Guidance notes for the revised Science Threshold Learning Outcomes 2023

1. Introduction

The development of the Science Threshold Learning Outcomes (TLOs), resulting from an ALTC-funded project completed in 2011 and led by Brian Yates and Sue Jones (1), has been enormously influential in determining directions for teaching and learning in science degrees throughout Australia (2,3). The original report suggested that the TLOs would provide a foundation for the evaluation of current science degree programs, future curriculum articulation and development, and for improving learning and teaching in science at the university level (1). It is very clear that this has been the case. The Science TLOs were endorsed by the Australian Council of Deans of Science (ACDS) and many Australian universities have designed their degree or major learning outcomes based on the TLOs (2). The TLOs have also promoted a sense of community, shared understandings of what a science degree entails and demonstrated the impact a consultative project can have on the sector (2,3). However, the TLOs are now twelve years old and there have been some changes to science degrees that are not covered by the original TLOs.

In 2022, the ACDS initiated a project to update the TLOs to reflect contemporary curricula and to maintain the positive impacts of the TLOs. The TLOs had always been intended as a living document and it is important that they keep pace with and anticipate directions for science curricula. The first stage of this project included a review of current science degree learning outcomes and consultation on what should be changed. This led to a preliminary version of the TLOs which was then shared widely with the science education community, via the ACSME community, discipline groups and science education leaders. Feedback was incorporated and further more limited consultation occurred. The final version of the revised TLOs was endorsed by the Australian Council of Deans of Science and released at ACSME 2023.

The five top level TLOs have not been changed, a testimony to the strength of the original formulation. However, the revised TLOs now include or extend some aspects of science degrees that were less visible twelve years ago. One important addition is the recognition of Indigenous knowledge systems and the cultural competence needed to work with Indigenous and other diverse communities. These components are now commonly incorporated into science degrees and it is appropriate that the TLOs recognise this and support further moves in this direction. The interaction between science and society has also been given greater prominence, including more emphasis on communication skills. This recognises the importance of scientific approaches to the many issues currently facing society and the need for improved science literacy in our community. One increasingly important aspect of this is the need to recognise and respond to misinformation and to be able to communicate the practice and outcomes of science, and their limitations, to the broader community. Inquiry and problem-solving has been expanded to reflect the broader reach and methodologies of science, especially where it interacts with society in addressing contemporary challenges. These changes highlight generic skills that contribute to improved employability of graduates, something which has also increased in importance over the last twelve years.

Sections 2 and 3 of this document are taken directly from the original TLO project report (1) as this provides an excellent introduction to the thinking behind the project, its aims and how science was defined. Section 4 describes the new Science Threshold Learning Outcomes and Section 5 provides descriptive notes that provide a framework for understanding, interpreting and applying the TLOs, modified from the original document to reflect the revised TLOs. The Good Practice Guides remain available as these still provide excellent resources for most of the TLOs, especially as the five major outcomes remain unchanged. However, we recognise that these are now incomplete as they do not cover the full range of the revised TLOs.

2. Nature and extent of science

Science encompasses both a body of knowledge and a reliable process of discovery; "it is a path to understanding" (4).

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" (5). 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 (5).

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 (6).

3. 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 (7) 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 (8).

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 (9).

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 (10).

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. The Science Threshold Learning Outcomes 2023

	Upon completion of a bachelor degree in science, graduates will:
Understanding science	**1. Demonstrate a coherent understanding of the nature 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 ways in which science is a social endeavour that influences and is influenced by society 1.3. evaluating how different traditions of thought contribute to the practice of science and acknowledging different ways of knowing, including Indigenous perspectives and knowledges.
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 and applying an interdisciplinary perspective where appropriate.
Inquiry and problem-solving	**3. Critically analyse and solve scientific problems by:** 3.1. gathering and synthesising information from a range of sources and critically evaluating scientific merit and reliability 3.2. developing questions and designing investigations by selecting and applying practical and/or theoretical techniques, technologies or tools 3.3. evaluating and applying quantitative and/or qualitative analytical methods appropriate to the relevant discipline area 3.4. collecting, accurately recording and interpreting data 3.5. drawing conclusions, evaluating evidence and constructing arguments, recognising the limitations and underlying assumptions of the approaches used.
Communication	**4. Be effective communicators of science by:** 4.1. communicating scientific results, information, or arguments with a range of audiences, for a range of purposes, and using a variety of modes 4.2. promoting the role and value of science in addressing current challenges facing local and global communities.
Personal and professional responsibility	**5. Be accountable for their own learning and scientific work by:** 5.1. being self-directed and reflective learners, able to work independently and collaboratively towards achieving goals 5.2. working effectively, responsibly and safely in diverse professional and cultural contexts, and respecting Indigenous voices when working with Indigenous people and issues 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.

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/OLT 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. Science graduates will recognise the nature of science as a form of evidence-based inquiry that seeks to establish objective and verifiable facts independent of belief or opinion.

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.

TLO 1.3

Science graduates will understand that science is one approach to the development of knowledge and will appreciate and respect other ways of knowing. They will recognise and value Indigenous knowledge systems.

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.

Interdisciplinary perspective: Science graduates will be expected to recognise the value of other disciplines and identify when it is appropriate to engage with them to address complex problems.

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. They also need to be able to recognise, and respond to, misinformation that is present on scientific topics.

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. They will understand that techniques and approaches change and develop and will respond with adaptability.

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. They will recognise that qualitative approaches are appropriate in some science disciplines or the interface between science and society.

Technologies and tools: The tools of science might include instruments, apparatus, mathematical and statistical approaches including modelling, digital technologies, artificial intelligence 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.

Evaluating evidence and constructing arguments: Science graduates will know the extent and limitations of their data when developing a scientific argument. They will understand that evidence must be interpreted.

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 15 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).

TLO 4.2

Promoting the role and value of science: Science graduates will not just recognise and critique misinformation, but will be able to communicate and advocate for the role of science in addressing current challenges to non-scientists.

Local and global challenges: Science graduates will be familiar with the role of science in addressing societal challenges at all levels, eg climate change, health and disease, food security, sustainable energy use but also more local and community-based issues that may be relevant to their university or surrounds.

Personal and professional responsibility

TLO 5.1

Self-directed and reflective: 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.

Individually and collaboratively: 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. They will also work independently when required.

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. They will respect diversity and show cultural competence, including behaving appropriately when working with Indigenous people and issues.

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.

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