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# Good Practice Guide

# (Science)

## THRESHOLD LEARNING OUTCOME 2
## Scientific knowledge

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Further information about these Good Practice Guides for Science can be obtained from Professors Susan Jones and Brian Yates, ALTC Discipline Scholars for Science.
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# Background

During the Australian Learning and Teaching Council (ALTC) Learning and Teaching Academic Standards (LTAS) Project for Science, Professor Susan Jones and Professor Brian Yates, the ALTC Discipline Scholars for Science, facilitated the development of five Threshold Learning Outcomes (TLOs) for Australian graduates of bachelor-level degrees in science (not necessarily a Bachelor of Science). The Science TLOs, which are applicable to all sub-disciplines within the Science cluster, are presented in the Science Standards Statement (Jones, Yates and Kelder, 2011).

The Science TLOs, which have been endorsed by the Australian Council of Deans of Science (ACDS), describe the minimum that a graduate of a bachelor-level degree in science will know, understand, and be able to do. The TLOs for science encompass the following domains:

TLO 1: Understanding science

TLO 2: Scientific knowledge

TLO 3: Inquiry and problem-solving

TLO 4: Communication

TLO 5: Personal and professional responsibility.

As a next step towards supporting sector-wide implementation of the Science TLOs, Professors Yates and Jones commissioned a set of Good Practice Guides, one for each Science TLO. The overall aim of the Guides is to provide contextual background and exemplars of teaching and assessment strategies that are clearly linked to specific Science TLOs (Jones et al. 2012). The Good Practice Guide for TLO 1 was published first, with the remaining four Guides, including this Guide for TLO 2, being published concurrently.

This Good Practice Guide supports the implementation of Science TLO 2: Scientific knowledge, which states that:

**Upon completion of a bachelor degree in science, graduates will:**

**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**

(Jones, Yates & Kelder, 2011).

While the Good Practice Guides for Science have a commonality of purpose, this Guide takes a somewhat different approach from the others. Rather than focus on providing a suite of practice-focused exemplars, it focuses on interpretation of TLO 2 in a broader educational context. It expands upon the succinct Notes on the Threshold Learning Outcomes for Science provided in the Science Standards Statement (Jones et al, 2011: pp.12–15). It does not set out to present an authoritative statement but, rather, to provide some clarification and to raise some pertinent issues and questions to be considered when designing undergraduate science curricula.

This Good Practice Guide aims, therefore, to:

1. explain what is meant by “well-developed knowledge in at least one disciplinary area” and how this may be achieved
2. discuss the rationale for requiring students to “demonstrate knowledge in at least one other disciplinary area”
3. reflect on how multidisciplinarity may be incorporated within bachelor-level science degrees
4. provide a suite of selected reference material on good practice in teaching tertiary-level science.

## A note on use of ‘discipline’ and ‘disciplinary area’

The Australian Qualifications Framework (AQF) Glossary of terminology defines ‘discipline’ as “a defined branch of study or learning”. In the ALTC LTAS project, the word ‘discipline’ was used to describe the overarching field of science. However, this term is also commonly used to describe specific ‘disciplinary areas’ within science, such as chemistry, physics, mathematics and biology. To avoid any confusion, the Science TLOs, in particular TLO 2, refer explicitly to ‘disciplinary areas’.

Please note that web links in this Guide were active at the time of publication.

# TLO 2: Scientific knowledge

The broad purpose of a bachelor-level degree in science is to prepare graduates for careers in science or to enter the general workforce as scientifically literate members of society. The Science TLOs were articulated with this purpose in mind and, therefore, they represent a strong move away from the more traditional view of science curricula as being 'content-heavy'. Indeed, it is already evident that "the use and further development of basic skills in communication, problem-solving and teamwork are becoming an integral part of the way science is taught and assessed" (Australian Council of Deans of Science (ACDS), 2001).

However, while a range of broad, perhaps more generic, learning outcomes are captured in the Science TLOs, science *knowledge* is recognised in Science TLO 2 as a being a key Threshold Learning Outcome for bachelor-level graduates.

## TLO 2.1: "well-developed knowledge in at least one disciplinary area"

The Australian Qualifications Framework (AQF) qualification type descriptor for a bachelor-level degree states that "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" (AQF 2013, p.48). Science TLO 2 references this broad descriptor, and also reflects the most common pattern of science degree construction – that students study at least one major to advanced level. Thus, science graduates are expected "to 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".[1]

So what do we mean by a "coherent body of knowledge"? Science degrees are often very flexible, with students offered a wide choice of disciplinary-based majors. This flexibility means that students will often achieve the Science TLOs by studying one or more science-based majors. In such cases, the major must provide learning activities and assessment that support students to achieve <u>all</u> of the Science TLOs. However, some degree programs include core subjects (units) that specifically address a sub-set of the TLOs. For example, the Bachelor of Science program at the Queensland University of Technology (QUT) includes six faculty core units that provide an introduction to the principles of science and an opportunity to learn by inquiry and to broaden understanding of the core sciences[2]; this suite of units, therefore, appears to address Science TLOs 1, 2.2 and 3. Science students at QUT also study a major within a particular disciplinary area of science.

A **major** is generally defined as a program of study in which the student progresses along a well-defined sequence of units/subjects within one disciplinary area to the advanced level (commonly recognised as being placed within the third full year of study). This pattern reflects the progressive manner in which science curricula are generally framed; it is

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[1] Notes on the Threshold Learning Outcomes for Science: pp.12–15 in Jones et al., (2011). Science Standards Statement.

[2] Information from the *QUT Undergraduate Course Prospectus for Science and Engineering*. Available at: <www.qut.edu.au/study/undergraduate-study/brochures>.

assumed that students must demonstrate achievement at introductory level before progressing to intermediate and, finally, to the advanced level of study. The body of knowledge they acquire as a result of this learning sequence should, therefore, reflect a coherent knowledge and understanding of the core principles and concepts of that disciplinary area.

There is some recognisable commonality amongst the range of units/subjects taught at introductory and even intermediate levels in science degrees. Diversity amongst institutions is most clearly reflected in the particular range of specialisations offered in a disciplinary area at advanced (third year) level. Advanced level subjects/units are generally focused on developing understandings and knowledge in areas of current research interest. It is not, therefore, appropriate to mandate particular areas of specific knowledge at this level. Science discipline knowledge is constantly expanding and curriculum overload is an issue of real concern (Hughes and Overton, 2010). However, it is pertinent to ask whether there is, or should be, some commonality amongst curricula at the introductory and intermediate levels of study in a particular disciplinary area. Without advocating for a common national curriculum, should there be an agreed common understanding of the fundamental concepts that students should be expected to have acquired as a basis for their advanced study? If so, how should such an understanding be reached?

The Subject Benchmark Statements published by the United Kingdom's Quality Assurance Agency (QAA) for a wide range of disciplinary areas, including, for example, biosciences, chemistry, earth sciences, environmental sciences and environmental studies, and physics, astronomy and astrophysics, provide a suite of key resources on core content. These Statements provide useful reference points, especially for those disciplinary areas currently without nationally-agreed threshold learning outcomes. Subject benchmark statements describe the nature and characteristics of programs in a specific subject or subject area. Although there is some stylistic variation between subject benchmark statements, most do contain details of the expected core knowledge for that discipline. For example, "Astrophysics and astronomy programs should normally include the application of physical principles to cosmology; the structure, formation and evolution of stars and galaxies; planetary systems; and high-energy phenomena in the universe"[3].

In some cases, the curriculum may be partially determined by professional bodies that set the requirements for course accreditation. The rationale for this is that graduates must have studied their disciplinary area in sufficient depth and breadth to be eligible for the relevant professional registration. For example, the Royal Australian Chemical Institute (RACI) accredits undergraduate chemistry courses in Australia. The Guidelines for Course Accreditation & Questionnaire (June 2010 revision) include specific comments about the Principles of Chemistry that all students must cover, and stipulate that the Accreditation Committee will review "the content of the chemistry units (subjects or topics) studied at each year level".

[3] Excerpt from the Subject Benchmark Statement for Physics, Astronomy and Astrophysics, 2008. Available at www.qaa.ac.uk/AssuringStandardsAndQuality/subject-guidance/Pages/Honours-degree-benchmark-statements.aspx.

In Australia, there have been some recent moves towards developing common understandings of the **core knowledge and skills** that characterise a particular disciplinary area. For example, the Office for Learning and Teaching (OLT)-funded Chemistry Discipline Network has surveyed universities across Australia with the aim of mapping current practice regarding content, delivery and assessment of undergraduate Chemistry. The OLT-funded Biology Network VIBEnet has taken a somewhat different approach. This group aims to create a Vision and Innovation Statement that will reflect their collective understanding of the knowledge and skills essential to the study of biology. Through this document, they aim to catalyse a shift away from strongly content-driven curricula towards inquiry-based approaches.

**Threshold concepts** (not to be confused with threshold learning outcomes, i.e. TLOs) provide a powerful conceptual framework for articulating the core principles and concepts of a disciplinary area, one that is particularly attuned to the notion of progression within a major or degree. Threshold concepts are those concepts which many students find difficult to learn and teachers find difficult to teach. Once understood, threshold concepts allow passage through a 'portal' or conceptual gateway to a previously inaccessible way of thinking. These conceptual gateways or *thresholds* are characterised as being *transformative, irreversible and integrative* (Meyer & Land, 2005). Threshold concepts are, therefore, those that are central to the mastery of the disciplinary area; a focus on threshold concepts enables teachers to make decisions about what is fundamental to the disciplinary area – a 'less is more' approach to curriculum design (Cousin, 2006). Threshold concepts, therefore, need to be considered in any discussion of the core curriculum.

It is also important that the students see the connections between what they learn at different levels/stages or in different units of their course. In his seminal text, *Teaching for Quality Learning at University*, John Biggs (1999) lists four factors that support learning. These are:

1. a well-structured knowledge base
2. an appropriate motivational context
3. learner activity
4. interaction with others.

Science TLO 2 clearly reflects Biggs' first factor – and note that he does not simply use the word 'knowledge' in isolation. Biggs (1999, p.73) emphasises that sound knowledge is based on interconnections, and that connections are best made hierarchically. He calls for teachers to connect new learning with old and make use of students' existing knowledge; to provide their students with a conceptual framework for the new knowledge they are acquiring; and to design curricula that emphasise structural connections between topics. These requirements highlight the need for careful course-level curriculum mapping and communication between academics teaching students at different levels.

Whatever approach is taken to define the core curriculum, it is vital that at least some aspects of the 'scientific knowledge' acquired by all graduates are informed by contemporary knowledge and current research in their field of study. Students must understand how science knowledge is developed, and that scientific knowledge is dynamic.[4] This premise highlights the interconnectedness between the Science TLOs: for example, scientific knowledge (TLO 2) will be acquired in the context of understanding science (TLO 1) and the processes of inquiry (TLO 3). Students need to acquire the 'ways of thinking' that will allow them to organise and apply disciplinary knowledge. The acquisition of factual content can no longer be emphasised at the expense of students learning how to 'think like scientists' (Wieman, 2007), and a wealth of literature now shows that active inquiry-based learning is more effective than traditional didactic teaching approaches. (See Good Practice Guides for TLO 1: Understanding Science, and for TLO 3: Inquiry and problem-solving.)

## Assessment of knowledge in science

Assessment involves making judgments about how a student's work meets appropriate standards (Boud and Associates, 2010) and, therefore, requires some discussion. Assessment of knowledge has sometimes been assumed to be less problematic than the assessment of higher order skills (Hughes and Magin, 1996). However, the challenge is to devise ways of assessing knowledge that require students to demonstrate understanding and application, synthesis or evaluation.

The traditional unseen closed-book examination has many weaknesses but continues to be a dominant mode of assessment of knowledge. As assessment tasks, examinations encourage 'surface learning'. Students rarely receive any useful feedback on their performance so they are unable to make further sense of what they have learned – or not learned (Race, 1999). Examinations favour students who happen to be skilled at doing exams (Race, 1999), but research shows that even students who 'do well' in examinations may in fact have a poor grasp of key (or threshold) concepts (Boud, 1990). Hughes and Magin (1996) explain this apparent contradiction using a framework originally devised by Biggs (1991), who considered students' progress through five stages of ascending complexity as their understanding of unfamiliar material grows, and they move from "incompetence" to "expertise". These five stages, termed the SOLO[5] taxonomy of levels of understanding, are:

1. prestructural – lack of coherent grasp of the material; isolated facts or skills may be acquired
2. unstructural – a single relevant aspect may be mastered
3. multistructural – several elements are mastered separately
4. relational – several relevant aspects are integrated into a theoretical structure
5. extended abstract – stage of "expertise" in which the material is mastered within its own domain and in relation to other knowledge domains.

Therefore, assessing recall of factual knowledge *per se* may not discriminate between students who are at different stages of mastery of the material. Assessment tasks need to be designed accordingly, in order to assess higher-order abilities and understandings. For example, are students required to 'define', 'state', 'describe', 'apply', 'construct' or 'assess' key aspects of disciplinary knowledge?

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[4] Notes on the Threshold Learning Outcomes for Science, p.12 in Jones et al. (2012).
[5] SOLO: Structure of the Observed Learning Outcomes.

Lord and Baviskar (2007) reflect on research that shows that many science students do not graduate with enduring or even accurate understanding of the core knowledge and concepts in their discipline. Indeed, how many instructors have complained that students do not seem to recall knowledge taught during their previous year of study? Lord and Baviskar (2007) argue that the core of this problem is that many university or college teachers construct examination questions based on recall or summarisation of information provided in lectures on the assumption that such assessment is convenient, less time-consuming and easy to mark. They show how Bloom's taxonomy[6] (Figure 1 below), referenced and often adapted by many university teaching and learning sites, can be used to frame science questions at increasing taxonomic levels of abstraction: *knowledge; comprehension; application; analysis; synthesis* and *evaluation*. The six categories are arranged hierarchically, from simplest (knowledge) to most complex (evaluation). The learning levels of Bloom's taxonomy are linked with appropriate student actions and question cue verbs.

Lord and Baviskar (2007) illustrate this linkage with a series of examples of themed questions, such as these on the subject of taste reception:

| | |
|---|---|
| *knowledge* | List the five taste sensations in the mouth. |
| *application* | Determine the location of the various taste receptor sites on the tongue for each of the unlabelled solutions provided. |
| *evaluation* | According to research by the American Obesity Association, approximately 127 million people in this country are seriously overweight. Discuss how gustatory reception and obesity are related. |

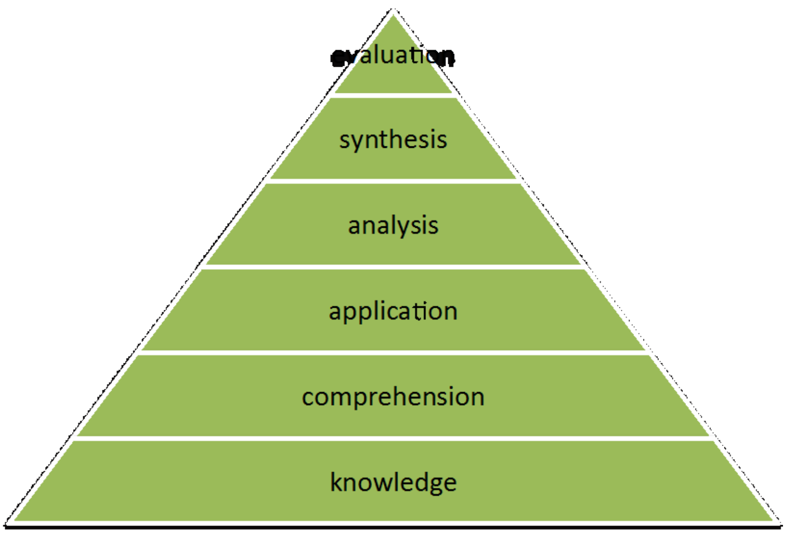


**Figure 1: A schematic of Bloom's taxonomy of educational objectives**

Bloom's taxonomy provides a useful construct for shaping assessment of knowledge through writing appropriately worded learning outcomes and appropriate assessment tasks. Even multiple-choice questions can be written so as to assess the higher order categories of *analysis, synthesis* or *evaluation* (see, for example, Palmer and Devitt, 2007). Other options

[6] Revised by Krathwol, D.R. (2002). A Revision of Bloom's Taxonomy: an Overview. *Theory into Practice*, *41*(4), 212–218.

include ‘scenario-style’ questions representing ‘authentic tasks’ (see Hughes & Magin, 1996) or non-multiple-choice randomised assignments administered via a learning management system (Schultz, 2011).

The challenge, then, is to design learning activities that support students to discover knowledge through inquiry, and assessment tasks that do more than test knowledge recall.

## Capstone units

The place of capstone units within science degrees should also be discussed briefly. A capstone is an integrating experience which draws together both content knowledge and skills and, therefore, helps to define disciplinary study. Capstone experiences link knowledge of an academic discipline with transition to the world of work (Holdsworth, Watty & Davies, 2009). They are generally designed to develop generic skills such as teamwork, communication, problem-solving and analytical skills, sometimes in a multidisciplinary environment. They may be real-world experiences (such as a work placement) or simulated (such as a studio design project).

Assessment in a capstone focuses on *application* of knowledge within an authentic context. Assessments tasks are typically complex and multi-dimensional and aspects of all the Science TLOs may be embedded in learning outcomes for the unit. A single capstone experience within a degree program is unlikely to allow a graduate to demonstrate full achievement of TLO 2.1, as the knowledge base drawn upon in the capstone is unlikely to be comprehensive. However, the potential place of capstone units as integrating experiences that allow students to demonstrate the full suite of TLOs should be a matter for future consideration as the Science TLOs continue to be implemented. As one avenue of investigation, capstone curriculum across disciplines is the focus of a 2013 National Senior Teaching Fellowship awarded by the OLT to Associate Professor Nicolette Lee, Victoria University[7], who will consider how learning standards may be evidenced through a range of capstone approaches.

[7] A brief description of this Fellowship is available at <www.olt.gov.au/system/files/Fellows_2013.pdf>.

## TLO 2.2: “knowledge in at least one other disciplinary area”

The Science TLOs require that a bachelor-level graduate of science possesses at least a basic foundation of knowledge in one or more other disciplinary areas. This is most usually termed a ‘minor’, i.e. a disciplinary area studied to at least intermediate level. Minors are often selected so as to be complementary to the area of the major. Most university websites describe a minor only in structural terms (as a sequence of units/points within a degree). The University of Southern California’s student advice webpages provide a more useful description, emphasising that minors may be used to add depth or breadth to a degree, or may reflect a personal ‘area of passion’. The Science TLOs, however, emphasise that a bachelor-level graduate in science with a particular major will have studied at least one other area of science to intermediate level. Science TLO 2.2 requires that majors are constructed such that a student exiting after two years of study (rather than completing a major) will have acquired ‘knowledge’ in that disciplinary area to complement and support study in their major.

This TLO reflects the strong interconnectedness between disciplinary areas in science. There is much debate about whether all science graduates should have acquired at least an introductory or intermediate level of achievement in *specific* disciplinary areas. A recent report (Dobson 2012) commissioned by Australia’s Chief Scientist highlights a continuing decline in students studying the so-called ‘enabling sciences’ of chemistry, physics and mathematics after their first year. Instead, biological sciences constitute the most significant proportion (36 per cent) of the average bachelor degree in natural and physical sciences. Does this restriction indicate an issue regarding the breadth of scientific knowledge commonly acquired by graduates?

The greatest focus of research in this area has been on mathematics, i.e. quantitative skills. Academics frequently report that a lack of ability to apply mathematical reasoning in different contexts hampers students’ ability to progress within their discipline (Ryland et al., 2013). However, the issue of how mathematical skills are best incorporated into a science curriculum is contentious. The recently completed OLT-funded project, Quantitative Skills in Science, *s*ought to address this problem by developing ‘curriculum models for the future’. The project website and final report contain an analysis of current practice and a suite of useful exemplars. Further research on effective strategies and mechanisms for the incorporation of the ‘enabling sciences’ into bachelor-level science curricula may be warranted.

Furthermore, there may be a strong case for a greater emphasis on interdisciplinarity, i.e. between *disciplinary areas*, as previously defined, within many science degrees to better prepare graduates to deal with real-world problems. Scientists increasingly work in interdisciplinary teams to solve complex problems; they need to be able to cross their own disciplinary boundaries in order to advance scientific knowledge. This authentic approach, therefore, needs to be mirrored in educational programs (MacKinnon, Hine & Barnard, 2013). Indeed, *BIO2010*, a major report on transforming undergraduate biology education, calls for major changes in undergraduate biology curricula. It recommends that all biology graduates have a strong foundation in mathematics, the physical sciences and information sciences, and calls for new approaches to teaching that emphasise interdisciplinarity in both theoretical and laboratory-based learning activities. This recommendation means moving beyond the notion of 'service teaching', defined as when a compulsory core course, or part of a core course, is taught by a discipline outside that of the program or department (Nankervis, 2008). For example, the Physics Education Group of the Australian Institute of Physics is contemplating different models of teaching physics to non-physics majors so as to best support learning in students from other disciplinary areas (Kirkup et al., 2007).

## Multidisciplinary science-related bachelor degrees

The original ALTC LTAS project did not address the issue of defining TLOs for multidisciplinary science degrees that have significant components representing non-science disciplines. At the time of writing, recent communications from the Higher Education Standards Panel (HESP) regarding 'learning standards for coursework' indicated that appropriate "reference points" must be utilised in defining course-level learning outcomes[8]. For multidisciplinary degrees, the Science TLOs will relate to the science-specific components of those degrees. However, in order to capture the multidisciplinary degrees, a range of other reference points (e.g. those relevant to Law or Business) will need to be consulted.

For such degrees, Science TLO 2 may not apply, or may need to be modified. When writing TLOs for a multidisciplinary science-related degree, Science TLO 2.2 (demonstrating knowledge in at least one other disciplinary area) could be re-interpreted as 'knowledge in a disciplinary area outside science'. Such an approach could be appropriate for double degrees, in which the student is effectively awarded two degrees – the non-science component would reference a different set of TLOs (e.g. the Law TLOs in the case of a Bachelor of Science and Bachelor of Laws). Double degrees are multidisciplinary in that graduates have studied two distinct disciplines. A more integrated approach to designing such curricula is desirable if students are truly to develop the skills in integrative thinking that could be an important outcome of such degrees (Welsman, 2007).

[8] See HESP Communique No. 8: *HES Reference Points and update on Organising Framework*. Available at <www.hestandards.gov.au/engagement>.

# Concluding remarks: Challenges for the future

This Good Practice Guide expands on the Notes on the Science TLOs provided in the Science Standards Statement (Jones et al, 2011: pp.12–15). The Guide has provided some context around TLO 2: Science knowledge, and has raised some questions and issues for practical consideration and for scholarly research as the higher education sector moves towards implementation of the Science TLOs. These questions and issues include:

- definition of the 'core knowledge and concepts' for specific disciplinary areas
- consideration of whether there is a core curriculum of science knowledge that all students should experience
- taking up the challenge to move away from a content-heavy approach to teaching science to inquiry-based learning that encourages students to discover information for themselves
- innovative strategies for effective assessment of science knowledge
- the role of service teaching in ensuring that all bachelor level science graduates meet TLO 2.2
- the place of capstone experiences in providing evidence that graduates meet the Science TLOs
- how the Science TLOs may be used as reference points for inter- or multidisciplinary courses.

These questions cannot be addressed by teaching academics working in isolation. The challenge now is to engage in collegial constructive discussions of the undergraduate curriculum, both within and across disciplinary areas. A holistic approach to curriculum design must be developed so that students' learning is structured and scaffolded to ensure they meet the Science TLOs at graduation. Discussions should be conducted at the institutional level. At the broader level, the Australian Council of Deans of Science (ACDS) Teaching and Learning (TL) Centre has established a Centre Project to:

1. provide advice to ACDS on the implementation of the Higher Education Standards panel (HESP) standards in science and mathematics
2. construct a five-year plan for developing the TLOs in course design and assessing learning outcomes.
3. recommend action for the ACDS TL Centre to support the use of Science TLOs in Science faculties.

Finally, the over-arching challenge for teachers of tertiary-level science is to improve students' learning and knowledge retention by replacing traditional transmission modes of teaching with active learning strategies, involving students in discovery, and allowing them to experience the excitement of science for themselves (Handelsman et al., 2004).

# Resources for TLO 2

The following short list of references, additional to those cited in the text of this document, presents a starting point for those who wish to learn more about current approaches to teaching tertiary-level science. This list is not intended to be exhaustive.

## Web-based resources

**Australian Council of Deans of Science (ACDS) Teaching and Learning Centre**
<www.acds.edu.au/tlcentre/
You are strongly encouraged to bookmark the (virtual) ACDS Teaching and Learning Centre, which is sponsored by the Australian Council of Deans of Science. This site, launched in 2013, aims to provide a central hub for innovation in and sharing of science education resources. The Centre will evolve as sectoral needs become evident.

**Science Disciplinary Network websites**
In 2012–13, the Office for Learning and Teaching funded several disciplinary networks within Science. These groups have focused on the definition and implementation of Threshold Learning Outcomes in their specific disciplinary contexts. Links to these websites can be found on the ACDS website (see above).

**Threshold Concepts: Undergraduate Teaching, Postgraduate Training and Professional Development: A short introduction and bibliography**
<www.ee.ucl.ac.uk/~mflanaga/thresholds.html>
With a wealth of scholarly literature on threshold concepts available, this website provides a brief overview, and contains a useful bibliography of key sources.

**Threshold Concepts in Biology**
<sydney.edu.au/science/biology/learning/threshold/>
This ALTC-supported project aimed to drive strategic change in biology education by identifying threshold concepts for their discipline and developing interventions addressing threshold concepts across the undergraduate curriculum. The website contains a Biology Thresholds Matrix, some specific examples of relevant teaching strategies, and useful references, including publications by the project team.

**Assessing learning in Australian universities**
<www.cshe.unimelb.edu.au/assessinglearning/index.html>
This website provides 'ideas, strategies and resources for quality in student assessment'. It is the outcome of a commissioned project conducted by the Centre for the Study of Higher Education (CSHE) for the Australian Universities Teaching Committee (AUTC). The website includes a suite of good practice examples, including many from science, and a link to a downloadable 64-page booklet summarising the web resources.

**Assuring Graduate Capabilities**
<//boliver.ning.com/>
This website is associated with Professor Beverley Oliver's OLT Fellowship project.

'Sign up' is necessary in order to access the resources. The website includes material on standards, curriculum mapping, evidence and benchmarking which, although focused on generic graduate capabilities, is translatable to the context of discipline-based learning outcomes.

## Text-based resources

Brownell, S. E. & Tanner, K. D. (2012). Barriers to faculty pedagogical change: Lack of training, time, incentives and tensions with professional identity. *CBE-Life Sciences Education*, *11*, 339–346.

This paper discusses general strategies for promoting effective pedagogical change within science disciplines, which is notoriously difficult to achieve. The authors argue that while "training, time and incentives" are most commonly cited as barriers to change, a scientist's professional identity as a researcher may also be a key barrier to pedagogical reform.

Hughes, C. & Magin, D. (1996). Demonstrating knowledge and understanding. Module 6 in: P. Nightingale et al. *Assessing Learning in Universities*, University of New South Wales Press, Sydney.

This module presents some useful case studies of innovative ways to assess knowledge and understanding; several are from science disciplinary areas. The section on "defining and assessing essential knowledge" concisely discusses strategies for objective testing of a student's knowledge base with a focus on multiple-choice testing.

McLoughlin, C. & Taji, A. (eds) (2005). *Teaching in the Sciences: Learner-centered approaches*. The Haworth Press, Binghamton NY. ISBN 1-56022-263-8.

This Australian-authored book contains case studies from a range of disciplinary areas within science. These case studies document approaches to teaching designed to engage undergraduate students, including the use of effective assessment and innovative pedagogical techniques.

Rice, J. W., Thomas, S. M. & P. O'Toole (2009). *Tertiary Science Education in the 21st century.* University of Canberra. Retrieved 5 June 2013 from <www.olt.gov.au/project-reconceptualising-tertiary-science-uc-2006>

This study affirms the importance of laboratory work in first year science curricula. It discusses laboratory classes as a unique learning environment, generic skills in the lab, the role and training of laboratory demonstrators, and the role of multimedia and simulations.

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