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Good Practice Guide (Science)

THRESHOLD LEARNING OUTCOME 1
Understanding Science

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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

This Good Practice Guide was commissioned by Professor Susan Jones and Professor Brian Yates, ALTC Discipline Scholars in Science, as part of the ALTC Learning and Teaching Academic Standards (LTAS) Project in Science. Through consultation with science academics, science students, employment groups and professional societies, the LTAS Project in Science resulted in the development of a set of five Threshold Learning Outcomes (TLOs) for undergraduate science students. These TLOs describe the minimum that a science graduate should know and be able to do by the time they graduate. The TLOs for science describe learning in 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

This Good Practice Guide supports the implementation of Science TLO 1: Understanding Science, which states that:

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

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 (Jones, Yates & Kelder, 2011).

This *Good Practice Guide* aims to:

1. Explain what TLO 1: *Understanding Science* entails
2. Review the literature on good practice approaches to teaching TLO 1: *Understanding Science*
3. Present an annotated bibliography of resources to support teaching and learning of TLO 1: *Understanding Science.* These resources include books, journal articles, videos, blogs and websites.
4. Present a range of good practice teaching approaches and assessment tasks related to TLO 1: *Understanding Science* currently used in Australian undergraduate science degrees
5. Identify issues requiring further exploration around TLO 1: *Understanding Science*

TLO 1: Understanding science

Throughout an undergraduate science degree, students learn about the knowledge that science has produced and practise some of the techniques used to generate that knowledge. TLO 1: *Understanding Science* requires that students take a step back to also consider how the collection of facts that science has produced and the range of practices it uses fit into a larger structure: the edifice of science itself. An understanding of science from this perspective is integral to the development of scientific literacy. Scientific literacy can be thought of as having three components[1]:

i. Knowledge of science concepts
ii. Knowledge of what science is and how it works
iii. An appreciation of the role of science in society

Of the three, it is argued that the latter two components (i.e. knowledge *about* science rather than knowledge *in* science) are the most important in developing scientific literacy (Bauer 1992). These two components are often referred to collectively as the *nature of science*. Regardless of whether our science graduates pursue a career in science, they should graduate as highly scientifically literate members of society, able to participate in decision-making and debate around socio-scientific issues. Therefore, it is important that our undergraduate students develop a broad scientific literacy by including TLO 1: *Understanding Science* in undergraduate science curricula.

TLO 1.1: Ideas for exploration

The first part of TLO 1 requires that students demonstrate a coherent understanding of science by articulating the methods of science and explaining why current scientific knowledge is both contestable and testable by further inquiry. Fundamental to students' ability to engage with these ideas is their ability to articulate what science is. Thus, TLO 1.1 asks students to explore what science is, the practices of science, including the methods and tools that scientists use, and the status of knowledge that science produces. Consideration of some of these ideas can lead to complex questions about which there are diverse views. It is important that students consider a range of positions so that they develop a nuanced understanding of science through a critical exploration of these ideas. As an example, some of the questions that students could be asked to explore related to TLO 1.1 are listed below.

What is science?

1. What are the characteristics of a *scientific* investigation? Does a theory need to be testable to be considered scientific?
2. Is it possible to distinguish science from pseudoscience? What criteria may be useful in attempting to do this?
3. What are the boundaries of science? What sorts of areas are outside the domain of science?

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[1] This definition of the three components of scientific literacy is based on Bauer's 1992 characterisation of scientific literacy.

The methods and tools of science

1. How are acceptable scientific methods of inquiry determined? Is there an externally determined universal scientific method, or are 'allowable' methods in science determined by consensus of scientists working in a discipline rather than by external rules?
2. What are the roles of observation, experiment and inference in science? Is experiment an intrinsic part of all scientific investigation?
3. What are the roles of hypotheses, laws, and theories in the practice of science?
4. What are the characteristics of a good scientific theory?
5. What is the role of statistical analysis in science? What is the relationship between statistical analyses and certainty?
6. What is the role of argument in the progress of science? If scientists argue about aspects of a theory, is this a weakness or a normal part of science?

The status of scientific knowledge

1. Are theories ever proven in science, or is there always a possibility that finding new data will mean that existing theories need to be revised?
2. What is the difference between a scientific fact and a scientific theory?
3. To what extent is objectivity achievable in the various stages of scientific inquiry?
4. What is the role of peer review in the development of new knowledge in science?

TLO 1.2: Ideas for exploration

The second part of TLO 1 asks that students are able to explain the role and relevance of science in society. Understanding the interrelationship between science and society is an integral part of scientific literacy and can assist science graduates to effectively participate in informed debate and decision-making about public issues related to science. It can also help future scientists to appreciate the contributions that science can make in society and the public responsibilities of science. Some of the questions that students could be asked to explore related to TLO 1.2 are listed below.

1. What are the roles and public responsibilities of science?
2. How does society influence topics chosen for research and the way scientific research is conducted?
3. What is the difference between science and technology?
4. What is the range of public perceptions of science?
5. What common misconceptions about science exist in the public sphere?
6. How important is scientific literacy for personal decision making about socio-scientific issues?

Whose understanding of science should students learn about?

The ideas that students are asked to engage with in TLO 1: *Understanding Science* are not straightforward. There is a surprisingly diverse range of views and much disagreement about how science works, the status of the knowledge it produces and how much interaction there is and should be between science and society. Views about these issues are likely to differ depending on whether one is a scientist, a philosopher of science, a historian of science, a sociologist of science, or a science educator. At one extreme, there are traditional views (often labelled as 'positivist' or 'scientistic') where strong claims are made about the certainty of scientific knowledge and the role of proof in the linear progress of scientific knowledge. People with these views may claim that science is superior to other academic endeavours and is the only means to knowledge of anything at all. At the other end of the continuum are radical views incorporating extreme relativist perspectives on the nature of science. People with these views may see scientific knowledge as wholly socially constructed and deny that science can make any claims to truth about reality or that science can be said to progress in any way. It is important to be aware of this continuum of perspectives when reading and evaluating the literature on the nature of science. An often conspicuously absent voice in many of the debates about the nature of science is that of scientists. Addressing TLO 1 in higher education science may provide a greater opportunity for the views of scientists to inform what university science students should learn about in order to gain a big-picture understanding of science.

Approaches to teaching TLO 1 in Australian universities

Understanding science requires a different way of thinking, and therefore a different way of teaching and learning, from learning about the products of science or scientific inquiry skills. Students need to grapple with nuanced issues rather than established concepts and skills. Thus higher-order thinking skills are required. Recent research into how secondary science students develop an understanding of the nature of science (abbreviated to NOS in the science education literature) has found that the most effective teaching approach is an *explicit/reflective* one where students are given formal instruction on various aspects of NOS followed by science inquiry activities where they reflect on how the activities exemplify certain NOS themes (Khishfe & Abd-El-Khalick 2002). Research with undergraduate science students has shown that while participation in authentic inquiry has some effect on students understanding of how science works, it does not appear to have much effect on students' understanding of the role and relevance of science in society nor on their ability to appreciate the tentative or contestable nature of scientific knowledge claims (Ryder, Leach & Driver 1999; Thoermer & Sodian 2002; Samarapungavan, Westby & Bodner 2006; Hunter, Laursen & Seymour 2006). Thus, relying on implicit messages about science in an undergraduate science curriculum is unlikely to be effective in enabling students to develop a big-picture understanding of science.

A further issue to consider for undergraduate science is appropriate curriculum models for teaching TLO 1. The main options are:

1. A dedicated subject approach where students explore issues around TLO 1 (there are currently at least 20 such subjects offered to undergraduate science students in Australia)
2. An embedded approach where ideas about the nature of science are taught alongside discipline specific content, either in lectures or laboratory classes
3. A combination of 1 and 2

Embedded approaches have been recommended as the most effective option for teaching academic skills (Catterall 2008) and graduate capabilities (Bath et al. 2004). However, learning to understand science is not simply a matter of developing skills in combination with discipline concepts. It seems likely that the most effective model for teaching TLO 1 would be to offer subjects dedicated to TLO 1 in combination with embedded opportunities for reflection on how science works during scientific inquiry activities. It is important that offering a subject dedicated to TLO 1 during a science degree is not seen as all that is needed for students to fully develop a big-picture understanding of science. Reinforcement and exemplification of TLO 1 related themes is needed throughout the science degree, although how to achieve this will need considerable thought. If dedicated subjects are offered, another issue to consider is the appropriate year level for students to take such subjects. Of the TLO 1 dedicated subjects currently offered in Australian science degree programs, more than half are offered at first year level. Some of them are offered within a science discipline (e.g. chemistry, physics, psychology), but most are open to all students in a science faculty. There is a need for Learning and Teaching research in this area to evaluate the various curriculum models for teaching TLO 1.

If TLO 1 is taught in dedicated subjects, appropriate teaching strategies need to be considered. The traditional one hour lecture is unlikely to be effective at getting students to reflect on the various issues related to TLO 1. Instead, tutorial-style classes where students participate in discussions and activities designed to encourage reflection on topics related to TLO 1 are likely to be more suitable. It is also important that students are given the opportunity to consider the range of views that exist about what science is, how it works, and its interrelationship with society. Students should be encouraged to develop their own informed positions about the range of issues related to TLO 1. Again, more research is needed to evaluate various teaching approaches to TLO 1 in undergraduate science. The assessment tasks in this Guide will provide some insight into possible teaching approaches for TLO 1.

The role of the history of science in learning to understand science

Because of the large amount of “content” that needs to be covered in order to give undergraduate science students a good basic grounding in a scientific discipline, there is often a heavy focus on the end-products of science in university courses. A focus on what we know, to the exclusion of how we came to know it, can give students a distorted picture of how science works in practice, obscuring the difficulties, uncertainties, and competing theories often involved in creating new knowledge in science. A lack of appreciation of these aspects of science may cause undergraduate students to experience a mismatch between their view of science and the kind of thinking expected of science undergraduates. University students are encouraged to critically evaluate scientific ideas, and yet this may contradict their prior experiences of learning science as unqualified and certain ‘text book style’ facts. If students have no opportunities to engage with the uncertainties of ‘science-in-the-making’, they may develop a shallow ‘products-focused’ picture of science in which the need for critical thinking does not arise. The inclusion in undergraduate science curricula of historical case studies demonstrating the problematic development of scientific theories (e.g. Einstein’s theory of relativity, Darwin’s theory of evolution, Lavoisier’s overturning of the phlogiston theory) could help to give students an appreciation of how competing knowledge claims are possible, thereby enhancing their critical thinking about ideas in science.

The skill of critical thinking is not only important in evaluating the ideas of others, it may also help students to critically evaluate their own thinking in order to better confront the challenges of learning often counter-intuitive scientific concepts. When learning science, students are often confronted with ideas that are at odds with their existing common-sense conceptions about how the world works (for example, it seems counterintuitive that solid objects such as chairs and tables are mostly made up of empty space). They may be unable to assimilate the new concept they are trying to learn with their pre-existing concepts. Thus a process of *conceptual change* (Posner, Strike, Hewson & Gertzog 1982), involving reorganisation or replacement of pre-existing conceptions, needs to occur to fully understand the new concept. In order for students to accommodate an alternative conception, they must first recognise that their naïve conception and the target conception are at odds and that the world is not always what common sense would indicate. If students have simplistic or absolutist views that scientific knowledge emerges unproblematically from direct observation, they would have less reason to challenge their own common sense-based misconceptions (Thoemer & Sodian, 2002). Alternatively, if students can be encouraged to develop a more sophisticated understanding of science by investigating historical or contemporary examples of 'science-in-the-making', they may learn to recognise that understanding new concepts in science often involves a suspension of previously held common sense beliefs.

The role of the philosophy of science in learning to understand science

Both the ways that science is practiced and views about what science is and how it works have changed over time. Over the years, philosophers of science have grappled with the nature of science, and an exploration of their insights can help undergraduate science students to develop a big-picture understanding of science. The philosophers that have most influenced current thinking about the nature of science are Karl Popper, Thomas Kuhn, Imre Lakatos and Paul Feyerebend. It is beyond the scope of this Guide to provide details of the thinking of each of these philosophers. Instead, it will recommend some introductory books on the philosophy of science which incorporate theirs and others' views.

Resources for TLO 1

Print resources

Pigliucci, M. (2010). *Nonsense on Stilts: How to Tell Science from Bunk*. Chicago: The University of Chicago Press.

This very readable book by Massimo Pigliucci, biologist and philosopher of science, takes a critical view of some of the nonsense currently being passed off as science and attempts to arm the reader with the thinking skills to tell the difference between science and pseudoscience. He examines the influence of the media, think tanks, religion and new-age thinking on the public perception of science. Pigliucci calls for a sensible balance between the two extremes of postmodern criticisms of science and intellectually arrogant ‘scientistic’ views of science. This book would be suitable for students.

Hodson, D. (2008). *Towards Scientific Literacy: A Teachers' Guide to the History, Philosophy and Sociology of Science.* Toronto: Sense Publishers.

This excellent book by Derek Hodson is primarily written for secondary science teachers (there are currently no similar books written for university science academics), but much of it has relevance for higher education science. In the first chapter, Hodson provides a useful discussion of scientific literacy and presents cogent arguments for the importance of developing students’ scientific literacy. The book then goes on to present science educators with some basic ideas from the history, philosophy and sociology of science in order to inform their teaching of the nature of science.

Ziman, J. M. (2002). *Real Science: What it is, and What it Means*: Cambridge University Press.

John Ziman’s goal in this book is to provide a realistic image of science. He highlights recent rapid changes in the way science is organised and conducted in universities, research institutes and industry. He examines the distinctive socially embedded culture of science and the external influences that affect the practice of science. Ziman explores the issues of universalism, disinterestedness, objectivity, reliability, originality and interdisciplinarity in science.

Chalmers, A. (1999). *What is this Thing Called Science* (3rd ed.). Brisbane: University of Queensland Press.

In this highly popular introduction to the philosophy of science, now in its third edition, Alan Chalmers provides a very accessible account of various attempts by philosophers of science to describe the nature of science. Technical jargon is kept to a minimum, and historical examples are used throughout to illustrate major themes. Topics explored in the book include the roles of observation and experiment in science; how induction and deduction are involved in the derivation of theories; Popper’s falsificationism and the responses of Kuhn, Lakatos and Feyerabend; Bayesian theories of science; and realist and antirealist views of science.

Bauer, H. H. (1992). ***Scientific Literacy and the Myth of the Scientific Method*****. Urbana and Chicago: University of Illinois Press.**

Henry Bauer uses insights from the history and philosophy of science to examine misconceptions about what science is and how it works. The main idea he challenges is that science can be defined by its use of a universal scientific method shared by all branches of science. Bauer argues that dispelling the myths about science is fundamental to promoting scientific literacy. Although the book is now 20 years old, many of the misconceptions Bauer explores still exist today.

Ladyman, J. (2002). ***Understanding Philosophy of Science*****. London: Routledge**

James Ladyman has produced a very readable introduction to the philosophy of science. He traces philosophical thought on the nature of science from the Scientific Revolution of the late sixteenth and early seventeenth century to present day theories in philosophy of science. The book has two parts. In part 1, The Scientific Method, Ladyman discusses the role of induction and deduction in science, starting with Bacon's characterisation of induction as a better tool than Aristotelian deductive logic for making inferences from observations of the natural world. The rest of part one deals with responses from various philosophers of science to the problem of induction, including Popper's falsificationism and Kuhn's paradigm shifts and scientific revolutions. Part 2, Realism and Anti-realism about Science, delves deeper into the philosophy of science and grapples with issues less immediately relevant to TLO 1. The book employs a helpful dialogue at the beginning of the first chapter and the ends of subsequent chapters between two characters, Alice and Thomas, who disagree about the nature of science on a number of levels.

Toplis, R. (2011). ***How Science Works: Exploring Effective Pedagogy and Practice*****: Taylor & Francis.**

Although this book by, edited by Rob Toplis, is written for a secondary school teaching audience, many of the very practical teaching ideas would be relevant to university science. The book aims to provide background and teaching strategies for the new UK National Curriculum strand: *How Science Works.* The most relevant chapters for tertiary science educators are chapter 3: How do scientists work?, chapter 5: Teaching controversial issues in science, and chapter 6: Argumentation.

Academic journals

Research related to TLO 1 Understanding Science can be found in a number of science education journals. Although many of these journals are primarily focussed on secondary school science, some articles are published that relate to university science.

Science and Education
http://www.springerlink.com/content/102992/

International Journal of Science Education
http://www.tandfonline.com/toc/tsed20/current

Journal of Research in Science Teaching
http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1098-2736

Science Education
http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1098-237X

Science Communication
http://scx.sagepub.com/

Journal of Science Education and Technology
http://www.springer.com/education+%26+language/science+education/journal/10956

Video resources

Theories, laws, hypotheses and facts

Science works! Scientific theory explained (9:50)
http://www.youtube.com/watch?v=ItxVLu8J_d0&feature=channel&list=UL

This video was produced by logical thinking.org. Three scientists, Eugenie C. Scott, Director, National Centre for Science Education (USA); James L. Powell, geologist; and Kevin Padian, professor of integrative biology talk about the difference between theories, laws, hypotheses and facts.

Scientific law vs. scientific theory (3:13)
http://www.youtube.com/watch?v=S2xhPgDuUIA

This video clearly explains the difference between a theory and a law and points out the fallacy of thinking that there is a hierarchical relationship between hypotheses, theories and laws.

Characteristics of a good hypothesis (1:59)
http://www.youtube.com/watch?v=t6Yv0HsdSNM&list=UUEnqjjz4VYha444Pi5Kjg5g&index=8&feature=plcp

A brief discussion of the characteristics of a good hypothesis in science.

Science and pseudoscience

Ben Goldacre: Battling bad science (14:20)
http://www.ted.com/talks/ben_goldacre_battling_bad_science.html

Epidemiologist, Ben Goldacre, critically examines the evidence behind some recent dodgy claims made in medical research and explains how drug trials can give a distorted picture of the efficacy of newly developed drugs.

How science works

How Does Science Work? Three Views (Part 3-1) (14:55)
http://www.youtube.com/watch?v=b_6ydWUwNKM&feature=channel&list=UL

A philosophy of science based perspective on how science works. The video manages to provide some depth about the more nuanced aspects of how science works in a clear and easy to understand way. The historical examples make the ideas easy to follow.

Science Works! How the Scientific Peer Review Process works (9:57)
http://www.youtube.com/watch?v=N-gzM8bsbpg&feature=related

Biologist Kevin Padian discusses the role of peer review in science. He explains how peer review is conducted and the criteria against which peer reviewers assess the worth of new scientific ideas. He finishes with a discussion of the lack of peer-reviewed research produced by proponents of (anti-evolution) intelligent design theory.

What is peer review? (1:55)
http://www.youtube.com/watch?v=bRH2mFXIGn8&feature=related

This short video was made in response to an online comment that we shouldn't trust the peer review process in science.

Science and Society

Steven Pinker: Science and society (4:37)
http://www.youtube.com/watch?v=OkpVykQIdDE

Steven Pinker discusses the place of science in society and argues that science should not be viewed as isolated from society but rather as one of many ways that people try to figure out how the world works. He stresses that scientists have a responsibility to better communicate their ideas to the public.

How Simple Ideas Lead to Scientific Discoveries (7:32)
http://www.youtube.com/watch?v=F8UFGu2M2gM&ob=av3e

In this TEDed video, Adam Savage gives some historical examples of major discoveries in science. He describes science, not as a closed black box, but as an open field in which we are all explorers with curiosity that can change the world.

Blogs

The Edge
http://edge.org/

The authors of this blog describe it as a place for "conversations at the edge of human knowledge". The blog was launched in 1996 and contains an extensive range of articles and videos from eminent scientists and thinkers on a range of topical issues.

Ben Goldacre's Bad Science
http://www.badscience.net/

Ben Goldacre writes about examples of bad science. There are some good articles on the misuse of statistics that could be used with science students.

Websites

Vision Learning (process of science)
http://www.visionlearning.com/library/cat_view.php?cid=49

This website contains an extensive set of online learning and teaching activities designed for undergraduate science students. There are some discipline-specific content modules and one module on the process of science. This module takes students through a series of readings on the way scientists work, scientific research methods, data analysis and scientific communication. Accompanying each reading is a set of multiple choice comprehension questions. The Vision Learning materials would be ideal for online independent study. Thanks to Norman Lederman for pointing out this site.

National Centre for Case Study Teaching in Science
http://libweb1.lib.buffalo.edu/cs/

This website has some excellent resources for teaching TLO 1, including a set of 439 science case studies on (amongst other topics) the history of science, scientific method, pseudoscience, science and the media and social issues. Cases are written in an engaging style and include discussion questions for each case.

Science Learning Hub (University of Waikato)
http://www.sciencelearn.org.nz/Nature-of-Science

This website from New Zealand has ideas and resources for teaching about the nature of science. Although aimed at secondary school science, the background information on the nature of science would still be useful for tertiary science educators, and some of the activities could be adapted for university science students.

The story behind the science
http://www.storybehindthescience.org/

This website aims to help students consider misconceptions about what science is and how scientists work by presenting 30 historical and contemporary case study stories of science across five disciplines (astronomy, biology, physics, geology and chemistry). For each case study, a link is made between the example and what it shows about the nature of science.

Experiment Resources.com
http://www.experiment-resources.com/cause-and-effect.html

This website contains clear information about the methods and tools of science. It has sections on scientific method, experimental design, statistical analyses, ethics in research, history and philosophy of science, and scientific reasoning. There are a number of very clear diagrams that could be useful for teaching TLO 1.

Good Practice Examples

The following good practice examples have been selected from subjects currently offered in Australian university science degrees which are dedicated to teaching the nature of science. For each example, an overview of the subject is first given, followed by examples of assessment from the subject. To ensure consistency, all examples below are called subjects even though they may be called units or courses at the institutions where they are offered.

Example 1

Subject: Science under the Microscope

University: Australian National University

Authors: Susan Howitt and Anna Wilson

Year level: First year (open to science and non-science students)

Description: The subject introduces students to what science is, how it works and why it works. The subject is taught as a series of case studies with 1 x 1 hour and 1 x 3 hour classes each week, with classes being largely discussion-based. The case studies and classes cover historical and contemporary examples, simple data analysis and interpretation exercises. Susan and Anna also draw on their own practice as scientists. Reading is provided for each case study and students are required to post discussion questions on the course website. Susan and Anna then design discussion-based classes using the student-generated questions, mini-lectures to extend the readings and small group activities.

Assessment: Assessment in the subject is assignment-based. There are no exams. At the beginning of the semester, students complete a short online survey (worth 2% of the total mark) designed to get a baseline measure of students' views about what science is and what scientists do. Throughout the semester, students produce short written reflections in response to either readings or lecture topics (worth 38% of total mark) and synthesise these reflections into a longer final integrative reflection task (worth 20% of the total mark). In the integrative reflection, students are encouraged to consider any ideas about science that challenged or surprised them and to reflect on how their ideas about science have changed over the course of the semester. The final assessment task is an essay (worth 40% of the total mark) in which students describe a critical discovery or change in scientific thinking, focussing on the context in which the discovery or change happened, any resistance to its uptake and its implications.

Advice: Based on her considerable experience in teaching *Science under the Microscope*, Susan offers the following advice for science academics considering setting up similar subjects: “Allow students plenty of time for discussion and reflection. Many students have a view of science as consisting of ‘true facts’ and have some resistance to the idea that science involves uncertainty. The role of uncertainty and the need to evaluate evidence need to be included in multiple ways and throughout the course. Two things that work well in our course are that we provide detailed individual feedback on reflective assignments, which is important in getting students to critically examine their own views, and that students hear each other's opinions, helping them to realise that they make assumptions about what science is and how it is practised."

Example 2

Subject: Biology and Society

University: University of Tasmania

Authors: Leon Barmuta and Sue Jones

Year level: Second or third

Description: This subject examines contemporary theories and concepts in ecology and evolutionary biology in terms of the ways that these ideas are used to inform both scientific progress and public debate. Modern zoological theories are profoundly affecting the ways that we view developmental biology, macroevolution, conservation, the impacts of introduced species, and the role of Darwinism in social policy. The subject is designed to develop critical thinking and debate about selected, currently topical concepts in Biology through a series of structured readings, self-guided research and group discussions. The emphasis is on improving skills in finding and collating scientific evidence, understanding and evaluating competing arguments, and integrating and presenting scientific arguments in a professional manner.

Assessment: The majority of the assessment in the subject comes from two 2,500 word module reports. These reports are written in groups and introduce a topic in ecology or evolution. The focus is on summarising and critiquing the topic, including how the topic is relevant to current society and links to broader social issues.

Example 3

Subject: Scientific Practice and Communication

University: Monash University

Authors: Ros Gleadow and Kirsti Abbott

Year level: Second Year

Description: *Scientific Practice and Communication* analyses how science is perceived, practised and interpreted in our society, and how scientific findings are applied and communicated to a broad range of audiences. It aims to give students an appreciation of how scientific knowledge is generated, the differences between good science, poor science and pseudoscience, and the importance of ethics and occupational health and safety issues in scientific endeavours. Effective skills for communicating science through written, spoken and visual means are promoted. Case studies are used to explore examples of current controversial issues that have a scientific basis or that can be potentially explained and rationalised by pursuing good scientific practice.

Assessment: The subject has a range of assessment tasks. The two that are most closely related to TLO 1 are a group presentation and a workshop paper. In the group presentation (worth 10% of the final mark), groups of four students arrange, plan and conduct an interview with an active scientific researcher. During the interview, students question the researcher about the story of their research, what they are currently working on, the implications of their research for society and where their research is headed in the future. The results of the interview are presented to the class in one of the following formats: radio interview, TV interview, conference presentation, or science show (with hands on experiments and activities).

The workshop paper (worth 5% of the total mark) is designed to develop students' sense of how science is communicated to the public. Students find a popular media article on a science story of some kind, and then track it back to the original primary article. During workshops throughout the semester, each student presents a summary of the science presented in the primary scientific article and how accurately it is portrayed in the media article. They compare the presentation styles of the popular media and primary scientific articles.

Example 4

Subject: Quantitative Skills for Sustainability

University: University of Canberra

Authors: Jim Hone

Year level: First year

Description: This subject examines, in modules, scientific philosophy and ethics, chemistry skills, environmental skills and spatial skills using themes such as sustainability. It draws on a wide range of case studies, including sustainability and climate change, in quantitatively analysing the way science is used to explore the world around us and convert science into policy and programs. There is no textbook; however, students purchase a handbook of tutorial exercises using published scientific papers. There are two one-hour lectures and a two-hour tutorial per week.

The learning outcomes expected at the end of the subject are that students will be able to;

(i) apply the knowledge of the quantitative methods of science to understand and analyse how science works.

(ii) apply skills of critical thinking as applied in science.

(iii) apply skills of interpretation and analysis of data and demonstrate competency in demonstrating ideas in quantitative ways, including in written presentations of findings and team work.

Assessment: Assessment in the subject consists of:

Assignment 1 (50%). This assessment item is a three page critical written review by each individual student of the scientific methods and results of a short published study (1 of 2 supplied in the unit Handbook). The assessment criteria are: demonstrated ability to interpret and evaluate the required study (including explicitly demonstrating links to topics in lectures and tutorials), and written communication (including organisation, clarity and length).

Assignment 2 (50%). This assessment item is a three page critical written review of the ethical aspects of a short published study (1 of 2 supplied in the unit Handbook). The assessment criteria are: demonstrated ability to interpret and evaluate the topic (including explicitly demonstrating links to topics in lectures and tutorials), and written communication (including organisation, clarity and length).

Advice: Jim offers the following advice for science academics considering setting up similar subjects: “The weekly tutorials are the most useful and popular parts of the unit. Students appreciate the opportunity to talk over the lecture topics and apply them to the set readings of each week’s scientific papers. My advice is to allow time for such discussions. The unit has students from many academic backgrounds, including those who have done little or no science. It is a first year unit so we start at an introductory level and use real-world examples to help students see the connections between scientific method and contemporary topics.”

Example 5

Subject: Science and Public Awareness

University: Australian National University

Authors: Lindy Orthia (Australian National Centre for the Public Awareness of Science)

Year level: First year

Description: SCOM1001 provides an introduction to contemporary social and communication issues in science, technology and society, including: the reasons for communicating science in the public arena; different theoretical approaches to communicating science; the diverse social, cultural, political and economic factors that shape public attitudes to science and make communication difficult; and practical methods for communicating science in different contexts with different audiences. The subject focuses heavily on current events and issues facing scientists, science communicators, policy makers, and the community. Students are encouraged to discuss their own views on the role of science and technology in the community and issues associated with communicating science with sectors of the public.

The subject has three modules: history and theory of science communication, public attitudes to science, and tools for effective science communication practice. Students have access to a blog (http://sandpaw.weblogs.anu.edu.au/) where they can share their discoveries about science communication matters with other students and the world.

Assessment: A project worth 40%, made up of two assignments. In this project, students investigate the way real scientists approach science communication by interviewing a scientist and then analysing several interviews conducted by classmates.

A project worth 45%, made up of two assignments where students think about a science topic that they believe is tricky to communicate, research why and how it is tricky to communicate, and then communicate an aspect of the topic for two different audiences.

Example 6

Subject: Science in Society

University: La Trobe University

Authors: Robyn Yucel, Tania Blanksby, Jeanette Fyffe and David Hoxley

Year level: First year core subject for the Bachelor of Science (Applications in Society)

Description: In this subject, students engage with a range of misconceptions about science reported in the public sphere in relation to a small number of topical socio-scientific issues (e.g. genetically modified foods, radiation and human health, child vaccinations). The subject is structured around common myths about what science is and how it works (e.g. that theories become laws with enough evidence, that there is a universal, step-by-step scientific method). Students also learn to analyse arguments and spot logical fallacies. Students then apply this knowledge to a chosen socio-scientific issue. They are asked to choose one of the issues and to explore the range and types of views presented in the media about the issue.

Assessment: The students' first task is to use media sources to identify and categorise arguments about their chosen issue as scientific arguments, economic arguments, social arguments, political arguments or ethical arguments. In the second task students are given an ill-informed, fictional "rant" about their chosen socio-scientific issue, constructed from some of the more extreme positions presented in the media on the issue. The "rant" contains factual inaccuracies, logical fallacies and misconceptions about science to which students must respond in a 1000 word written piece. In the final piece of assessment for the subject, students collaborate in small groups to produce a mini-documentary style video (approx. 10 mins in length) about their chosen issue which explores the range of public perceptions and misconceptions about the issue. These three tasks (and associated learning activities) comprise the entire assessment for the subject, and there are no exams.

Example 7

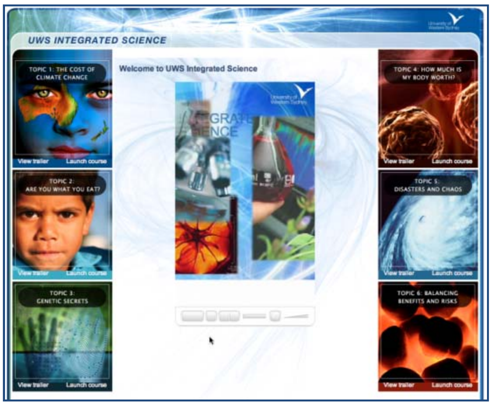
Subject: Integrated Science (http://www.cadre.com.au/uws/integratedscience/)

University: University of Western Sydney

Authors: Pauline Ross

Year level: First year

Description: Integrated Science is a problem-solving, inquiry based subject for learning science at a university level. The aim of the modules in the subject is to connect the concepts between the traditional science disciplines and stimulate science students to relate what they are learning to the real world.



The content of the subject is based on an integrated mixture of the disciplines of science and mathematics covering hot topics in science, which are important for our future and life on earth. Such topics often span the discipline areas and include physics, chemistry, biology and the central role of mathematics is emphasised and embedded throughout. Students are engaged in researching an authentic and meaningful context for learning from the first semester in their first year at university. Integrated science is about current concepts and issues such as war, firewalking, AIDS, population growth, the ozone layer, hacking into the human brain, corruption and degeneration of the human brain. Integrated science applies concepts developed within a scientific discipline to other scientific disciplines.

Assessment: Students complete three modules in the subject and assessment consists of fact sheets and a newspaper article aimed at a general audience.

Future research opportunities

The move towards a broader education about science is a welcome emerging trend in Australian undergraduate science education. This Good Practice Guide for TLO 1 has aimed to provide undergraduate science educators with information and resources to assist in teaching their students to gain a big-picture understanding of science. However, much further work needs to be done to inform curriculum design around TLO 1 and to evaluate the outcomes of this type of science education.

Research is needed to compare the dedicated subject approach to teaching TLO 1 themes and embedded approaches where TLO 1 themes are taught along-side discipline specific concepts. The dedicated subject approach has the advantage of providing enough space and time in the curriculum for explicit teaching about the nature of science and opportunities for students to discuss and reflect on nature of science concepts. It would also be easier to map the teaching and learning of themes related to TLO 1 throughout a science degree program if more than one dedicated subject were offered. However, there would also be advantages in linking discipline-specific concepts to TLO 1 concepts in existing subjects either with lecture content or in practical classes. The challenge will be to find ways to integrate both of these approaches. Authentic scientific inquiry is a promising context for exploration of the methods of science and the testable and contestable nature of scientific knowledge. The relationship between scientific inquiry and the nature of science is interesting. Recent research into Australian undergraduate science students' experiences of authentic inquiry suggests that without an understanding of the nature of science, students may not successfully develop scientific inquiry skills (Wilson et al. 2012). Conversely, learning scientific inquiry skills does not ensure that students gain a sophisticated understanding of the nature of science (Thoermer & Sodian 2002; Samarapungavan, Westby & Bodner 2006; Hunter, Laursen & Seymour 2006). More research is needed to investigate the complex relationship between understanding the nature of science and participation in authentic scientific research at undergraduate level.

In addition to researching effective curriculum models for teaching *Understanding Science*, there is also a need to explore effective pedagogical approaches. Science cannot be described or defined by a series of easy to understand statements. To really understand the nature of science, students will need to grapple with some nuanced questions relating to the nature and status of scientific knowledge. Thus, discussion and reflection form an essential part of teaching TLO 1 themes. However, as yet, there has been little research into the effectiveness of these activities as strategies for learning about the nature of science in higher education. Assessment of TLO 1 themes is also an important consideration. The assessment task types presented in this Good Practice Guide provide a range of innovative approaches to assessing students' big-picture understanding of science. However, investigation is needed into the relative effectiveness of various approaches to assessment of TLO 1 themes. Assessment tasks need to be designed to ensure that TLO 1 is actually assessed, rather than simply being a context for assessment of non-TLO 1 related concepts and skills. Threshold Learning Outcomes for science are part of the LTAS standards framework for higher education science. Thus, it is important to consider how institutions will be able to demonstrate that their students have reached at least the minimum threshold standard for TLO 1.

This Good Practice Guide has advocated that inclusion of TLO 1 in undergraduate science curricula would be highly beneficial for the development of students' scientific literacy. It is also likely that such science learning could provide a stimulating and engaging learning environment which encourages critical thinking and highlights the relevance of science to students' lives. However, there is, as yet, little support for these claims at the undergraduate level. There has also been little investigation of the views of science academics about the teaching and learning of concepts related to TLO 1 or of their level of preparedness to teach this way of thinking about science. For curriculum development around TLO 1 to be successful, the voices of both science students and academics need to be heard.

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