Learning and Teaching Academic Standards Project

SCIENCE

Learning and Teaching Academic Standards Statement September 2011

AUSTRALIAN LEARNING & TEACHING COUNCIL
Promoting excellence in higher education

An initiative of the Australian Government Department of Education, Employment and Workplace Relations

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September 2011

EXECUTIVE SUMMARY

The Learning and Teaching Academic Standards (LTAS) project was established to facilitate and coordinate the definition and implementation of academic standards by discipline communities.

The approach for the Science LTAS project was defined at a Learning and Teaching Forum organised by the Australian Council of Deans of Science in Sydney on 15 July 2010. It was agreed to develop overarching threshold learning outcomes (TLOs) for bachelor degrees in science, with examples of how these could be adapted for specific disciplinary areas such as chemistry and mathematics.

Initial ideas for the science threshold learning outcomes were developed by the Discipline Scholars in conjunction with a small advisory group of academic experts. These ideas were then presented to the larger reference group with membership drawn from universities, professional societies, employer groups and students. A Reference Group, the Advisory Group and the Discipline Scholars revised the Science TLOs over a period of four months, considering feedback from a number of initial workshops, in order to produce a consultation paper for public comment in December 2010. This consultation paper contained the draft Science Standards Statement.

The consultation paper was distributed widely to the science sector in Australia. During February–April 2011, the science community was given many opportunities to comment on and contribute to the Science Standards Statement through consultation workshops at 32 universities, meetings with various representatives, an online survey and written submissions. The final version of the Science Standards Statement was endorsed by the Reference Group in early June 2011 and by the Executive of the Australian Council of Deans of Science on 22 June 2011.

The Science Standards Statement is intended to offer a succinct description of the nature and extent of science, and to describe the threshold (or minimum) level of achievement that can be expected of an Australian bachelor level graduate in science. The Statement is not prescriptive. Higher education providers are encouraged to design and deliver programs that reflect their niche by going beyond the five threshold learning outcomes or by requiring the learning outcomes be met at a higher standard in their own organisation. If implemented appropriately, the Statement will support each provider's autonomy, diversity and reputation. The Notes section provides a useful background to each learning outcome and provides guidance on how to interpret the different elements of each learning outcome statement.

In addition to the overarching work focused on science as a discipline, draft honours level threshold learning outcomes for science were developed in consultation with the Advisory Group; the chemistry community developed a Standards Statement for Chemistry; and an equivalent statement for mathematics is in development. A number of follow-up projects have been planned to assist with the implementation of the Science Standards, including the development of teaching activities and assessment tasks that facilitate student achievement of the TLOs.

The Australian Council of Deans of Science has maintained an active involvement in the Science LTAS project from its inception, and will continue to ensure carriage of the project's outcomes into science degree programs, particularly through curriculum design and renewal.

We are grateful to all who contributed to the development of the Science Standards Statement. The engagement with the academic, professional and student community has been very strong and the final outcome is truly a collegial achievement.

Endorsement

The Australian Council of Deans of Science (ACDS) commends the consultative process and the outcomes of the 2010–2011 ALTC Learning and Teaching Academic Standards project for science.

The Council endorses the Learning and Teaching Academic Standards Statement for Science as a generic, high-level statement of Bachelor of Science threshold learning outcomes.

The ACDS regards these generic science standards as a platform on which specific sub-discipline standards may be built and articulated. The project has demonstrated that this indeed can work with a sub-discipline group developing threshold learning outcomes for chemistry graduates based on this established generic framework.

Project Leaders

Discipline Scholars: Professor Sue Jones and Professor Brian Yates
Project Officer Dr Jo-Anne Kelder

1. Learning and Teaching Academic Standards Project Background

The Australian Government is developing a new Higher Education Quality and Regulatory Framework which includes the establishment of the Tertiary Education Quality and Standards Agency (TEQSA).

TEQSA will be a national body for regulation and quality assurance of tertiary education against agreed standards. In developing the standards, the Australian Government is committed to the active involvement of the academic community. The Australian Government has commissioned the ALTC to scope aspects of the Learning and Teaching Academic Standards component of the framework. The approach was designed to ensure that discipline communities would define and take responsibility for implementing academic standards within the academic traditions of collegiality, peer review, pre-eminence of disciplines and academic autonomy.

In 2010–11, both directly through a specific contract and indirectly through base funding of the Australian Learning and Teaching Council, the Australian Government funded a demonstration project to define minimum discipline-based learning outcomes as part of the development of Learning and Teaching Academic Standards.

The project took as its starting point the award-level descriptors defined in the Australian Qualifications Framework (AQF). Threshold learning outcomes (TLOs) were defined in terms of minimum discipline knowledge, discipline-specific skills and professional capabilities including values and behaviours that are expected of a graduate from a specified level of program in a specified disciplinary area. The process took account of and involved the participation of professional bodies, accreditation bodies, employers and graduates as well as academic institutions and teachers. These representatives of the discipline communities were encouraged to take responsibility for the project and the outcomes within broad common parameters. Some disciplines extended the brief to begin consideration of the implications of implementing standards at institutional level.

1.1 Disciplines encompassed by the demonstration project

Discipline groups were defined according to Australian definitions of Field of Education from the Australian Standard Classification of Education. They correspond to the most common broad structural arrangements of faculties or aggregates of departments within Australian universities.

Ten broad discipline groups participated in the project:

- architecture
- arts, social sciences and humanities
- building
- business, management and economics
- creative and performing arts
- education
- engineering and ICT
- health, medicine, and veterinary science
- law
- science.

Discipline Scholars were appointed to lead each discipline. The key deliverable for each Discipline Scholar was the production of a document of minimum learning outcomes for a specified discipline at an agreed AQF level or levels. This booklet represents that outcome for this discipline.

2. Science in the Learning and Teaching Academic Standards Project

2.1 Scope

For the purposes of this project, the science discipline grouping encompasses a range of disciplinary areas, including:

- agricultural sciences
- biological sciences
- chemical sciences
- earth sciences
- environmental sciences
- mathematical sciences
- physics and astronomy.

It does not include, for example, engineering, information and communication technology, architecture, psychology and the behavioural sciences. In addition, this grouping does not include those health or veterinary sciences which include a component of health care delivery.

2.2 Rationale

Documentation available on academic standards for science discipline areas from Europe, the UK and other countries, in particular, the European Tuning Project and UK Quality Assurance Agency (QAA) statements, were taken into account. In most cases, these documents describe subject-specific standards (for example, separate sets of standards for chemistry, physics and mathematics). This project has taken the broader approach of defining learning outcomes for a science graduate. This approach was endorsed by a group of colleagues at the workshop presented by Professor Christine Ewan and the Discipline Scholars at the Australian Council of Deans of Science (ACDS) Learning and Teaching Forum, Sydney, 15 July 2010.

Thus, the primary project goal was to identify and define a set of Threshold Learning Outcome (TLO) Statements for graduates of bachelor degrees in science (not specifically the Bachelor of Science). The focus was to define a set of Science TLOs that are common to all disciplinary areas encompassed within the science cluster.

A second goal was to demonstrate that the Science TLOs could be adapted successfully to specific disciplinary areas within science. Chemistry and mathematics were nominated as being appropriate groups to test this because they represent an experimental and a non-experimental disciplinary area. In addition, there is substantial international documentation regarding standards for chemistry and mathematics graduates via, for example, the Tuning and QAA Projects. Thus, separate working parties were set up for chemistry and for mathematics (Appendix 2). Their brief was to adapt the emerging Science TLOs to their disciplinary context and to seek consensus on these from their discipline community.

This project did not address multi-disciplinary science degrees that have significant components from non-science disciplines. However, the Science TLOs will relate to the science-specific components of those degrees. It is also recognised that although some science-related degrees, e.g. biomedical sciences, may not be situated within faculties of science, the Science TLOs will be applicable to those degrees.

2.3 Consultation and development process

The approach for the Science Learning and Teaching Academic Standards (LTAS) project was first presented at the Teaching and Learning Forum of the Australian Council of Deans of Science (ACDS) on Thursday, 15 July 2010. This approach was formally endorsed by the Executive of the ACDS.

The timeline for this project was:

July–December 2010	Initial consultation and development of draft Science Standards Statement (SSS)
January–April 2011	Widespread consultation and revision of the SSS, focussing particularly on the TLOs
May–June 2011	Final review of the SSS.

To ensure comprehensive stakeholder input in the development of the TLOs, the Discipline Scholars engaged in a sustained and iterative program of communication and consultation with science stakeholders. Communication mechanisms to provide opportunities for stakeholders to find out about the project were:

- science contributions to the national LTAS project's *Disciplines Setting Standards* newsletter
- the *LTAS – Science* webpage
- three *LTAS – Science Project* newsletters (December 2010, April 2011, June 2011).

Stakeholders could sign up to receive updates on the project via a Survey Monkey link and workshop participants also provided their contact details. The project communication database grew to around 750 individual stakeholders by the conclusion of the project.

Development of the Draft Science Standards Statement

In consultation with the Executive of the ACDS, an Advisory Group of four discipline experts was formed to provide prompt feedback and expert advice (Appendix 1). The formal process of writing TLOs for science was begun at the first Advisory Group meeting on Thursday, 19 August 2010. Background material for this meeting included the Australian Qualifications Framework descriptors, documents from the UK Quality Assurance Agency, material from the European Tuning project and examples of graduate attributes for science graduates from a number of universities across Australia.

With further assistance of the Executive of the ACDS, a Science Discipline Reference Group was formed, consisting of a broad representation of stakeholders, including academic discipline experts, peak professional bodies, employer groups and students (listed in Appendix 1). The primary role of the Reference Group was to provide input into the development of the Science TLOs (see Appendix 1 for the Terms of Reference for the Science Reference Group).

The Reference Group initially met on Monday, 27 September 2010. The main points of discussion at the Reference Group meeting were:

- the draft TLO statements as initially developed with the Advisory Group
- what learning outcomes specifically characterise science graduates versus those that are generically applicable to all bachelor level graduates
- whether over-arching science TLO statements can accommodate both experimental and non-experimental sciences
- employer expectations of science graduates.

Presentations in the first phase of the project (informing the science community about the project and inviting responses) are listed below:

29 September	Royal Australian Chemical Institute (RACI) accreditation committee
30 September	UniServe Science Conference
19 October	Australian Council of Deans of Science AGM
27 October	Macquarie University (Teaching and Learning meeting)

2 November	University of Tasmania (UTAS) Faculty of Science, Engineering and Technology Heads of School
3 November	UTAS Local Reference Group of science education experts
5 November	UTAS Academic Senate
5 November	Royal Australian Chemical Institute (RACI) Tasmanian Branch
10 November	Queensland University of Technology (Curriculum renewal workshop)
11 November	University of Western Sydney (Curriculum renewal workshop)
13 November	RACI National Assembly
17 November	Australian Learning and Teaching Council Assessment Forum
18 November	Australian Technology Network Assessment Conference
23 November	ACDS Teaching and Learning Forum
30 November	Australian Academy of Science
1 December	University of Queensland (curriculum renewal workshop)
8 December	La Trobe University (curriculum renewal workshop).

The Reference Group met for a second time on Wednesday, 24 November 2010 to discuss draft versions of the TLOs and the draft Science Standards Statement December 2010 prior to its dissemination as a consultation paper to the broader discipline community. This version of the Science Standards Statement was the product of a five-month process of consultation and communication with a local reference group of University of Tasmania academics within the Faculty of Science, Engineering and Technology, the Advisory Group and Reference Group. In addition, feedback was harvested at the presentations and workshops as listed above.

Consultation on the Draft Science Standards Statement

From December 2010 to 15 April 2011, the project team invited formal and informal responses to the draft Science Standards Statement from all stakeholders. Mechanisms for feedback were an online survey, face-to-face workshops and formal submissions.

Online Survey

An online survey was developed to provide stakeholders with a mechanism for comment that was accessible, simple to complete and provided a structured format for commenting on each element of the draft TLOs.

Specifically, the aims of this survey were to:

- gather quantitative evidence on the extent of sectoral agreement on the TLOs for Science
- gather qualitative feedback on individual TLOs
- establish general perceptions on whether current Australian science degree programs allow ALL graduates to meet these ideal TLOs
- identify the extent to which stakeholders think the longer-term objectives of the project in science will be met and mechanisms to support its implementation.

Preliminary survey questions (n=122 respondents) gathered demographic data (level of science education; respondent perspective (student, science graduate, employer, university academic) and discipline perspective, e.g. chemistry, mathematics, etc. Respondents were then asked to evaluate the TLO categories as ‘not relevant, relevant, important, essential’, as well as to suggest alternative categories. The TLO statements were then broken into elements and respondents asked to evaluate each element, e.g. “Have a broad knowledge of science”, according to “Importance for ALL science graduates” and “Extent of development in current degree programs” on a five-level scale from ‘Low’ to ‘High’. Free text boxes were available for further comment, which many respondents used, providing significant and useful insights into their thinking. The last section of the survey asked for responses to the longer-term objectives of the LTAS project, the perceived usefulness of the TLO statements and future steps to ensure longer-term outcomes are sustained.

Consultation Workshops

All Australian universities that deliver science degree programs were requested (via Associate Deans, Teaching and Learning) to host a workshop and invite academics, students and employers of science graduates to participate. The first consultation workshop to critique and evaluate the draft Science Standards Statement was hosted on 4 February 2011 by the Brisbane Universities Network of Science Educators (BUNSE) at the Queensland University of Technology. Three workshops were conducted after the formal consultation period had ended. Some institutions opted to host a workshop jointly or to attend a workshop hosted nearby.

2011	HOST UNIVERSITY
4 February	Queensland University of Technology
11 February	Charles Sturt University (4 campuses)
18 February	The University of Melbourne
21 February	University of Western Sydney (3 campuses)
01 March	Southern Cross University
08 March	The University of Sydney
11 March	Flinders University
15 March	Griffith University
16 March	Murdoch University
17 March	Edith Cowan University
17 March	University of Notre Dame
18 March	Curtin University
21 March	University of Technology, Sydney
24 March	Universities of Adelaide and South Australia
25 March	RMIT University
28 March	University of Canberra
29 March	Australian National University
30 March	University of New England
6 April	University of Ballarat
7 April	Deakin University
7 April	The University of Melbourne
8 April	Macquarie University
11 April	Swinburne University
12 April	La Trobe University
13 April	Monash University
14 April	James Cook University
15 April	Charles Darwin University
19 April	The University of New South Wales
21 April	University of Tasmania
19 May	University of Sunshine Coast
20 May	Central Queensland University.

Representatives from the Australian Academy of Science, the Australian Catholic University, the Australian Defence Force Academy, Commonwealth Scientific and Industrial Research Organisation (CSIRO), South Australian Government Department of Further Education, Employment, Science and Technology (DFEEST), Lachlan Macquarie College, The University of Western Australia and Victoria University attended hosted workshops. Some additional meetings were held with specific stakeholder groups (teaching and learning staff, and students) at several universities.

Formal Submissions

Formal submissions were received from the following organisations and people:

- Association of Mining and Exploration Companies (Inc.)
- Chemskill
- Australian Institute of Geoscientists
- Geological Society of Australia
- Professor Peter Adams, The University of Queensland
- Associate Professor Peter Meier, University of Technology Sydney.

In addition, several informal comments were emailed to members of the project team.

Final revision and endorsement of Science Standards Statement

Revisions to the draft standards were made in light of advice from the discipline community. A further mapping was conducted to ensure the bachelor TLOs were aligned with the AQF level 7 descriptors and the Dublin descriptors (cycle 1) used by Tuning Europe (Appendix 5). Responses to the document from the discipline community were a key part of the revision process. The revised version of the Science Standards Statement document was presented to the Science Discipline Reference Group on 4 May 2011, generating further advice and prompting further revision.

The final version of the Threshold Learning Outcome Statements, accompanying notes and statement on the nature and extent of science were endorsed by the Australian Council of Deans of Science on 22 June 2011.

Additional project outcomes

The Chemistry Working Party successfully adapted the Science TLOs to the chemistry context. They produced a final report to the Discipline Scholars in the form of a Standards Statement for Chemistry (Appendix 3).

Work is in progress on an equivalent document for the mathematical sciences.

A draft set of TLOs for honours degrees in science was developed by the Discipline Scholars and the Science Advisory Group. As there was no opportunity for consultation on these honours TLOs, the project team did not seek their endorsement by the Australian Council of Deans of Science. There is some debate as to the future of honours as a pathway into professional or research work in science in Australia. The draft honours TLOs are, therefore, provided (Appendix 4) as a foundation for future development and discussion.

A selective list of resource material related to developing learning and teaching academic standards for science has been compiled (see Appendix 6).

3. Learning and Teaching Academic Standards Statement for Science

This Science Standards Statement contains a description of the nature and extent of science, a statement of the Science Standards expressed as threshold learning outcomes (TLOs), and some descriptive notes that provide a framework for understanding, interpreting and applying the TLOs. It provides a foundation for the evaluation of current science degree programs and for future curriculum development.

3.1 Nature and extent of science

Science encompasses both a body of knowledge and a reliable process of discovery; "it is a path to understanding".[1]

The British Science Council provides the following definition: "Science is the pursuit of knowledge and understanding of the natural and social world following a systematic methodology based on evidence"[2]. In this context, the 'natural world' refers to any aspect of the physical universe. This includes matter, the forces that act on matter, energy, the biological world, humans, human society and the manufactured products of that society.[2]

Science is founded upon the recognition of fundamental laws that make nature systematic and reproducible. Scientists observe, measure, classify and perform experiments upon the natural world. They employ scientific methods to test hypotheses and use empirical evidence to support or refute their hypotheses. The natural variability, or uncertainty, inherent in the natural world means that scientific conclusions are reliable but contestable; they may be revised or modified as new evidence emerges. Scientists are curious about the natural world and are creative in formulating hypotheses and in designing approaches to problem solving.

It must be acknowledged, however, that science includes a broad spectrum of disciplinary areas which may have significant differences in philosophy and methodology. Mathematics and related disciplines are sometimes termed the 'formal sciences'. The formal sciences are founded upon axioms and proofs rather than empirical experimentation and, as such, are differentiated from the so-called 'natural sciences'. The methods of mathematics are used by other science disciplines to model and analyse real-world systems using a wide variety of numerical techniques and mathematical ideas. Scientific data are often analysed and interpreted using statistical methods.

Science operates within a paradigm of peer review and replication that provides a collective responsibility for the reliability of scientific knowledge. Scientists have a responsibility to communicate the outcomes of their work clearly, accurately and without bias to their peers and to society.

Science is embedded in a context that reflects both the history of scientific endeavour and the culture of present society. Scientists generate and build knowledge, develop technologies, investigate and solve problems. They must be accountable to society for their work, maintain the professional standards of science, and conduct themselves in an ethical manner.[3]

1. University of California, Museum of Paleontology. Understanding science 101.Retrieved from: <http://undsci.berkeley.edu/article/whatisscience_01> 17 November 2010.

2. The Science Council (2010). What is science? Retrieved from: <http://www.sciencecouncil.org/content/what-science> 17 November 2010.

3. Committee on Science, Engineering, and Public Policy, National Academy of Sciences, National Academy of Engineering, and Institute of Medicine (2009). On being a scientist: A guide to responsible conduct in research. 3rd edn. Retrieved from: <http://www.nap.edu/catalog/12192.html> 9 June 2011.

3.2 Australian science graduates

While they will have received a broad education in science, Australian graduates with bachelor level degrees in science may or may not work as scientists. A study by the Australian Council of Deans of Science[4] found that eight years after graduation about 50 per cent of science graduates are employed in science, technology or related positions, while the remaining 50 per cent find managerial or other professional employment outside science. These graduates apply the skills and knowledge they have developed during their science degree to a diverse range of professions such as public servant, educator, intellectual property researcher, patent attorney, journalist, business analyst or banking professional.[5]

Submissions to this project by industry groups show that employers value a core set of scientific knowledge and skills, personal motivation, ethical conduct, verbal and communication skills, and personal skills in team work, with potential for leading teams. Also valued is graduate adaptability and willingness to perform scientific work in fields broader than the training of their disciplinary area.[6]

Many of the issues which face contemporary society demand a scientifically literate community. The Australian Academy of Science articulates this as follows:

> Many big challenges loom for Australia – in health, energy, water, climate change, infrastructure, sustainable agriculture and preservation of biodiversity. To tackle these challenges, we need highly creative scientists and engineers, drawn from many disciplines, and a technologically skilled workforce. We need leaders and policy-makers who are scientifically well-informed. We need a scientifically literate community.[7]

To meet this challenge, we need to review our science curricula to ensure that all our science students can acquire the graduate capabilities that will equip them to be scientifically literate members of society. The Threshold Learning Outcomes for Science will assist in this task.

4. Australian Council of Deans of Science (2001). Why do a science degree? (ACDS Occasional Paper No. 2). May 2001. Retrieved from: <http://www.acds.edu.au/whydoa.html> 17 November 2010.
5. Careers for Science Graduates. Graduates Careers Australia. Retrieved from: <http://www.graduatecareers.com.au/ucm/groups/public/documents/document/careers_for_science_graduates.pdf> 17 November 2010.
6. Submissions received from Association of Mining and Exploration Societies, Australian Institute of Geoscientists, Chemskill, Geological Society of Australia and Geoscience Australia (2011).
7. Australian Academy of Science (10 August 2010) Academy 2010 election statement: 'Empower science, power the future'. Retrieved from: <http://www.science.org.au/reports/election-statement.html> 26 November 2010.

4. Threshold Learning Outcomes for Science

	Upon completion of a bachelor degree in science, graduates will:
Understanding science	1. Demonstrate a coherent understanding of science by: 1.1 articulating the methods of science and explaining why current scientific knowledge is both contestable and testable by further inquiry 1.2 explaining the role and relevance of science in society.
Scientific knowledge	2. Exhibit depth and breadth of scientific knowledge by: 2.1 demonstrating well-developed knowledge in at least one disciplinary area 2.2 demonstrating knowledge in at least one other disciplinary area.
Inquiry and problem solving	3. Critically analyse and solve scientific problems by: 3.1 gathering, synthesising and critically evaluating information from a range of sources 3.2 designing and planning an investigation 3.3 selecting and applying practical and/or theoretical techniques or tools in order to conduct an investigation 3.4 collecting, accurately recording, interpreting and drawing conclusions from scientific data.
Communication	4. Be effective communicators of science by: 4.1 communicating scientific results, information, or arguments, to a range of audiences, for a range of purposes, and using a variety of modes.
Personal and professional responsibility	5. Be accountable for their own learning and scientific work by: 5.1 being independent and self-directed learners 5.2 working effectively, responsibly and safely in an individual or team context 5.3 demonstrating knowledge of the regulatory frameworks relevant to their disciplinary area and personally practising ethical conduct.

5. Notes on the Threshold Learning Outcomes for Science

These notes are intended to offer guidance on how to interpret the Threshold Learning Outcome (TLO) statements. The notes and the TLOs should be considered in the context of the statement of the 'nature and extent of science'.

These TLOs have been developed to describe a pass level graduate from a bachelor degree program. A 'bachelor degree' is defined according to the Australian Qualifications Framework (AQF), within which it represents a level 7 qualification. Appendix 5 provides a comparison of the Science TLOs with the AQF and the Dublin Descriptors used by Tuning Europe for bachelor level (cycle one) qualifiers.

The TLOs are not intended to be equally weighted across the degree program, nor does the numbering imply a hierarchical order of importance. However, the numbering may be used to provide easy reference to a specific TLO.

In many places in this and other ALTC documents, the word 'discipline' has been used to describe the overarching field of science. This usage is applied consistently throughout this document. However, we acknowledge that this term might be more commonly used to describe 'disciplinary areas' such as chemistry, physics, mathematics and biology. Where necessary, care has been taken to refer to these disciplinary areas explicitly.

Some general definitions

Learning outcomes: The set of knowledge, skills and/or competencies a person has acquired and is able to demonstrate after completion of a learning process. In the AQF these are expressed in terms of knowledge, skills and application.

Threshold: Minimum standard of achievement or attainment.

Understanding science

A coherent understanding: Graduates need an appreciation of science as a broad discipline. They will have a general understanding of scientific principles and the nature of science.

TLO 1.1

The methods of science: Although science is a systematic and logical study of phenomena, it is also about creating new knowledge and designing new frameworks in which to understand the natural world. Science graduates will understand the innovative and creative aspects of science and the need to think beyond the confines of current knowledge.

Science graduates will be able to recognise the limitations of the methods of science as well as their strengths, and understand that sometimes serendipity is involved in making new discoveries.

Contestable: A science graduate will have an appreciation and understanding of the historical evolution of scientific thought. A science graduate will understand the need to re-evaluate existing conclusions when subsequent findings become available.

Testable: All scientific knowledge is, in principle, testable. A science graduate will understand that many scientific 'facts' have already been tested (and can be reproduced), while other scientific knowledge has been developed by a logical process of scientific thought and awaits testing by experiments which have yet to be designed. Scientific knowledge is dynamic.

TLO 1.2

Role and relevance: This phrase encompasses the impact, significance and relevance of science to society. Science graduates will have a holistic or overarching understanding of the role of science, and will understand that science creates both challenges and opportunities for society at both the local and global level. Graduates will be able to place current scientific issues within the context of their understanding of science.

Society: The impact of science is very broad and a science graduate will understand that 'society' includes not only the local community in which they live, but may also include one's fellow students and academic colleagues; the social, environmental, technological, industrial and military sectors; and the world-wide community of scholars and others.

Scientific knowledge

Depth and breadth: Science graduates will have depth of knowledge in a particular disciplinary area. Science graduates will be able to understand how their disciplinary area relates to others and integrate their knowledge across the various disciplinary areas in which they have studied.

Scientific knowledge: This is the currently accepted body of facts and theories that has arisen from a systematic study of the natural world.

TLO 2.1 and 2.2

Well-developed knowledge versus knowledge: Science graduates will have specialised in their study and will have acquired a coherent body of knowledge in a particular disciplinary area (which may be recognised as a major in a science degree). They will understand the structure of this knowledge and the way it is integrated, and have some command of the principles, concepts and core knowledge of the disciplinary area.

At the same time, a bachelor level science graduate will be expected to have at least a basic foundation of knowledge in one or more other disciplinary areas.

Disciplinary area: This term is used in this document to describe a sub-discipline of science, such as mathematics, physics, chemistry, biology, earth sciences or agriculture. This term is intended to cover any coherent body of scientific endeavour which is readily distinguished from other areas of science.

Inquiry and problem solving

Critically analyse: Graduates will use critical thinking skills to analyse and solve problems.

Scientific problems: Graduates will have the skills to solve problems with well-defined parameters, as well as tackle more open-ended research questions.

TLO 3.1

Gathering and synthesising information: Science graduates will be able to identify, access, select and integrate information.

Critically evaluating information: It is important that science graduates are able to assess the validity of the information that they gather in the context of their knowledge and understanding of science as described in TLO 1.1.

Range of sources: This term is used to indicate that information can be gathered from traditional sources (including books, refereed papers and journal articles, conference presentations, seminars, lectures and colleagues) as well as non-traditional sources (including non-refereed articles, reports, 'grey literature' and electronic posts). It also could include information that is generated through experimentation or the analysis of existing data.

TLO 3.2

Designing and planning: Science graduates will be able to apply a sequence of data acquisition, analysis and the drawing of conclusions that is recognised as a 'scientific method' in the appropriate disciplinary area. They will be able to form hypotheses in a logical manner and then design activities or experiments to test these hypotheses. This supports a systematic approach to problem solving. In addition, science graduates will have an appreciation of how to frame a problem so that it might be solved in a creative and innovative way by applying scientific method.

TLO 3.3

Selecting and applying: Through their undergraduate training, science graduates will have some knowledge of the most appropriate techniques to use to solve different types of problems.

Practical and/or theoretical techniques: It is recognised that practical, experimental and field techniques will vary from one area of science to another. Science graduates will be able to use practical techniques that are appropriate for their disciplinary area, and will have an appreciation of the techniques used in other areas of science. They will be prepared to work in the office, the laboratory or the field, as appropriate to their disciplinary area.

Tools: The tools of science might include instruments, apparatus, mathematical and statistical approaches including modelling, or information and communication technologies.

TLO 3.4

Collecting and accurately recording: It is important that science graduates can accurately record data from experiments or other sources. They will understand that, while different scientists may interpret the data differently, the raw data themselves are inviolate.

Interpreting data and drawing conclusions: Science graduates will be able to use holistic forms of analysis and explanation to interpret data. They will have the capacity to develop arguments and draw valid conclusions based on their interpretation of the data.

Scientific data: Science graduates will use reproducible evidence which is able to be verified. Quantitative evidence will have been evaluated using one or more of the techniques of reproducibility, numerical uncertainty, precision or statistical analysis. In addition, qualitative evidence may also be used to inform scientific judgements.

Communication

TLO 4.1

Communicate: This term implies more than just presenting information. Science graduates will engage with their audience and be able to convey their message in a clear and understandable manner. In particular, science graduates will be able to present quantitative data in a variety of ways, including charts, graphs and symbols, which show clearly the trends or conclusions from their analysis as well as the accuracy of the underlying data.

A range of audiences: Science graduates will be able to communicate with their peers, scientific non-experts and the general community.

A range of purposes: Science graduates will be able to present their findings in both a technical and non-technical manner. They will use scientific language correctly and appropriately and follow the conventions of discipline-specific nomenclature. This might include the use of standard symbols, units, names or key terms. Science graduates will be aware of the need to communicate the details of their investigations according to conventions that are usually specific to their sub-discipline, and which may be defined by publishers, editors or professional associations.

A variety of modes: Science graduates will communicate using a range of media, including both written and oral, and a variety of other techniques. Such communication could include a range of formats (such as technical report, newspaper or journal article, and poster presentation) and new media (such as wikis, blogs and podcasts).

Personal and professional responsibility

TLO 5.1

Independent and self-directed: Science graduates will take responsibility for their own learning. They will be able to work autonomously and evaluate their own performance. In order for science graduates to make an ongoing contribution to a society in which scientific knowledge is continually evolving, it is important that they are motivated to continue to learn after graduation. This is also referred to as lifelong learning.

TLO 5.2

Working effectively, responsibly and safely: A graduate in science will understand how to take responsibility for themselves and others in the conduct of scientific investigations or in other work situations. This term includes the occupational health and safety requirements of some forms of scientific work. It also includes, for example, an understanding of time management and the onus on individuals to fulfil their role as part of team projects.

Individual context: Science graduates will be able to work independently with limited supervision.

Team context: Science graduates will have gained the skills to function effectively as members or leaders of scientific or multidisciplinary teams. They will appreciate that science is primarily a collaborative activity.

TLO 5.3

Regulatory frameworks relevant to their disciplinary area: Science graduates will have an awareness of the regulatory frameworks that apply to their disciplinary area. These might be the legal frameworks for experimentation and data collection, quality control procedures, or the necessity to obtain government permits for certain types of activity. They will be prepared to abide by these regulatory frameworks as they move into professional employment, and understand the consequences if they do not.

Ethical conduct: Science graduates will have demonstrated that they learned to behave in an ethical manner during their period of undergraduate study and are equipped to do so into the future. This might include accurate data recording and storage, proper referencing and avoidance of plagiarism, intellectual integrity, animal ethics or human ethics. It is important that science graduates have some understanding of their social and cultural responsibilities as they investigate the natural world.

6. Future steps

The Science Threshold Learning Outcomes provide a foundation for articulating and developing the higher education science curriculum, and for improving learning and teaching in science at the university level. It is envisaged that a number of follow-up activities to this ALTC project will be undertaken and that many of these activities will be driven by the Australian Council of Deans of Science.

Suggested implementation activities for the higher education science sector

Suggested implementation activities include:

- map university science curricula against the Science TLOs
- develop examples of teaching activities to achieve TLOs
- develop examples of assessment of the learning outcomes
- develop TLOs for a number of different disciplinary areas of science, as have been developed for chemistry
- define the relationship between the TLOs and accreditation
- plan for ongoing review of the TLOs and monitor their effectiveness in supporting curriculum development.

Appendix 1: Terms of reference and membership of advisory panels

Discipline Reference Group

Terms of Reference

The Reference Group will support the implementation of the Learning and Teaching Academic Standards (LTAS) project as defined in the project plan for each discipline group. The Discipline Reference Group is convened by the Discipline Scholars. The focus of the Reference Group will be TLOs for science graduates at bachelor degree level. Two working parties (chemistry and mathematics) will be formed in the project, led by chemistry and mathematics experts, to adapt the Science TLOs to these sub-disciplines.

The Science Discipline Reference Group will have the following Terms of Reference:

- provide advice to the Discipline Scholars on the direction and implementation of the Science LTAS project
- review drafts of project-related material, including statements of threshold learning outcomes
- assist the Discipline Scholars in communicating and engaging commitment across the science discipline community and relevant stakeholders
- consider and approve the draft threshold learning outcomes prior to their dissemination to the broader discipline communities and facilitate such dissemination
- consider and endorse the final TLO statements for reporting to ALTC
- facilitate dissemination of the TLOs developed by this project
- provide expert advice to the Discipline Scholars and the ALTC on the next steps to be undertaken once the TLO statements for science undergraduate degrees have been approved and endorsed
- the Reference Group will take advice from the chemistry and mathematics working parties on the application of the Science TLOs to their specific sub-disciplines.

Membership

Chair	Professor Will Price (Chair of Reference Group), Secretary/Treasurer, Australian Council of Deans of Science (ACDS); Dean of Science, University of Wollongong
Professional Societies	Dr Cathy Foley, President, Federation of Australian Scientific and Technological Societies (FASTS); Chief Research Scientist, CSIRO Materials Science and Engineering
	Associate Professor Brian James, President, Australian Institute of Physics (AIP), School of Physics, The University of Sydney
	Associate Professor Roger Read, Nominee of the Royal Australian Chemical Institute (RACI); Associate Professor, School of Chemistry, and Associate Dean (Research and International), Faculty of Science, The University of New South Wales
	Professor John Rice, Executive Director, ACDS; Honorary Professor, Department of Mathematics and Statistics, The University of Sydney
	Dr Leigh Wood, Nominee of the Australian Mathematical Society (AustMS); Associate Dean, Learning and Teaching, Faculty of Business and Economics, Macquarie University

Discipline-based experts and associate deans

Ms Karen Burke da Silva	First year Biology coordinator/lecturer, Flinders University
Professor Ian Fitzsimons	Professor, Department of Applied Geology, WA School of Mines, Curtin University
Associate Professor Victor Galea	Senior Lecturer, School of Land, Crop and Food Sciences, The University of Queensland
Dr Elizabeth Johnson	Senior Lecturer, School of Biochemistry and Associate Dean (Academic), La Trobe University
Associate Professor Michelle Livett	Dean, Undergraduate Studies, School of Physics, The University of Melbourne
Associate Professor Pauline Ross	Assistant Associate Dean Academic (Health), College of Health and Science, University of Western Sydney
Professor Janet Taylor	Director Teaching and Learning, Southern Cross University
Dr Neil Williams	Retired CEO Geoscience Australia, Fellow of the Australian Academy of Technological Sciences and Engineering

Employer representatives

Ms Anna Davis (or nominee Peter Russo)	President, Australian Science Teachers Association (ASTA)
Dr Lesley Macleod (or nominee Colin Jones)	CEO, Dairy Innovation Australia
Mr Frank Yu	Head, Australian Bureau of Statistics Methodology and Data Management Division

Student representative

Ms Phillipa Hunter	Graduate student representative, Council of Australian Postgraduate Associations (CAPA).

Advisory Group

Terms of Reference

The Science Discipline Advisory Group consists of a small group of expert colleagues who will act as a high level working party of 'critical friends'. The Advisory Group members were selected for their expertise in science education and to represent a breadth of sub-disciplines within the science cluster.

The Advisory Group will be consulted more frequently than the Discipline Reference Group (who will meet three times during the project) and communication will usually be electronic. Their responsibilities will be to:

- provide the Discipline Scholars with prompt feedback on drafts of threshold learning outcomes and associated documents
- provide expert advice to the Discipline Scholars throughout the project.

Membership

Associate Professor Les Kirkup	Physics and Advanced Materials, University of Technology, Sydney
Associate Professor Simon Pyke	School of Chemistry and Physics, Associate Dean, Faculty of Sciences, The University of Adelaide
Dr Charlotte Taylor	School of Biological Sciences, Director of Learning and Teaching, Faculty of Science, The University of Sydney
Professor Neville Weber	Head of School, School of Mathematics and Statistics, Faculty of Science, The University of Sydney

Local Reference Group

Terms of Reference

The local Reference Group comprised experienced educators from the Faculty of Science, Engineering and Technology, University of Tasmania. Their role was to provide peer feedback at key stages in the project:

- initial development of the Science TLOs
- survey design
- effective workshop presentation for the consultation phase.

Membership

Associate Professor Leon Barmuta	School of Zoology
Dr Chris Burke	National Centre for Marine Conservation and Resource Sustainability
Dr Julian Dermoudy	Bachelor of Science Degree Coordinator, School of Computing and Information Systems
Dr Simon Ellingsen	School of Mathematics and Physics
Dr Michael Gardiner	School of Chemistry
Associate Professor Mark Hovenden	School of Plant Science
Associate Professor Peter Lane	School of Agricultural Science
Dr Jon Osborn	School of Geography and Environmental Studies

Research support

Research support was provided by Mr Reyne Pullen, School of Chemistry, University of Tasmania.

Appendix 2: Chemistry and mathematics working parties

Terms of reference

The working parties will work in parallel with the Discipline Scholars and the Science Discipline Reference Group during the Science (LTAS) project (end date 30 June 2011).

They will:

- adapt the emerging Science TLOs for their discipline
- consider and, if appropriate, define additional TLOs that are specific to their discipline
- seek consensus and preliminary endorsement of these TLOs by their discipline community, including the relevant peak body, the Royal Australian Chemical Institute (RACI), or the Australian Mathematical Society (AustMS) and the Statistical Society of Australia (SSA)
- provide a progress report in March 2011 and a final report by 31 May 2011 to the Discipline Scholars that will include the discipline-adapted TLOs and a commentary on the process of their development.

Membership – Chemistry Working Party

Professor Mark Buntine	(Chair of Working Party), President-elect RACI; Head, Department of Chemistry, Curtin University
Associate Professor Trevor Brown	Deputy Head, School of Science and Technology, University of New England
Professor Will Price	LTAS Science Discipline Reference Group; Dean of Science, University of Wollongong
Professor Frances Separovic	Head, School of Chemistry, The University of Melbourne
Dr Richard Thwaites	Chair, Royal Australian Chemical Institute (RACI) Qualifications and Accreditation Committee.

Membership – Mathematics Working Party

Professor Peter Adams	(Chair of Working Party), Professor of Mathematics and Associate Dean Academic, Faculty of Science, The University of Queensland
Associate Professor Leigh Wood	Chair of AustMS Standing Committee on Mathematics Education; Associate Dean, Learning and Teaching, Faculty of Business and Economics, Macquarie University; Member of LTAS Science Reference Group
Professor Merrilyn Goo	President of the Mathematics Education Research Group of Australasia (MERGA); Director of the Teaching and Educational Development Institute, The University of Queensland
Professor Tim Marchant	proposed by the Australian Mathematical Society; Dean of Research and Professor of Applied Mathematics in the School of Mathematics and Applied Statistics, University of Wollongong
Dr Peter Howley	Co-chair for the Statistical Education section of the Statistical Society of Australia; Senior Lecturer, School of Mathematical and Physical Sciences, The University of Newcastle.

Appendix 3: Final report of the Chemistry Working Party, May 2011

The contents of the Chemistry Academic Standards Statement are the result of the work of the Chemistry Working Party, including consultation at a discussion workshop held at The University of Melbourne on 21 February 2011. This workshop was jointly sponsored by the School of Chemistry at The University of Melbourne, and the Royal Australian Chemical Institute (RACI).

The Chemistry Working Party membership

Professor Mark Buntine	Curtin University (Chair)
Professor Will Price	University of Wollongong; Australian Council of Deans of Science
Professor Frances Separovic	The University of Melbourne
Associate Professor Trevor Brown	University of New England
Dr Richard Thwaites	Chair RACI Qualifications Committee.

Draft statements were developed following the workshop mentioned above. In addition to working party members, workshop delegates were:

Dr Mal McLeod	The Australian National University
Dr Domenico Caridi	Victoria University
Associate Professor Kieran Lim	Deakin University
Dr Robert Baker	The University of Sydney
Associate Professor Brendan Abrahams	The University of Melbourne
Dr Danielle Meyrick	Murdoch University
Professor Joe Shapter	Flinders University
Professor Lawrrence Gahan	The University of Queensland
Dr Andrew Seen	University of Tasmania
Mr Trevor Rook	RMIT University
Dr Gary Bowman	Chair, RACI Industrial Chemistry Division
Dr Ian Jamie	Macquarie University
Professor John Bartlett	University of Western Sydney
Professor David Wood	President, RACI

Apologies were received from representatives of The University of New South Wales, The University of Western Australia and The University of Adelaide.

Feedback on the draft report (circulated for comment in late February 2011 and posted on the ALTC website) was received until mid April 2011. This final report incorporates feedback received and has been prepared under the supervision of the Chemistry Working Party.

Nature and extent of chemistry

"The goal is always finding something new, hopefully unimagined and, better still, hitherto unimaginable."
K. Barry Sharpless, Nobel Prize in Chemistry Lecture, 2001.

Chemistry is concerned with the study of the interactions of matter and energy. One of the main functions of the chemist is to produce new substances or to understand how substances are formed and removed in the environment. Chemistry is the science of analysing, transforming or manipulating substances and the molecular interpretation of the world around us. It is at the molecular level that major advances are made in many diverse areas such as medicine, agriculture, biology, materials, energy and the environment. Chemistry is considered to be the 'central science' because of its role in connecting the sciences, e.g. physics, biology, earth sciences. Chemistry has an important effect on our economy by playing a vital role in developing new technologies and influencing all human activity.

The conceptual understanding of chemistry involves three related levels: macroscopic or observable properties and changes; the explanation of those properties and changes in terms of a microscopic or molecular-level description; and the use of chemical language and symbols to represent both the macroscopic and microscopic phenomena.

Matter is everything that can be touched, seen, smelt, tasted or felt; hence, the extent of chemistry is limitless. Traditionally, chemistry has been classified into three main branches: inorganic chemistry, organic chemistry and physical chemistry. Analytical chemistry has become accepted as a fourth branch. However, the nature of chemistry is such that there are no distinct boundaries between the branches of the discipline, or indeed with other disciplines. While the aforementioned categories remain relevant, modern chemistry is increasingly described thematically; encompassing topics that overlap the traditional branches and address the interfaces of chemistry with other disciplines, such as chemical biology and chemical physics, and with applied fields, such as environmental chemistry and materials chemistry.

	Upon completion of a bachelor degree with a major in chemistry, graduates will be able to:
Understanding the culture of chemistry	Understand ways of scientific thinking by: • demonstrating a knowledge of, and applying the principles and concepts of chemistry • recognising that chemistry is a broad discipline that impacts on, and is influenced by, other scientific fields • recognising that chemistry plays an essential role in society and underpins many industrial, technological and medical advances • recognising the creative endeavour involved in acquiring knowledge, and the testable and contestable nature of the principles of chemistry.
Inquiry, problem solving and critical thinking	Investigate and solve qualitative and quantitative problems in the chemical sciences, both individually and in teams, by: • formulating hypotheses, proposals and predictions and designing and undertaking experiments in a safe and responsible manner • applying recognised methods and appropriate practical techniques and tools, and being able to adapt these techniques when necessary • collecting, recording and interpreting data and incorporating qualitative and quantitative evidence into scientifically defensible arguments • synthesising and evaluating information from a range of sources, including traditional and emerging information technologies and methods.
Communication	Communicate chemical knowledge by: • appropriately documenting the essential details of procedures undertaken, key observations, results and conclusions • presenting information, articulating arguments and conclusions, in a variety of modes, to diverse audiences, and for a range of purposes.
Personal and social responsibility	Take personal, professional and social responsibility by: • recognising the relevant and required ethical conduct and behaviour within which chemistry is practised • demonstrating a capacity for self-directed learning • demonstrating a capacity for working responsibly and safely • understanding and being able to articulate aspects of the place and importance of chemistry in the local and global community.

Explanatory notes for Chemistry TLOs

These notes are intended to offer non-prescriptive guidance on how to interpret the Chemistry TLOs. The notes and the TLOs should be considered in the context of the statement of the 'nature and extent of chemistry'. The notes should not be interpreted as a more detailed prescription of the TLOs. These TLOs describe a 'pass' level student graduating from a bachelor degree. They are not intended to be equally weighted across the degree program, nor does the sequencing imply a hierarchical order of importance.

Understanding the culture of chemistry

Demonstrating a knowledge of and applying principles and concepts of chemistry.

- Principles and concepts of chemistry: This is the currently accepted body of facts and theories that has arisen from a systematic study of the natural world. These can be defined as areas which include but are not limited to: stoichiometry, structure and characteristic properties of chemical substances; methods of structure determination; properties of matter in relation to structure; chemical thermodynamics, equilibrium and kinetics; reaction processes and syntheses which can transform substances into very different products; reactions of metal and non-metal compounds including carbon compounds; quantifying concentrations of elements and compounds in simple and complex mixtures; and experimental methods for the investigation of these matters.
- Knowledge and application: Chemistry graduates should demonstrate an understanding of these principles and be capable of applying them in routine and familiar contexts.

Recognising that chemistry is a broad discipline that impacts on, and is impacted by, other scientific fields.

- Discipline of chemistry: Chemistry includes, but is not limited to, traditional sub-discipline areas of analytical, inorganic, organic and physical chemistry.
- Impact of chemistry: Chemistry is often referred to as the 'central science' because it provides a general framework for the physical, life, earth, environmental and applied sciences (including medicine and engineering). Chemistry also plays a fundamental role in multi-disciplinary fields of endeavour including nanotechnology and the forensic, biomedical and materials sciences.
- Broad: Chemistry graduates should demonstrate an understanding of the concepts underpinning the traditional sub-discipline areas and some appreciation of the role chemistry plays in a range of kindred scientific disciplines.

Recognising the creative endeavour involved in acquiring knowledge, and the testable and contestable nature of the principles of chemistry.

- The creative endeavour and acquiring knowledge: Although chemistry is a systematic and logical study of phenomena, it is also about creating new knowledge and designing new frameworks in which to understand the molecular world. Chemistry graduates should understand the innovative aspects of chemistry and the need to think beyond the confines of current knowledge.
- Testable: All chemical knowledge is, in principle, testable. A chemistry graduate will understand that many chemical 'facts' have already been tested (and can be reproduced), while other chemistry knowledge has been developed by a logical process of scientific thought and awaits testing by experiments which have yet to be designed.
- Contestable: A chemistry graduate should have some appreciation and understanding of the historical evolution of scientific thought. A chemistry graduate will understand the need to re-evaluate existing conclusions when subsequent findings become available.

Inquiry, problem solving and critical thinking

Investigate: This term is used to describe the qualitative and quantitative processes of discovery and inquiry. A chemistry graduate will understand how to plan and execute an investigation. A chemistry graduate will also be aware of how new knowledge and ideas are acquired through a research/ investigative process.

Formulating hypotheses, proposals and predictions and designing and undertaking experiments in a safe and responsible manner.

- Formulating hypotheses, proposals and predictions and designing and undertaking experiments: An important aspect of chemistry is the ability to form hypotheses and propose and predict outcomes in a logical manner and then design activities or experiments to test these predictions. This supports a systematic approach to problem solving. In addition, chemistry graduates should have an appreciation that many problems are not straightforward and solving them requires creativity and innovation.

- In a safe and responsible manner: A chemistry graduate should understand how to take responsibility for themselves and others in the conduct of scientific investigations or other work situations. This term includes the occupational health and safety and risk assessment requirements of the discipline. Graduates should have the appreciation of how to interpret chemical hazard information, e.g. via Materials Safety Data Sheets or online databases, to minimise risks to themselves and others.

Applying recognised methods and appropriate practical techniques and tools, and being able to adapt these techniques when necessary.

- Recognised methods of chemistry: Chemistry graduates will be able to apply a sequence of data acquisition, sampling, analysis and drawing conclusions that is recognised as a 'scientific method'. Chemistry graduates should be able to recognise the limitations of the methods they employ as well as their strengths, and understand that sometimes serendipity is involved in making new discoveries.
- Appropriate practical techniques: It is recognised that practical, experimental and field techniques will vary from one sub-discipline area of chemistry to another. Chemistry graduates will be able to use practical techniques that are appropriate for a range of sub-disciplinary areas and will have an appreciation of the techniques used in other areas of chemistry.
- Appropriate tools: The tools of chemistry might include instruments, apparatus, sampling, mathematical and statistical approaches, or information and communication technologies.
- Adaption: Chemistry graduates will have learnt to recognise the need to adapt established techniques and methods as required.

Collecting, recording and interpreting data and incorporating qualitative and quantitative evidence into scientifically defensible arguments.

- Collecting, recording and interpreting data: Chemistry graduates should be competent at collecting and recording data from their investigations (including computational/theoretical) and subsequently analyse and evaluate these data in the context of their understanding of chemistry to describe chemical phenomena. Chemistry graduates should be able to synthesise chemical explanations from the data generated.
- Qualitative and quantitative evidence: Chemistry graduates will use evidence which is able to be verified. They will be able to evaluate evidence and make judgements regarding the validity, reliability, accuracy and precision of information. This will often incorporate aspects of reproducibility, error analysis, numerical uncertainty or statistical analysis.
- Scientifically defensible arguments: Chemistry graduates should have the capacity to pose and evaluate arguments based on scientific evidence. They should understand how their data support justifiable solutions, proofs or conclusions.

Synthesising and evaluating information from a range of sources, including traditional and emerging information technologies and methods.

- Synthesising information: Chemistry graduates should be able to identify, access, select and integrate information.
- Evaluating information: It is important that chemistry graduates are able to assess the validity of the information that they gather in the context of their knowledge and understanding of chemistry. Graduates should be able to conduct a series of systematic investigations to justify unexpected data. For example, in industry, a set of 'out-of-specification' results would normally require an investigation that may include a chemical assessment to explain why the results have deviated from the expected outcome.
- Range of sources: This term is used to indicate that information can be gathered and critically evaluated from traditional sources (including books, refereed papers and journal articles, conference presentations, seminars, lectures and colleagues) as well as non-traditional sources (including non-refereed articles, reports, 'grey literature' and electronic posts).

- Range of technologies and methods: This term is used to indicate both the diversity of methods and technologies that may be used to search for information, as well as the diversity of technologies that may be used for storing that information.

Communication

Appropriately documenting the essential details of procedures undertaken, key observations and results.

- Appropriately documenting: Chemistry graduates should be able to keep clear, accurate records of their work, including all relevant data and observations; using appropriate notebooks, journals and databases; and using media ranging from traditional to emerging information technologies. Documentation should be of sufficient detail that the procedure can be replicated.

Presenting information, articulating arguments and conclusions, in a variety of modes, to diverse audiences, and for a range of purposes.

- Presenting: Chemistry graduates should engage with their audience and be able to convey their message in a clear and understandable manner. In particular, chemistry graduates will be able to present quantitative and qualitative data in a variety of ways, including tables, charts, graphs and symbols, which show clearly the evidence from which conclusions are drawn. Graduates should demonstrate an ability to conceptualise and visualise three-dimensional structures at the molecular and macroscopic levels and present these concepts in a variety of ways, e.g. using structures, spectra and diagrams.
- A variety of modes, to diverse audiences: Chemistry graduates should be able to communicate to their peers, to chemistry and scientific non-experts, and to the general community. They will communicate using a range of media, including written, oral and visual media, and a variety of other techniques. Such communication could include a range of formats (such as laboratory notebooks and reports, technical reports, newspapers, journal articles, online forums, posters and oral presentations).
- A range of purposes: Chemistry graduates will be able to present their findings in both a technical and non-technical manner. They should use scientific language correctly and appropriately, and follow the conventions of chemical nomenclature. This might include the use of standard symbols, units, names or key terms. Chemistry graduates will be aware of the need to communicate the details of their investigations according to conventions of the discipline, and those which may be defined by publishers, editors or professional associations.

Personal and social responsibility

Recognising the relevant and required ethical conduct and behaviour within which chemistry is practised.

- Relevant ethical frameworks: Chemistry graduates will have an awareness of the ethical requirements that are appropriate for the discipline. These may include the importance of accurate data recording and storage, proper referencing (and the need to avoid plagiarism), intellectual integrity, having an awareness of the impact on the environment of their activities, and an appreciation that chemistry can generate new knowledge with benefits and risks to society. It is important that chemistry graduates have some understanding of their social and cultural responsibilities as they investigate the natural world.

Demonstrating a capacity for self-directed learning.

- A capacity for: While many chemistry graduates will be competent self-motivated learners, others will be just beginning to develop this capability at the time of graduation. Thus ‘a capacity for’ encompasses this range of abilities.
- Self-directed learning: Chemistry graduates should be able to take responsibility for their own learning. This involves an ability to work autonomously and evaluate their own performance. In order for chemistry graduates to make an ongoing contribution to a society in which scientific knowledge is continually evolving, it is important that they are motivated to continue to learn after graduation. This is also referred to as life-long learning.

Demonstrating a capacity for working responsibly and safely.

- Working responsibly and safely: A chemistry graduate should understand how to take responsibility for themselves and others in the conduct of scientific investigations or other work situations. This term includes the occupational/environmental health and safety and risk assessment requirements of the discipline. It also includes, for example, an understanding of time management, and the onus on individuals to fulfil their role as part of team projects; chemistry graduates should be able to work independently with limited supervision and have an awareness of the need to function effectively as members of teams.

Understanding and being able to articulate, some aspects of the place and importance of chemistry in the local and global community.

- Understand and be able to articulate: A chemistry graduate should be able to contribute to society by using their scientific literacy to understand and explain chemistry-related issues. Graduates should be able to articulate the inter-relatedness of various chemistry sub-disciplines. For some graduates this might involve being an advocate for chemistry; however, all chemistry graduates should have some appreciation of, and be able to speak about, chemistry in the larger context of society.
- Place and importance: This phrase encompasses the impact, significance, and relevance of chemistry to the community. Chemistry graduates should have some understanding of the role of chemistry, appreciate the fundamental role of chemistry in connecting the sciences and understand that chemistry creates both challenges and opportunities for the community.
- Local and global community: The impact of chemistry is very broad and a chemistry graduate should understand that the community includes not only one's fellow students and academic colleagues, but may also include the local community in which they live, the social, environmental, technological, and industrial sectors and others.

Appendix 4: Draft threshold learning outcomes for honours graduates in science

We provide a set of draft threshold learning outcomes for honours graduates in science as a basis for future consideration by the sector. These honours TLOs were developed by the Discipline Scholars and the Science Advisory Group. They are informed by the Science TLOs for bachelor degrees in science (as endorsed by the Australian Council of Deans of Science) and by the Australian Qualification Framework (AQF) level 8 descriptor of an honours level degree (AQF, 2011).[8]

It should be noted that an honours student is deemed to have already met the bachelor level TLOs. The draft honours TLOs, therefore, represent additional levels of achievement.

The purpose of an honours degree

"The purpose of the bachelor honours degree qualification type is to qualify individuals who apply a body of knowledge in a specific context to undertake professional work and as a pathway for research and further learning" (AQF 2011:p39).[8]

Honours may, therefore, offer students:

- a research pathway (progression into a research higher degree)
- a professional pathway (meeting professional requirement or enhancing employment prospects)
- academic enrichment (opportunity to study a subject at advanced level) (Kiley et al., 2009).[9]

For example, an honours degree in Archaeology is regarded as the "fundamental level of achievement required for entry to the profession and higher degree research" (Beck and Clarke, 2008 :p1).[10]

Honours is a uniquely Australian qualification that is not widely recognised at an international level (Kiley et al. 2009)9. An upper second or first class honours degree is currently a direct entry route into a postgraduate research degree in Australia. This system contrasts with the European Bologna Process, in which the pathway to doctoral studies is though a masters degree (Department of Education, Science and Training, 2006).[11] This difference has led to considerable discussion across the sector as to the continuing role of the honours degree in Australian higher education.

Models of honours degree programs

There are diverse models of honours programs across the sector, and even within institutions (Kiley et al. 2009).[9]

- The bachelor honours degree (sometimes termed bachelor degree with honours) normally requires four years of full time study (3+1): termed the 'add-on' or 'end-on' model. In the final year, the student undertakes a substantial research project and/or studies advanced level coursework units.
- Honours may be 'embedded', in that the student selects extra honours components (typically a research project) within the same timeframe as the bachelor degree.
- In some cases, an honours degree is awarded on the basis of outstanding achievement in an undergraduate (bachelor degree) program: an 'accorded model'. This model is used internationally, and in some professionally-orientated courses in Australia.

8. The Australian Qualifications Framework 2011 (2011). Available at: <http://www.aqf.edu.au/AbouttheAQF/AQFQualifications/tabid/98/Default.aspx>.
9. Kiley, M., Boud, D., Cantwell, R. Manathunga, C. (2009). The role of honours in contemporary Australian higher education. The original report was commissioned by the Australian Learning and Teaching Council Ltd, an initiative of the Australian Government Department of Education, Employment and Workplace Relations. Available at: <http://www.aushons.anu.edu.au/>
10. Beck, W. and Clarke, C. (2008). By Degrees: Benchmarking archaeology degrees in Australian universities. Teaching and Learning Centre, University of New England. Support for the original work was provided by the Australian Learning and Teaching Council Ltd, an initiative of the Australian Government Department of Education, Employment and Workplace Relations. Available at: <http://www.altc.edu.au/project-benchmarking-archaeology-honours-2006>
11. Department of Education, Science and Training, Australian Government (2006). The Bologna process and Australia: Next steps. Available at: <http://www.dest.gov.au/sectors/higher_education/publications_resources/profiles/bologna_process_and_australia.htm>

In science, the 'add-on' model of honours is probably most typical and this is the model we had in mind when drafting the honours TLOs.

Entry into an honours program is often selective, on the basis of high achievement in a bachelor level degree (Kiley et al., 2009).[9] Honours degrees are commonly awarded at levels: Third, lower second, upper second, first class.

Features of an honours curriculum

Students studying at honours level generally exhibit a more sophisticated level of intellectual engagement than is usual in undergraduate programs (Kiley et al. 2009). A comprehensive review of the role of honours in contemporary higher education (Kiley et al. 2009) found general agreement on three core curriculum features of honours programs, although the relative weightings of these three elements vary considerably across programs, reflecting different disciplinary goals:

- advanced disciplinary knowledge
- research training
- a substantial independent research thesis/project.

Honours level Threshold Learning Outcomes for Science

	Upon completion of a Bachelor Degree in Science with Honours, graduates will:
Understanding science	Demonstrate through their own practice: 1.1 an advanced understanding of the methods and processes of science as a creative endeavour 1.2 that current scientific knowledge is both contestable and testable by further inquiry.
Scientific knowledge	Exhibit depth and breadth of scientific knowledge by: 2.1 demonstrating advanced knowledge in one or more disciplinary areas 2.2 demonstrating the potential to make original contributions to scientific knowledge 2.3 integrating their own research findings with the current body of disciplinary knowledge/paradigms.
Research, inquiry and problem solving	Conduct a research investigation under supervision in a research or professional environment by: 3.1 critically analysing a challenging complex or multi-faceted problem, identifying research questions, designing and planning a project 3.2 selecting and applying practical and/or theoretical techniques or tools to address a research question 3.3 analysing, interpreting and critically evaluating research findings.
Communication	Be effective communicators of science by: 4.1 communicating scientific ideas and research findings to informed professional audiences using a variety of modes.
Professional responsibility and personal development	Be accountable for their own learning and scientific work by: 5.1 demonstrating initiative and intellectual independence 5.2 collaborating effectively 5.3 complying with regulatory frameworks and practising professional ethics relevant to their disciplinary area.

Appendix 5: Mapping bachelor level TLOs in Science

	LTAS bachelor level TLOs in Science Upon completion of a Bachelor degree in Science, graduates will:	**AQF specification for the bachelor degree (level 7)**	**Dublin Descriptors/Tuning (first cycle)** Qualifications that signify completion of the first cycle are awarded to students who:
Understanding Science	1. Demonstrate a coherent understanding of science by: 1.1 articulating the methods of science, and explaining why current scientific knowledge is both contestable and testable by further inquiry 1.2 explaining the role and relevance of science in society.	Graduates of a bachelor degree will have: • a broad and coherent body of knowledge	
Scientific knowledge	2. Exhibit depth and breadth of scientific knowledge by: 2.1 demonstrating well-developed knowledge in at least one disciplinary area 2.2 demonstrating knowledge in at least one other disciplinary area.	Graduates of a bachelor degree will have: • a broad and coherent body of knowledge, with depth in the underlying principles and concepts in one or more disciplines as a basis for independent lifelong learning • cognitive and technical skills to demonstrate a broad understanding of knowledge with depth in some areas.	• have demonstrated knowledge and understanding in a field of study that builds upon their general secondary education, and is typically at a level that, whilst supported by advanced textbooks, includes some aspects that will be informed by knowledge of the forefront of their field of study.
Inquiry and problem solving	3. Critically analyse and solve scientific problems by: 3.1 gathering, synthesising and critically evaluating information from a range of sources 3.2 designing and planning an investigation 3.3 selecting and applying practical and/or theoretical techniques or tools in order to conduct an investigation 3.4 collecting, accurately recording, interpreting and drawing conclusions from scientific data.	Graduates of a bachelor degree will have: • cognitive skills to review, critically, analyse, consolidate and synthesise knowledge • cognitive and creative skills to exercise critical thinking and judgement in identifying and solving problems with intellectual independence • cognitive and technical skills to demonstrate a broad understanding of knowledge with depth in some areas. Graduates of a bachelor degree will demonstrate the application of knowledge and skills: • with initiative and judgement in planning, problem solving and decision making in professional practice and/or scholarship • to adapt knowledge and skills in diverse contexts.	• have the ability to gather and interpret relevant data (usually within their field of study) to inform judgements that include reflection on relevant social, scientific or ethical issues • can apply their knowledge and understanding in a manner that indicates a professional approach to their work or vocation, and have competences typically demonstrated through devising and sustaining arguments and solving problems within their field of study.

	LTAS bachelor level TLOs in Science Upon completion of a Bachelor degree in Science, graduates will:	AQF specification for the bachelor degree (level 7)	Dublin Descriptors/Tuning (first cycle) Qualifications that signify completion of the first cycle are awarded to students who:
Communication	4. Be effective communicators of science by: 4.1 communicating scientific results, information, or arguments, to a range of audiences, for a range of purposes, and using a variety of modes.	Graduates of a bachelor degree will have: • communication skills to present a clear, coherent and independent exposition of knowledge and ideas.	• can communicate information, ideas, problems and solutions to both specialist and non-specialist audiences.
Personal and professional responsibility	5. Be accountable for their own learning and scientific work by: 5.1 being independent and self-directed learners. 5.2 working effectively, responsibly and safely in an individual or team context. 5.3 demonstrating knowledge of the regulatory frameworks relevant to their disciplinary area and personally practising ethical conduct.	Graduates of a bachelor degree will have: • a broad and coherent body of knowledge..... as a basis for independent lifelong learning. Graduates of a Bachelor Degree will demonstrate the application of knowledge and skills: • with responsibility and accountability for own learning and professional practice and in collaboration with others within broad parameters.	• have developed those learning skills that are necessary for them to continue to undertake further study with a high degree of autonomy.

This document contains selected resource material related to developing learning and teaching academic standards for science. The material was complied by Professor Susan Jones (University of Tasmania) and Professor Brian Yates (University of Tasmania) as part of the Learning and Teaching Academic Standards project. Please note that the links in this document were correct at the time of publication, June 2011.

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A. Literature concerning a standards-based approach to higher education in other international spheres

Quality Assurance Agency (QAA) (U.K.): Subject benchmark statements

The QAA Subject benchmark statements set out expectations about standards for degrees in a range of subject areas. They describe what gives a discipline its coherence and identity, and define the abilities and skills needed to develop understanding or competence in the subject at graduate level. Subject benchmark statements are available for most of the major disciplines within science, e.g. biosciences; chemistry; physics; mathematics, statistics and operational research. Some more applied fields of science are also included, e.g. agriculture, horticulture, forestry, food and consumer sciences; earth sciences, environmental sciences and environmental studies.
<http://www.qaa.ac.uk/academicinfrastructure/benchmark/honours/default.asp>

TUNING: Subject area documentation

TUNING Educational Structures in Europe is a body that develops “reference points for common curricula on the basis of agreed competences and learning outcomes” for many subject areas. The subject areas covered to date include several disciplines within science: agriculture, chemistry, earth sciences, mathematics, physics. The Tuning documents include a description of the subject area, graduate profiles, learning outcomes and information on learning, teaching and assessment.
<http://www.unideusto.org/tuningeu/subject-areas.html>

The Degree Qualifications Profile

The Degree Qualifications Profile developed by the Lumina Foundation (USA) is a framework for defining and assessing the general knowledge and skills students need to acquire in order to earn degrees at various levels regardless of their majors or fields of study.
<http://www.luminafoundation.org/publications.html>

B. Developing a standards-based framework for a discipline: Two Australian case studies

Benchmarking archaeology degrees at Australian universities

The purpose of this ALTC-funded project was to formulate a list of achievement standards for Australian honours graduates in archaeology. These are detailed in the project’s final report. The project methodology should be transferable to other disciplines.

Beck, W and Clarke, C (2008). *Benchmarking archaeology degrees at Australian universities: Final Report.* Available from <http://www.altc.edu.au/resource-benchmarking-archaeology-degrees-une-2008>.

Psychology graduate attributes

This paper presents a set of graduate attributes and suggested learning outcomes for undergraduate psychology degrees in Australia. It also describes the consultative process that was undertaken in order to arrive at these agreed graduate outcomes.

Cranney, J, Turnbull, C, Provost, SC, Martin, F, Katsikitis, M, White, FA, Voudouris, NJ, Montgomery, IM, Heaven, PCL, Morris, S and Varcin, KJ.(2009). 'Graduate attributes of the 4-year Australian undergraduate psychology program', *Australian Psychologist,* 44: 4, 253–262. DOI: 10.1080/00050060903037268 Available from <http://dx.doi.org/10.1080/00050060903037268>.

C. Selected articles on tertiary science education

Addressing the Science TLOs

This paper explores student and staff perceptions of the importance of generic skills in science. It provides supportive evidence for the scope of the Science TLOs.

Leggett, M, Kinnear, A, Boyce, M and Bennett, I. (2004). 'Student and staff perceptions of the importance of generic skills in science', *Higher Education Research & Development,* 23: 3, 295–312.

Why do a science degree?

This occasional paper, available from the website of the Australian Council of Deans of Science (ACDS), reviews the findings of the ACDS commissioned report, *What did you do with your science degree?* This report finds that Australian science graduates do not follow a particular defined career pathway, but often move from technical/science professional jobs towards managerial positions during their careers. Available from <http://www.acds.edu.au/whydoa.html>.

Tertiary science education in the 21st century

This publication is the major report of the ALTC-funded project, 'Re-conceptualising tertiary science education for the 21st century'.

Rice, J, Thomas, SM. and O'Toole, P (2009), 'Tertiary science education in the 21st century'. Available from <http://www.altc.edu.au/project-reconceptualising-tertiary-science-uc-2006>.

Approaches to teaching the methods of science

Adoption of the Science TLOs may require a more explicit attention to the teaching of scientific methodology and science process skills. This paper advocates the incorporation of such learning opportunities early in science courses, and provides some examples of how this may be achieved.

Coil, D, Wenderoth, MP, Cunningham, M, Dirks, C. 2010. 'Teaching the process of science: Faculty perceptions and an effective methodology', *CBE Life Sciences Education,* 9(4), 524-535. Available from <http://www.lifescied.org/content/vol9/issue4/index.dtl#ARTICLES>.

D. Writing learning outcomes

A staff guide to writing learning outcomes

This booklet is an example of a clear guide to writing meaningful learning outcomes. It is available for download as a pdf or may be purchased as single or multiple copies from the associated website.

Baume, D (2009). *Writing and using good learning outcomes,* Leeds: Leeds Metropolitan University. Available from <http://www.leedsmet.ac.uk/Learning_Outcomes.pdf>.

Appendix 7: Abbreviations

ACDS	Australian Council of Deans of Science
ALTC	Australian Learning and Teaching Council
AQF	Australian Qualifications Framework
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DFEEST	Department of Further Education, Employment, Science and Technology (State Government, South Australia)
LTAS	Learning and Teaching Academic Standards
QAA	Quality Assurance Agency for Higher Education (UK)
SSS	Science Standards Statement
TEQSA	Tertiary Education Quality and Standards Agency
TLO	threshold learning outcome

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Authors:
Professor Sue Jones
Professor Brian Yates
Dr Jo-Anne Kelder

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AUSTRALIAN LEARNING & TEACHING COUNCIL

Promoting excellence in higher education

PO Box 2375 Strawberry Hills NSW 2012 Australia
Telephone 02 8667 8500 Facsimile 02 8667 8515
www.altc.edu.au
ABN 30 109 826 628

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