Development of Threshold Learning Outcomes for Australian Graduates in Physics

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Academic standards for physics across Australian universities have been collaboratively developed, to aid with emerging regulatory requirements, and to foster good practice in higher education in physics.

This paper describes the process, and presents the results to date, of a community effort to develop agreed minimum academic standards for students graduating with a physics major from an Australian university. These standards describe what graduates will know and be able to do upon completion of a major in physics, at Bachelor level.

"…what graduates will know and be able to do upon completion of a major in Physics"

The aim is to develop truly representative and useful standards. This development of learning standards for physics is taking place in an environment of increasing emphasis on quality assurance and monitoring of standards in higher education, eg: the Australian Quality Framework and TEQSA. Agreed standards have a role to play in compliance frameworks and professional accreditation. Developed threshold learning outcomes (TLOs)for physics will provide a means for evaluation of existing physics degree programs, and be a design tool for future curriculum development. The intent is to aid genuine improvement in the quality of our programs.

Development of the standards has been an iterative and collaborative process. Standards have been expressed succinctly as TLOs. The outcomes cover knowledge,

Table 1: Bachelor Level Threshold Learning Outcomes for Physics

	Upon completion of a Major in physics, graduates will:
Understanding science	1. *Demonstrate a coherent understanding of the nature of physics by:* 1.1 Articulating how physics uses observations of relationships between measurable quantities to create conceptual frameworks which can be used to explain, interpret and predict other observations. 1.2 Identifying the role of fundamental physics concepts (such as laws of conservation) in a variety of different contexts. 1.3 Acknowledging that there are physical reasoning processes characteristic of the discipline 1.4 Explaining the role and relevance of physics in society.
Scientific knowledge	2. *Exhibit depth and breadth of scientific knowledge by:* 2.1 Demonstrating well-developed knowledge in the subject areas of the physics discipline. 2.2 Demonstrating knowledge in the related disciplinary area of mathematics.
Inquiry and problem solving	3. *Critically analyse physical situations by:* 3.1 Gathering, documenting, organising, synthesising and critically evaluating information from a range of sources. 3.2 Designing, planning, carrying out and refining a physics experiment or investigation. 3.3 Selecting and critically evaluating practical, computational and/or theoretical techniques or tools in order to conduct an investigation. 3.4 Applying appropriate physics concepts to the interpretation of experimental or observational data and the drawing of conclusions from that data.
Communication	4. *Be effective communicators of physics by:* 4.1 Communicating physics data, results and analysis, to a range of audiences, for a range of purposes, and using a variety of modes. 4.2 Understanding and interpreting arguments or opinions based on physics, presented by others.
Personal and professional responsibility	5. *Be accountable for their own learning and scientific work by:* 5.1 Being independent and self-directed learners. 5.2 Working effectively, responsibly and safely in an individual or team context. 5.3 Exhibiting intellectual integrity and practising ethical conduct.

skills, and values that govern professional work practices. Comprehensive guidance on how to interpret the TLOs, providing a framework for applying the standards, is also provided. The latest version of the physics TLOs appears in Table 1. Also, an excerpt from the accompanying explanatory notes, relating to the process of inquiry and problem solving, is included as Insert 1. Known contributors to the document are acknowledged above. It is envisioned that the full, final document will be published on the AIP website.

Insert 1: Explanatory notes for TLO 3: Inquiry and problem solving.

Inquiry and problem-solving

Approach: Graduates will be able to use critical thinking skills and a quantitative approach to analyse physical situations and solve complex problems.

Domain: Graduates will be able to apply physical principles in a range of contexts. They will have the skills to solve problems that lie within the domain of traditional physics, as well as tackle more open-ended research questions.

TLO 3.1

Gathering, documenting, organising and synthesising information: Physics graduates will be able to identify, access, record in appropriate format, collate and integrate information.

Critically evaluating information: Physics graduates will be able to assess the soundness of the information that they gather against the criteria of their knowledge and understanding of physics.

Range of sources: It is recognised that information about the physical world is available from a variety of sources, such as books, refereed and non-refereed journal articles, conference presentations, seminars, lectures, peers and the internet. Information processing also deals with data generated as a consequence of experimentation or observation, or the analysis of existing data.

TLO 3.2

Designing, planning and problem-solving: Physics graduates will be able to devise a sequence of data acquisition and analysis using methods based on accepted physical principles. They will be able to form hypotheses and then design activities or experiments to test these hypotheses. Physics graduates will use a systematic approach to problem-solving using the laws of physics. In addition, physics graduates will have an appreciation of how to frame a problem so that it might be solved in a creative or innovative way.

Refining: Physics graduates will be able to review the effectiveness of the methods they have used so as to improve their approaches and to acquire qualitatively and quantitatively superior data.

TLO 3.3

Techniques and tools: Physics graduates will be able to use a range of the tools of physics, including instruments, apparatus, mathematical and statistical approaches, including modelling, and information and communication technologies. They will be able to use a range of measurement and data analysis tools to collect data with appropriate precision. Through their undergraduate learning experiences, physics graduates will be knowledgeable of techniques used to solve different types of problems. Physics graduates will be able to use appropriate (combinations of) practical, theoretical and computational tools to solve problems in their discipline, and will have an appreciation of the techniques used in other areas of science.

TLO 3.4

Applying appropriate physics concepts: Physics graduates will be able to identify the physical concepts that apply to a particular situation or phenomenon being investigated. They will recognise the limits and boundaries of models.

Interpretation of experimental or observational data: Physics graduates will be able to analyse data to yield justifiable conclusions. They will evaluate quantitative evidence, to judge the quality of data and results, using one or more of the techniques of measurement uncertainty, reproducibility, precision, or statistical analysis.

Drawing conclusions Physics graduates will have the capacity to develop defensible arguments based on evidence and draw valid conclusions based on their interpretation of data. They will be able to explain the influence of theoretical or empirical models and measurement uncertainties when drawing conclusions from experimental, simulated or observational data.

As a first step in the development of agreed standards, a Draft Statement of Learning and Teaching Academic Standards for Physics was prepared by a small group of physics academics from around Australia. "Learning and Teaching Academic Standards: Science Standards Statement" [1] was the starting point for discussion of learning outcomes for physics graduates. This document had emerged from a large-scale, pan-Australian project with extensive consultation. Use was also made of work that had been done to translate the generic science standards to chemistry [2], a discipline closely-related to physics via its experimental nature. Because the physics draft was adapted from the general science standards and the standards mapped to chemistry, there can be confidence that the physics statement is well-suited to express both what a person trained in physics has in common with graduates of the other sciences, and what makes the physics-trained graduate distinct from other disciplines.

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The next stage was consultation with the dedicated physics education community. An invitation to provide feedback on the Draft TLOs via email was sent to a group self-identified as interested in physics education. The Physics Education Group, a special interest group of the AIP, has over the last decade or so fostered a growing awareness of good practice through collaborative projects, workshops and research of individual members. The Australia-wide network of physics educators that has grown up is a way to communicate ideas and to share resources on teaching development.

Members of the Physics Education Group had the opportunity to refine ideas about physics learning outcomes at a national workshop. Participants were asked to brain-storm what makes a physics graduate special. They then classified their responses according to the general Science TLOs, and the TLOs and the Notes about implementing them were discussed from the specific points of view of teaching and assessing them in physics. During this analysis the overwhelming importance of inquiry/problem-solving skills for physics became obvious. Also, it was decided to specify the particular related disciplinary area of mathematics as expected knowledge in Scientific knowledge TLO 2.2. After this discussion, the document was substantially revised.

"… learning outcomes can help define the voice of Physics amongst the other sciences, and in the national education setting"

Consultation with the broad membership of the physics community then occurred. Input was requested from each university via Heads of Departments. It was suggested that Heads or their nominees prompt discussion within institutions. At the time of invitation, Heads were advised that agreement with the TLOs would be assumed if they did not notify otherwise by a deadline date, and that a consensus document would be presented publicly at the AIP National Congress 2012. The document was again revised to incorporate feedback. A Keynote address in the Education stream of AIP Congress included significant time for discussion by delegates.

The iterative process used to engage the community with the TLOs – working in stages towards larger numbers of people being involved – has strengths because it aids workability, helps refine ideas, and means that the end-product should be genuinely representative. Strategies used here are similar to the "Define Your Discipline stakeholder consultation process" based on the Modified Delphi Technique, used recently to define graduate outcomes in engineering [3].

During the stage of broad consultation with physics academics, a realisation emerged that TLO 1: Understanding science is really about the *nature* of the discipline – a cultural kind of aim. Note that the purpose of the TLOs (and the AIP Accreditation criteria) is not a listing of mandated topics. The current AIP Accreditation document lists criteria in terms of "competencies for a graduate physicist:

1. Demonstrate knowledge of fundamental physics concepts and principles;
2. Evaluate the role of theoretical models and empirical studies in the past and in the current development of physics knowledge;
3. Apply physics principles to understand the causes of problems, devise strategies to solve them and test the possible solutions.
4. Use a range of measurement and data analysis tools to collect data with appropriate precision and carry out subsequent analysis with due regard to the uncertainties.
5. Use the tools, methodologies, language and conventions of physics to test and communicate ideas and explanations;
6. Work effectively and ethically in a multi-faceted scientific environment; and
7. Be responsible, critically reflective, self-directed and motivated learners." [4].

These do not quite have one-to-one correspondence with the statements of the TLOs.

Early draft statements of the TLOs were presented to the AIP Executive Council and AIP Accreditation Panel, and further involvement sought from these arms of the professional body. Discussions with leaders of AIP Accreditation Panel resulted in in-principle agreement that alignment of AIP criteria for accreditation and TLOs (for other quality assurance purposes) would be useful. Throughout consultation, it's been clear that academics involved with accreditation (especially those with high-level management experience) see the idea of TLOs as valuable. The latest version of the Statement of Learning and Teaching Academic Standards for Physics was presented at the AIP Executive Council Meeting, 2013. Council asked members of the Accreditation Panel to form a Working Party to deliver unification of physics TLOs and AIP Accreditation criteria. The Working Group includes Stephen Collins (Chair of AIP Accreditation Panel), Judith Pollard and Margaret Wegener. If you have comments about the TLOs and accreditation, please contact a member of the group.

By stating what we stand for, learning outcomes can help define the voice of physics amongst the other sciences, and in the national education setting. Recent events have lifted the importance of this aspect. The Australian Council of Deans of Science has committed to support some education development activities with cohesion across the sciences, and various science disciplines have gained funding for networks to facilitate communication amongst their educators. Representatives of a variety of disciplines in science and mathematics met at the Australian Council of Deans of Science National Workshop - Advancing Science TLO's, in February, 2013, to discuss and compare progress in interpreting TLOs for individual disciplines.

There were relatively few differences between what has been developed so far by different disciplines. The modification by physics of the Science Communication TLOs to incorporate the two-way nature of communication (the Science TLOs mention only the outward-bound process) was acknowledged generally as useful. Alignment of our discipline with maths, sharing strong theoretical and computational aspects, was apparent. Physics has emphasised ethics that relate to intellectual integrity in the Personal and professional responsibility TLO. This can relate to experimental, observational and theoretical endeavours. For some other disciplines regulatory frameworks were seen as the most important aspect of professional responsibility. The feature of the physics TLOs of having to cater for various sub-disciplinary branches (such as theory vs experiment) was matched in some other disciplines by comparable disciplinary divisions. It is expected that the expressions of TLOs that are common to different disciplines will evolve to be the same.

Important next steps for physics will relate to themes that have already emerged from discussion, such as assessment of outcomes, and higher standards (rather than just minimum outcomes). A group funding application has been submitted to support a Physics Education Network, with one of the main aims being development of staff and resources to implement physics TLOs.

REFERENCES

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[4] "Information for Australian universities seeking to have a qualification accredited by the Australian Institute of Physics 2013-2016", http://www.aip.org.au/info/sites/default/files/AIPAccreditationRegs2012updatedAug121.pdf

AUTHOR BIO

Margaret Wegener is a lecturer at The University of Queensland. She has just completed four years as leader of the AIP's Physics Education Group, and is now its Deputy Convenor. She is involved in physics education via teaching, professional service, and research. She teaches aspiring physicists and physics service courses in Engineering and the life sciences. Major themes of her work are the creation of environments for learning physics, via inquiry-based lab learning, contextualisation, and technology-enabled resources, and the effect of student attitudes on learning. She is deeply interested in the interrelationships between science and the arts.