturing, resources and environmental industry sectors. This certificate is made up of eight units including four core units and four electives and students are assessed based on competency.

## 2.2 Recommendations

### Recommendation 3

To incorporate into all senior science subject syllabuses, elements of the practical focus from Authority-registered subjects on how students work safely and effectively in a science workplace. The achievement of competency in practical scientific skills could be assessed separately as part of a checklist in a similar manner to the United Kingdom and New York State.

### Recommendation 4

To provide students completing the Authority-registered subjects Science in Practice 2015 and Agricultural Sciences 2014 with the option to be credited towards the calculation of OPs and FPs because of the significant overlap between these subjects and the Authority subjects Science21 and Agricultural Sciences; this may involve additional assessment focused on knowledge and theoretical constructs.

### Recommendation 5

To research the benefits of diversifying approaches to teaching, learning and assessment outlined in the syllabuses, depending on the specific characteristics of science subjects. This includes taking into consideration the recommendations from the Education and Innovation Committee 2013 report, e.g. numeric marking against standards, and focusing more on ensuring students understand and can apply the basic content of subjects like chemistry and physics.

## 2.3 Comparable syllabuses from selected Australian and international jurisdictions

Teaching, learning and assessment focuses vary across the three domestic and three international jurisdictions in terms of how they are prescribed, evaluated and moderated, especially with respect to the flexibility given to teachers to design their own curriculum, pedagogy and assessment. In New South Wales, Western Australia and Victoria senior science subject syllabuses are detailed in their prescription of content but concepts are generally described as ‘big ideas’. The ACA science syllabuses prescribe in great detail content coverage, allotted time for practical activities and assessment strategies particularly during Year 12 (A-levels), which are independent to Year 11. The Ontario and New York State syllabuses are less prescribed leaving more flexibility for teachers and schools to develop context-relevant student experiences.

In New South Wales senior science subjects are organised into preliminary units (Year 11) and Higher School Certificate (HSC) units (Year 12). A student must complete a preliminary course before studying that course for the HSC. BOSTES examines a large number of courses that then contribute to the Australian Tertiary Admission Rank (ATAR). Board Endorsed Courses are developed by schools, TAFE and universities and do not have an external exam: assessment is school-based. Board Endorsed Courses count towards a student’s HSC, but are not considered in the calculation of a student’s ATAR. All science subjects in New South Wales end with a HSC examination that makes up a substantial portion of a student’s assessment. In New South Wales VET courses can be studied either at school or through TAFE. VET courses can contribute towards a student’s HSC and Australian Qualifications Framework VET credentials, which are recognised by industry and employers throughout Australia. Some VET courses include an optional HSC exam so students can choose to have the result count towards their ATAR. Biology, Chemistry, Earth and Environmental Science, Physics and Senior Science are classified under the ‘science’ learning area. Agriculture appears under ‘technology’; Marine Sciences is a Board Endorsed Course, which does not contribute to the HSC; and Science Life Skills is a Life Skills Course and cannot contribute to ATAR. New South Wales senior science syllabuses prescribed the percentage of course time that should be spent on practical skills, and describe the breakdown of learning experiences into knowledge and understanding skills in planning and conducting first-hand investigations, and communicating and developing scientific thinking and problem-solving.

Both Western Australia (School Curriculum and Standards Authority) and Victoria (Victorian Curriculum and Assessment Authority or VCAA) have based their senior science syllabuses in these subjects on the Australian Curriculum, and therefore present very similar teaching, learning and assessment focuses. The courses are organised into four units, two delivered in Year 11 and two delivered in Year 12. In Victoria, there are also optional study areas for students, which are conceptualised differently to the Australian Curriculum. For example, in ‘Physics Unit 2: What do experiments reveal about the physical world?’, 12 options are available for selection in Area of Study 2. Each option is based on a different observation of the physical world. One option is selected by students from the following:

- What are stars?
- Is there life beyond Earth's Solar System?
- How do forces act on the human body?
- How can AC electricity charge a DC device?
- How do heavy things fly?
- How do fusion and fission compare as viable nuclear energy power sources?
- How is radiation used to maintain human health?
- How do particle accelerators work?
- How can human vision be enhanced?
- How do instruments make music?
- How can performance in ball sports be improved?
- How does the human body use electricity?

In Western Australia, senior science subject assessment is prescribed, with Year 11 and 12 assessment comprising the same types of assessment but sometimes weighted differently: science inquiry (Yr 11 = 30%, Yr 12 = 20%), extended response (Yr 11 = 10%, Yr 12 = 10%), test (Yr 11 = 25%, Yr 12 = 20%), and exam (Yr 11 = 40%, Yr 12 = 50%). In Victoria, the assessment levels of achievement in units 1 and 2 (Year 11) of senior science subjects are based on school decisions. In units 3 and 4 (Year 12) internal assessment comprises 40% (unit 3 16%, unit 4 24%), while the VCAA conducts the end of Year 12 examination worth 60%.

In the United Kingdom there are five A-level qualification authorities.[1] AQA is the focus of this report. In science subject syllabuses there are specific references to developing problem solving skills through understanding of the procedures needed for valid testing of ideas and, in particular, the collection, interpretation and validation of evidence. All units are assessed with written exams. In most science subjects practical skills are assessed separately by the teacher based on competency.

The Ontario Ministry of Education is responsible for senior science curriculum. There are four types of courses offered in Grade 11 and 12 science programs: university preparation, university/college preparation, college preparation and workplace preparation. Students are able to choose between these options based on their interests, achievement and postsecondary goals. There is just one science syllabus in Ontario that covers all subjects including Biology, Chemistry, Earth and Space Science, Environmental Science, Physics and Science (an equivalent subject to

[1] Welsh Joint Examinations Committee (WJEC) www.wjec.co.uk, Pearson Edexcel http://qualifications.pearson.com/en/home.html, Oxford, Cambridge and RSA Exams (OCR) www.ocr.org.uk, Examinations Assessment (CCEA) http://ccea.org.uk and AQA www.aqa.org.uk.

Science in Practice). Teaching and learning overviews are set out for each subject within the syllabus and include broad overviews of fundamental knowledge of, and skills relating to, the subject, as well as recommendations for 'big ideas' to be covered. Assessment is not specifically delineated for each of the subjects but is instead provided as an overview, where 70% of a student's achievement of overall expectations is conducted throughout the course and should reflect the student's most consistent level of achievement (special consideration can be given to more recent evidence of achievement). The remaining 30% of the grade is based on a final evaluation, which could be in the form of an 'examination, performance, essay, and/or other method of evaluation suitable to the course content and administered towards the end' (Ministry of Education 2008, p. 30).

The New York State Education Department is responsible for setting student learning expectations expressed as standards but it is the responsibility of each local school district to develop curriculums based on the standards and to develop pacing charts (which detail scoping and sequence). The idea behind this approach is to focus learning on conceptual understanding in the core content areas and to focus instruction on understanding important relationships, processes, mechanisms and applications of concepts. Assessment in the senior science course of New York State is focused on testing students' ability to explain, analyse, and interpret scientific processes and phenomena. At the end of Year 12, science students sit Regents Examinations and checklists of competency in scientific skills are recorded separately. The New York State Education Department develop and issue the Regents Examinations. These exams are created at a conference where selected teachers are invited from each of the disciplines to highlight the skills and knowledge that should be tested. The Regents Examinations are completed three years in advance to allow for testing and research.

## 2.4 Recommendations

### Recommendation 6

To consider how to maintain the flexibility Queensland senior science syllabuses offer schools and teachers in terms of the design of teaching, learning experiences and school-based assessment with the introduction of significantly weighted external assessment (up to 50% depending on the subject).

### Recommendation 7

To trial a longstanding practice in New York State and invite select groups of teachers from subject areas to participate in the preparation of external assessment for Queensland senior science subjects; and to prepare external assessment two to three years in advance to allow time for testing and research.

### Connections with the Australian Curriculum (AC)

| Syllabus type | Syllabus | Path | AC subject |
|---|---|---|---|
| **Authority syllabuses** | • Agricultural Science 2013<br>• Biology 2004, amended 2006 and 2014<br>• Chemistry 2007, amended 2014<br>• Earth Science 2000<br>• Marine Science 2013<br>• Physics 2007, amended 2014<br>• Science21 2010 | No<br>Yes<br>Yes<br>Yes<br>No<br>Yes<br>No | No<br>Yes<br>Yes<br>Yes<br>No<br>Yes<br>No |
| **Authority-registered syllabuses** | • Agricultural Practices 2014<br>• Aquatic Practices 2014<br>• Science in Practice 2015 | No<br>No<br>No | No<br>No<br>No |

The Authority syllabuses of Biology, Chemistry, and Physics have pathways from Foundation (Prep) Year to Year 10 in relation to the F–10 Australian Curriculum learning areas and also have a comparable senior secondary Australian Curriculum course. There is a pathway and comparable senior secondary course for Earth Science but it differs in that it incorporates both Earth and Environmental Science. Both Western Australia (School Curriculum and Standards Authority) and Victoria (VCAA) have based their senior science syllabuses in these subjects on the Australian Curriculum. Agricultural Science, Marine Science, Science21 and all three of the Authority-registered syllabuses lack pathways from Foundation (Prep) Year to Year 10 in relation to the F–10 Australian Curriculum learning areas and also lack comparable senior secondary Australian Curriculum courses.

In all four of the Authority syllabuses that have pathways and comparable secondary Australian Curriculum courses, the need for multidisciplinary curriculum is highlighted. In each science subject description, the pathways are described as multidisciplinary including a specific focus on the skills developed within mathematics and science inquiry strands.

In each of the science subjects, particular emphases are identified that will be further developed creating the pathway between F–10 Australian Curriculum and the senior secondary Australian Curriculum course. In Biology, this is identified as continuing to develop knowledge of how 'a diverse range of living things have evolved on Earth over hundreds of millions of years, that living things are interdependent and interact with each other and their environment, and that the form and features of living things are related to functions that systems perform.' In Chemistry this is identified as continuing to develop knowledge of how 'chemical and physical properties of substances are determined by their structure at atomic scale; and that substances change and new substances are produced by the rearrangement of atoms through atomic interactions and energy transfer.' In Physics this is identified as continuing to develop knowledge of how 'forces affect the behaviour of objects, and that energy can be transferred and transformed from one to another.’ Achievement standards across senior science subjects in the Australian Curriculum involve understanding concepts, models and application and developing inquiry skills. A unique feature of the Australia Curriculum is ‘representation of cross-curriculum priorities’. The cross-curriculum priorities include: an appreciation of Aboriginal and Torres Strait Islander Peoples’ knowledge; Asia and Australia’s engagement with Asia; and, exploring and investigating sustainability.

## 2.5 Implications for the redevelopment of Queensland syllabuses

There are similarities between Queensland syllabuses in Biology, Chemistry, Earth Science (although the Australian Curriculum subject combines Earth and Environmental Science) and Physics in terms of core content and knowledge acquisition. The Australian Curriculum senior subjects are more simply designed with just four units and a consistent set of achievement standards between Year 11 and Year 12, but an increase in expectations built into the standards from one year to the next. Most of the key features of the Australian Curriculum are incorporated into the Queensland syllabuses including inquiry learning and the understanding of concepts and processes, but the Queensland syllabuses involve a greater diversity of learning experiences, assessment opportunities and achievement standards. A feature of the Australian Curriculum that is not found in the Queensland syllabuses is the incorporation of cross-curriculum priorities. Embedding cross-curriculum priorities into senior science and also junior science curriculum could increase the number of students electing to study science by increasing the relevance and connection of these subjects to the pursuit of greater number of careers (Goodrum, et al. 2012).

## 2.6 Recommendations

### Recommendation 8

To facilitate opportunities for schools and teachers to incorporate cross-curriculum priorities into senior science courses such as an appreciation of Aboriginal and Torres Strait Islander peoples’ knowledge; Asia and Australia’s engagement with Asia; and exploring and investigating sustainability.

# 3 Learning expectations

## 3.1 Scope of learning across Australian and international jurisdictions

Across jurisdictions there are many similarities in how learning is scoped, organised and described, but the terminology used differs (Table 3). In all jurisdictions, learning is first described as broad aims or subjects and the content and skill development are then described in progressively more detail, and all jurisdictions describe sets of standards. New South Wales and New York State include descriptions of performance indicators. The AQA, Ontario, Western Australia and Victoria describe learning outcomes. Ontario is the only jurisdiction that scopes learning with course outcomes described in the context of the learning that will be attained by students, whether content or skills. Other jurisdictions have an initial focus on subject area content.

In Queensland science subjects, the learning scope is described as a set of general objectives that are derived from the interaction of the global aims, rationale and view of science and science education. The learning scope and depth of subject matters are developed within units of work and over the course of study; and should increase in complexity from Year 11 to 12. Learning is organised into broad principles of a respective science subject, a more detailed set of key concepts and finally with the most involved level of detail, descriptive key ideas. Learning is described within these key ideas as a set of standards.

In New South Wales science subjects, the learning scope is described as aims, objectives and a set of performance indicators. Learning is organised into a Year 11 preliminary course with four units and a Year 12 HSC course with three units and one an elective with set choices (20%), each course has a requirement of 120 hours. There is also a requirement to complete 80 hours of practical/field work with a requirement of greater than 35 hours in the HSC year. Learning is described within the syllabus as covering three domains:

- *knowledge and understanding*
- *skills* including planning, investigating, communicating information and understanding, developing scientific thinking and problem solving techniques and working individually and in teams
- *values and attitudes.*

In Western Australia science subjects, the learning scope is described as aims for Years 11 and 12 with mathematical skill expectations identified separately. Content within the science subjects is separated into the following:

- *science inquiry skills*
- *science as a human endeavour*
- *science understanding*.

Learning is organised into separate syllabuses for Years 11 and 12, which are each made up of two units, each a semester long and comprising 55 class contact hours. Each unit includes a description of the focus learning outcomes, which is a set of statements describing the learning expected, and unit content, which is to be taught and learnt. Learning is described as the attainment of a set of seven general capabilities:

1. *literacy*
2. *numeracy*
3. *information and communication technology and capability*
4. *critical and creative thinking*
5. *personal and social capability*
6. *ethical understanding*
7. *intercultural understanding.*

In Victoria science subjects, the learning scope is organised into aims, course overview, with course overviews separated into four core units without electives. The learning is organised into four units, two in Year 11 and two in Year 12, and each unit deals with between two to four areas of study, but also include optional study areas for students. Outcomes are then described within each of these study areas. Learning is described within each of the outcomes and these outcomes are broadly separated into key knowledge, which is presented as broad to more specific content statements, and key science skills. These are presented as behavioural, or action statements.

In the AQA the scope of learning is described as subject core content, which is further described with specifications in a two-column format. The left-hand column describes specific content that all students must cover and that can be assessed in written exams. The right-hand column exemplifies opportunities for skills to be developed throughout the course. As such, knowledge of individual experiments on the right-hand side of the table is not assumed knowledge for assessment. Learning is organised into two qualifications: Advanced Subsidiary Level Qualification (AS-levels) and Advanced Level Qualification (A-levels). AS-levels (equivalent to Queensland Year 11) can be taken as stand-alone qualifications or as the first part of an A-level (equivalent to Queensland Year 12). A-levels are distinguished from AS-levels with the aims of developing analytical skills, critical thinking and knowledge. Syllabuses are referred to as qualifications and within these qualifications specific references are made to mathematical skills, apparatus and techniques, and practical skills.

In Ontario, the scope of learning is described as course/student outcomes, and these outcomes are organised into six distinct but related strands. The first strand, referred to as A, focuses on scientific investigation skills that are similar for all courses; the remaining five strands (B to F) represent the major content areas for the course. Each of the Year 11 and 12 science courses is organised into these six strands. Learning is described in connection with the three goals of the science program that are to:

- relate science to technology, society and the environment
- develop the skills, strategies and habits of mind required for scientific investigation
- understand the basic concepts.

In New York State, the scope of learning is described as key ideas, which are broad, unifying, general statements of what students should know, understand and experience. Performance indicators are statements of what students should be able to do to provide evidence that they understand key ideas. Additional content is also provided in a section called 'major understandings' which are also linked to performance indicators. Learning is described as a set of standards for 'Mathematics, science and technology', which include:

- Students will use mathematical analysis, scientific inquiry and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.
- Students will access, generate, process and transfer information using appropriate technologies.
- Students will, through the integrated study of number sense and operations, algebra, geometry, measurement, and statistics and probability, understand the concepts of and become proficient with the skills of mathematics, communicate and reason mathematically and become problem solvers by using appropriate tools and strategies.
- Students will understand and apply scientific concepts, principles and theories pertaining to the physical setting and living environment and recognise the historical development of ideas in science.
- Students will apply technological knowledge and skills to design, construct, use and evaluate products and systems to satisfy human and environmental needs.
- Students will understand the relationships and common themes that connect mathematics, science and technology and apply the themes to these and other areas of learning.
- Students will apply the knowledge and thinking skills of mathematics, science and technology to address real-life problems and make informed decisions.

**Table 3: Summary of how learning is organised and described between the seven jurisdictions reviewed.**

| Jurisdiction | Learning expectations |
|---|---|
| **Queensland** | • broad principles<br>• key concepts<br>• descriptive key ideas; described as standards |
| **New South Wales** | • aims<br>• objectives<br>• performance indicators |
| **Western Australia** | • focus<br>• learning outcomes<br>• unit outcomes<br>• unit content |
| **Victoria** | • area of study<br>• outcomes; separated into knowledge and skills |
| **AQA** | • subject core content<br>• specific content<br>• skill development |
| **Ontario** | • course outcomes<br>• six strands: A (scientific investigations) and B–F (major content area that relates to the specific subject) |
| **New York State** | • key ideas<br>• performance indicators<br>• major understandings |

## 3.2 Recommendations

### Recommendation 9

To incorporate within the general objectives of science subjects a more explicit consideration of the role science plays in society, technology and the environment, which is the approach taken by Ontario and New York State. This may assist students to appreciate science as a career path, and scientific literacy as useful in decision-making within other careers and modern society (Tytler 2007, Goodrum, Druhan & Abbs 2012).Recommendation 10

To trial the approach taken by the AQA and New York State and more explicitly integrate mathematical and technological (use of sensors, data-loggers, modern scientific equipment, relevant software) learning experiences and skill development into Queensland senior science subject key ideas and standards.

# 4 Future focus: 21st century skills

Through its own initial research, QCAA has determined a set of 21st century skills that reflect current educational trends.

| 21st century skills | Elements |
|---|---|
| **Critical thinking** | • analytical thinking<br>• problem solving<br>• decision making<br>• reasoning<br>• reflecting and evaluating<br>• intellectual flexibility |
| **Creative thinking** | • innovation<br>• initiative and enterprise<br>• curiosity and imagination<br>• creativity<br>• generating and applying new ideas<br>• identifying alternatives<br>• seeing or making new links |
| **Communication** | • effective oral and written communication<br>• using language symbols and texts<br>• communicate ideas effectively with diverse audiences |
| **Collaboration and teamwork** | • relating to others (interacting with others)<br>• recognise and utilise diverse perspectives<br>• participating and contributing<br>• community connections |
| **Personal and social skills** | • adaptability/flexibility<br>• management (self, career, time, planning and organising)<br>• character (resilience, mindfulness, open- and fair-mindedness, self-awareness)<br>• leadership<br>• citizenship<br>• cultural awareness<br>• ethical (and moral) understanding |
| **ICT skills** | • operations and concepts<br>• accessing and analysing information<br>• being productive users of technology<br>• digital citizenship (being safe, positive and responsible online) |

## 4.1 Implications for the redevelopment of Queensland syllabuses

The 21st century skills identified by the QCAA to focus on in the future are essential and, although not new, there is a strong need in education for the teaching of these skills to be more explicit (Rotherham and Willingham 2010). These skills are also a list of generic capabilities relevant to most, if not all, academic disciplines. The nature of these skills arguably changes depending on context; and science has its own definitions and sets of learning experiences that relate to these skills (Fensham 200, Bybee 2015). This is implied throughout the Queensland science syllabuses, rather than explicit. In Western Australia, many of these skills have been explicitly drawn out as a list of seven general capabilities, which include personal and social capability, ethical understanding, and intercultural understanding. These 21st century skills could be embedded more explicitly as part of the learning descriptions so that the schools and teachers can envision these opportunities more clearly within the context of the subject matters being studied. What is essential is that these skills are taught within the context of science subjects and not separately since Queensland science subjects already contain reference to many of these skills, particularly within the general objectives of investigating and evaluating. What should be incorporated into the senior science syllabuses is an additional section that identifies explicitly where and how 21st century skills can be addressed within a senior science subject. This could include recommendations as to whether they could be assessed formatively and/or summatively (Silva 2009); or how skills could be modelled and practised during learning experiences with increasing complexity through to Year 12. Consideration should also be given to assessing collaborative working skills within Year 12 of senior science subjects, therefore replicating normative practice in scientific disciplines of working collaboratively across large interdisciplinary projects (Bell 2010).

21st century skills development in senior science subjects may assist students to transition to being a self-regulated learner. This represents a significant challenge, as it involves developing students' metacognitive skills (Martin, et al. 2000). Metacognition is defined as the ability to think about and evaluate your own thinking processes (Ausubel 1968). Meaning cannot be transmitted by a teacher, but is instead only created by students in the activities that they undertake (Biggs 1999). There is a large body of literature on understanding metacognition of science students at all different levels of their education (Martin, et al. 2000, Peters 2007, Watters and Watters 2007), but interestingly few studies have been conducted on teaching science students explicitly how to become more meaningful learners. Reflective practice and the impetus to become life-long learners are a key graduate capability, but one often not explicitly addressed in science (Schwartz, et al. 2003). At the same time, poorly integrated activities around self-reflection can feel contrived and meaningless for students.

Self-regulatory skills may already be displayed by some senior secondary students and some may already have developed strategies to effectively reflect and adapt over time, but the majority of secondary school leavers have not developed these strategies (Martin, et al. 2000). It is necessary for learning strategies to be explicitly taught with opportunities for formative feedback and advice on both the process and product (Peters 2007). The use of inquiry-based learning alone was not found to be effective at teaching students from an epistemological perspective, but inclusion of a reflection diary as part of the research task was found to encourage a deeper more philosophical understanding of the nature of science (Schwartz, et al. 2003). This process also functioned as a primer towards becoming a self-regulated learner ( Schraw, Crippen and Hartley 2006, Peters 2007).

Learning journals could be an option as formative or summative assessment across Year 11 and 12 of senior science subjects. Learning journals can be used as guided autobiographies or personal documents to facilitate opportunities for students to critically evaluate their own learning process and develop a more meaningful metacognitive approach to learning (Black, Sileo and Prater 2014). Learning journals can assist students in the development of professional practice that is reflective — the internal examination and exploration of an issue that is initiated by an experience which clarifies meaning and changes one’s thinking (Thorpe 2010).

Digital and online tools have increased the flexibility and range of types of reflection that are available for students to receive formative feedback on their reflections in learning journals (Gardner and Van der Veer 1998, Hartford 2005). Online communities of practice such as private Google Community sites could also be established to encourage reflective dialogue between students, collaborative working groups and teachers (Sherer, Shea and Kristensen 2003).

## 4.2 Recommendations

### Recommendation 11

To build opportunities within the curriculum for students to develop the skills of meaningful independent learners that may involve the use of learning journals as formative or summative assessment. Learning journals may also help to address concerns expressed by teachers that during inquiry-based group learning activities it can be difficult to distinguish individual student contributions (Education and Innovation Committee 2013).

### Recommendation 12

To avoid adding 21st century skills as an additional set of general capabilities for schools and teachers, but to embed more explicit reference to these skills throughout the syllabus, including an additional section within senior science syllabuses that explicitly detail where these skills could be developed within courses. Western Australia senior science syllabuses have adopted this model including describing learning as the attainment of a set of seven general capabilities.

# Bibliography

Ausubel, D 1968, *Educational Psychology: A cognitive view*, Holt, Rinehard and Winston, New York.

Barron, B 1998, 'Doing while understanding: Lessons from research on problem and project-based learning', *Journal of Learning Sciences*, vol. 7, pp. 271–311.

Bell, S 2010, 'Project-based learning for the 21st century: Skills for the future', *The Clearing House*, vol. 83, pp. 39–43.

Biggs, JB 1999, 'What the student does: Teaching for enhanced learning', *Higher Education Research and Development*, vol. 18, no. 1, pp. 57–75.

Black, RS, Sileo, TW and Prater, MA 2014, 'Learning journals, self-reflection, and univerity student's changing perceptions', *Action in Teacher Education*, vol. 21, no. 4, pp. 71–89.

Blumenford, PC, Soloway, E, Marx, RW, Krajcik, RW, Guzdial, M and Palincsar, A 1991, 'Motivating project-based learning: Sustaining the doing supporting the learning.' *Educational Psychologist*, vol. 26, no. 3, pp. 369–398.

Board of Studies, Teaching And Educational Standards (BOSTES) 2014, *New South Wales Senior Secondary Review and Evaluation: Science reference report*, www.boardofstudies.nsw.edu.au/australian-curriculum/pdf_doc/senior-secondary-reference-report-science-2014-08.pdf.

Bybee, R 2015, 'Scientific literacy', *Encyclopedia of Science Education*, pp. 944–947.

Chubb, I 2013, *Science, Technology, Engineering and Mathematics (STEM) in the National Interest: A strategic approach*, www.chiefscientist.gov.au/wp-content/uploads/STEMstrategy290713FINALweb.pdf.

Chubb, I 2014, 'Science, research and policy', paper presented to *Universities Australia Higher Education Conference*, Canberra.

Department of Education Training and Employment 2014, *Queensland Review of Senior Assessment and Tertiary Entrance*, Australian Council for Educational Research.

Education and Innovation Committee 2013, *The Assessment Methods in Senior Mathematics, Chemistry and Physics in Queensland Schools*, Education and Innovation Committee, Brisbane.

Edwards, PN, Jackson, SJ, Chalmers, MK, Bowker, GC, Borgman, CL, Ribes, D, Burton, M, & Calvert, S 2013, 'Knowledge infrastructures: Intellectual frameworks and research challenges', University of Michigan, Ann Arbor, http://hdl.handle.net/2027.42/97552.

Fensham, PJ 2009 'Real world context in PISA Science: Implications for context-based science education', *Journal of Research in Science Teaching*, vol. 48, no. 6, pp. 884–896.

Gardner, J & Van der Veer, G 1998, *The Senior Year Experience: Faciliating integration, reflection, closure and transition,* Jossey-Bass, San Francisco.

Goodrum, D, Druhan, A & Abbs, J 2012 *The Status and Quality of Year 11 and 12 Science in Australian Schools*, prepared for the Office of the Chief Scientist, Australian Academy of Science, Canberra.

Hartford, T 2005, 'Facilitation and assessment of group work using web-based tools', *Bioscience Education*, vol. 5, http://www.bioscience.heacademy.ac.uk/journal/vol5/beej-5.5.pdf.

Herrington, A & Herrington, J 2006, 'What is an authentic learning environment?', in A Herrington & J Herrington, *Authentic Learning Environments in Higher Education*, Idea Group Inc, Hershey, PA, pp. 1–8.

Martin, BL, JJ Mintzes & Clavijo, IE 2000, 'Restructuring knowledge in Biology: Cognitive processes and metacognitive reflections', *International Journal of Science Education*, vol. 22, no. 3, pp. 303–323.

Ministry of Education 2008, *The Ontario Curriculum Grades 11 and 12: Science*, http://www.edu.gov.on.ca/eng/curriculum/secondary/2009science11_12.pdf

Peters, EE 2007, 'The effect of nature of science metacognitive prompts on science students' content and nature of science knowlege, metacognition, and self-regulatory efficacy', Doctor of Philosophy thesis, George Mason University.

Rotherham, AJ & Willingham, DT 2010 '"21st-Century" skills not new, but a worthy challenge.' *American Educator*, vol. Spring, pp. 17–20.

Schraw, G, KJ Crippen & Hartley, K 2006, 'Promoting self-regulation in science education: Metacognition as part of a broader perspective on learning', *Research in Science Education*, vol. 3, pp. 111–139.

Schwartz, RS, Lederman, NG & Crawford, BA 2003, 'Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry', *Science Education*, vol. 88, pp. 610–645.

Sherer, PD, Shea, TP & Kristensen, E 2003, 'Online communities of practice: A catalyst for faculty development', *Innovative Higher Education*, vol. 27, no. 3, pp. 183–194.

Silva, E 2009, 'Measuring skills for 21st-century learning', *The Phi Delta Kappan*, vol. 90, pp. 630–634.

Thorpe, K 2010, 'Reflective learning journals: From concept to practice', *Reflective Practice: Interdisciplinary and multidisciplinary perspectives*, vol. 5, no. 3, pp. 327–343.

Tytler 2007, 'Re-imagining science education: Engaging students in science for Australia's future.' *Australian Education Review*, vol. 51, http://research.acer.edu.au/aer/3.

Watters, DJ & Watters, JJ 2007, 'Approaches to learning by students in the biological sciences: Implications for teaching', *International Journal of Science Education*, vol. 29, no.1, pp. 19–43.