Scientific Inquiry Skills in First Year Biology: Building on Pre-Tertiary Skills or Back to Basics?

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Abstract

The introduction of the Australian secondary education curricula (ACARA, 2012) provided a unique opportunity to benchmark first year biology across the tertiary sector. Specifically we asked will first-year undergraduate subjects build on and offer further development of the skills and capacities that students will acquire once the Australian curriculum is implemented? The answer to this question has important implications for student transition to, and success at university. Overall first year biology subjects are well placed to build on the skills that pre-tertiary students bring with them when the national senior biology curriculum is fully implemented. However if secondary schools choose to focus on open inquiry methods, then given the status of current curricula, universities will not build on the skills developed at secondary level, and curriculum developers need to aware of this potential difference. Other notable differences and their implications for first year biology courses are highlighted.

Introduction

The introduction of the Australian secondary education curricula (ACARA, 2012) provided a unique opportunity to benchmark first year biology across the tertiary sector. Specifically we asked will first-year undergraduate subjects build on and offer further development of the skills and capacities that students will acquire once the Australian curriculum is implemented? The answer to this question, we believe is important for two reasons. First, alignment of secondary school coursework and assessments with those in higher education can positively impact on subsequent tertiary completions (Achieve, 2007). Second, as the diversity of students' backgrounds is set to further increase over the next decade (Bradley, Noonan, Nugent, & Scales, 2008), program developers need to be aware that academic preparation at entry level plays an important role in successful transition

The purpose of first year biology subjects is twofold: to attract the next generation of biologists and for the significant proportion of students who will not become biologists to help them achieve biological literacy which underpins progress towards completion of a degree in the life sciences (Wood, 2009). An understanding of the nature of science and developing scientific inquiry skills, in the university context, is viewed as a continuum from novice to expert (Lederman, 2006). And the growing concern about the dwindling number of students choosing science at university has led to reforms in pre-tertiary education from K-12, strongly suggesting that training in understanding science and applying inquiry skills begin at the earliest stages of education (Goodrum & Rennie, 2007; Universities Australia, 2012).

The Australian Government commissioned National Action Plan for Australian School Science Education Report (Goodrum & Rennie, 2008) was a timely response in recognition of the need for scientific literacy for effective citizenship in a society becoming increasingly dependent on science and technology. According to Goodrum and Rennie (2008), scientifically literate people have an understanding of science, science as a process, and can draw evidence-based conclusions and make informed opinions about their environment and their own well-being.

One of the educational initiatives ensuing from this report, has been the development of a standardized national curriculum across the K-12 education system by the Australian Curriculum Assessment and Reporting Authority (ACARA). The proposed national biology curriculum includes a focus on understanding role and relevance of science, as well as scientific inquiry, in addition to the development of generic skills - in context of the discipline - rather than knowledge acquisition *per se* (see Learning Outcomes, ACARA, 2012).

One component of scientific literacy is scientific inquiry which has been variously defined (Halonen, Bosack, Clay, McCarthy, Dunn, Hill, McEntarffer, Mehotra, Nesmith, Weaver, & Whitlock, 2003). It is however, useful to define scientific inquiry as the process by which scientific knowledge is derived (Lederman, 2006). For this report, scientific inquiry refers to 'the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world' (Wenning, 2007).

'As long as there were people asking each other questions, we have had constructivist classrooms' Jacqueline Grennon Brooks (1999).

Scientific inquiry operates across a number of domain and skills areas, including description and conceptualization, the scientific method including reasoning and ethical approaches, and thus has considerable potential to develop student generic skills in critical thinking and problem solving as well as their recognition of the uncertainty and limitations of their data.

In the university context, scientific inquiry-based teaching approaches include 'hands-on' activities, such as those found in science laboratory classes. It is widely accepted that laboratory practice not only motivates and engages students but provides opportunities for students to experience how knowledge is generated within a scientific context. Students consistently value these experiences and they have been shown to positively impact on their achievement in science courses (von Secker & Lissitz 1999; Deacon & Hajek, 2011; Lee, Lai, Yu, & Lin, 2011). Often students are able to develop these skills along with their communication skills through production of written tasks including laboratory reports and essays. The laboratory experience also provides an opportunity for building team-work skills, highly-regarded by employers (Tytler & Symington, 2006).

The implementation of a national curriculum raises a number of important questions for university educators. One crucial question is whether students undertaking first year biology will have opportunities to further develop the scientific inquiry skills acquired as part of the new national senior secondary school biology curriculum. To address this question, we benchmarked scientific inquiry skills in first year undergraduate biology across the tertiary sector and aligned them with the inquiry skills proposed in the senior secondary biology curriculum. Here we report our preliminary findings.

Methods

This study was conducted by a team of first year biology convenors from four universities (University of Melbourne and Flinders, Monash and La Trobe Universities). The project team members have on-going links with secondary school educators and have a thorough knowledge of their own State's senior secondary biology curricula. The data gathered for these analyses comprised part of a comprehensive benchmarking of first year biology subjects offered at thirty-nine Australian Universities. In this report we provide an analysis of thirty-seven biology subjects across thirty-one universities. These institutions included at least four members of every major university grouping (Table 1).

Data collection

Information regarding first year biology topics was compiled on the basis of the institutional grouping of each university (Table 1; current as at June 2012) and subject theme: Molecules, Genes, Cells and Tissues (MGCT), and Ecology, Evolution & Biodiversity (EEB). The rationale for aligning data with institutional groupings was to investigate whether there were any trends in the first year biology programs that might reinforce the particular focus of each grouping. The subjects were categorised into themes based on the course type, together with unit synopsis and curricula information.

The benchmarking data was compiled by a range of methods, including initial evaluation of subject description website information by team members, followed by telephone conversations and email exchanges with subject convenors. The collated data relevant to this report included syllabus details (topics, learning outcomes and skills), assessment tasks and weightings, contact hours and type of contact (e.g. tutorial, lecture, and practical). Subject convenors were contacted by team members via telephone and/or email, to confirm, expand or refine particular details where handbook entries were limited.

Alignment of Scientific Inquiry Skills

Learning objectives proposed in the Australian Curriculum (ACARA, 2012) for senior biology are organised into three strands: Science Inquiry Skills, Science as Understanding and Science as a Human Endeavour. Although specific skills are listed under the strand entitled, 'Science Inquiry Skills', the three strands are closely integrated to reflect the fact that the work of scientists is concerned with understanding nature, that is influenced by the needs of society and depends on sound scientific inquiry.

The learning outcomes for the three strands in the Australian Curriculum were aligned to the Threshold Learning Outcomes for a pass level graduate from a bachelor degree program (Learning and Teaching Academic Standards (LTAS; Jones, Yates, & Kelder, 2011). The rationale here is that the skills listed in the LTAS document: 1. Are those deemed necessary for graduates in the 'Knowledge economy', 2. Use similar language/terms to items listed in handbook statements for science subjects in the tertiary sector, 3. Are not specific to a tertiary sector education, and 4. are skills that can be acquired at any stage but become increasingly sophisticated as students progress through their education.

Table 1: Surveyed universities and their institutional groupings (GO8 - Group of Eight; IRU - Innovative Research Universities; ATN - Australian Technology Network; RUN – Regional University Network; OTH - Other or non-grouped universities)

University	Institutional Grouping
Australian National University Monash University The University of Adelaide The University of Melbourne The University of New South Wales The University of Queensland The University of Sydney The University of Western Australia	GO8
Charles Darwin University Flinders University Griffith University James Cook University La Trobe University Murdoch University The University of Newcastle	IRU
Queensland University of Technology RMIT University University of South Australia University of Technology Sydney	ATN
Central Queensland University University of Ballarat University of New England University of Southern Queensland University of the Sunshine Coast	RUN
Charles Sturt University Macquarie University University of Canberra University of Notre Dame University of Tasmania University of Western Sydney University of Wollongong	OTH

We aligned similar Learning Outcomes in the two documents. We have called this alignment, the Aspirational Scientific Skills (ASS) i.e those for the proposed National Biology Curriculum that also complemented the Threshold Learning Outcomes. See Appendix 1 for details of the alignment.

We adapted the definitions for types of inquiry employed by Spronken-Smith, Walker, Batchelor, O'Steen and Angelo (2011). 'Open inquiry' refers to students who use a self-directed approach from formulating the questions to designing and undertaking the investigation. In 'Guided inquiry' the teacher provides the question and either (a) an outline for addressing it or (b) students are self-directed in terms of exploring the question. The purpose of this distinction in definitions was to determine to what extent these different teaching approaches were being used in first year biology.

Development of Generalised Scientific Skills (GSS)

The generation of the ASS was used to score learning outcomes contained in first year biology handbook entries in order to derive the Generalised Scientific Skills (GSS) being taught across the tertiary sector.

For this report, the specific information retrieved from subject description entries, and which were directly related to subject objectives and assessment tasks, were; (i) 'What scientific inquiry skills are listed as learning outcomes for the subject?' and (ii) What assessment components are included in this subject? (iii) Does this subject require or assume prior learning?

This involved scoring Learning Outcomes in subject descriptions available on university websites or as provided by subject coordinators (see Table 1). Data collection was undertaken by scoring specific learning outcomes against the ASS for Cell Biology subjects, as well as assessment components and pre-requisites. Only subjects with practical components are included in this data collection

The GSS skills were derived by team members benchmarking first year biology across the tertiary sector, i.e what are current and common learning outcomes. The data is represented in Table 2 as the % of universities that include a specific learning outcome in their subject descriptions. This table includes alignment of GSS and ASS (see Table 2).

Assumptions and Limitations

In generating the data for GSS a number of assumptions were made regarding categorisation of GSS components for each subject. These included, acceptance at face value of learning outcomes provided in subject descriptions. If for example there was a statement in the subject description about developing an understanding of the scientific method in the broad overview of the subject, this was scored under 'Understanding Science'. If there was a specific statement about using the scientific method in the laboratory (whether additional to the statement in the broad overview or not) this was scored under 'Inquiry and Problem Solving'. Thus, for first year biology subject descriptions, only specifically stated learning objectives aligning with the ASS were scored, while recognizing that subject descriptions do not reflect all activities (learning objectives) that may take place in the subject.

In addition, some learning outcomes may form part of a student's discipline/major/program and may not be represented in the learning outcomes in first year biology handbook entries. The learning objectives in the tertiary biology subject descriptions were valid as of January 2012; if there were changes after this, our data collection does not reflect these changes.

Assessment Components in First Year Biology.

For each subject, data was collected and grouped according to the percentage of final score allocated to each of final exam, practical component and other activities. The final exam is generally 2-3 hours in length and can be entirely multiple choice, or a mixture of multiple choice and written answers. We did not investigate the format of the final exam further. The final exam is a single component score. The practical component can include scores for written reports, worksheets or assignments completed in the practical class or later, and may include some sort of attendance mark. Assessment guidelines and rubrics were provided by some coordinators but a more thorough analysis of assessment practices is beyond the scope of this report. Finally, the 'other' component variously includes scores for on-going assessments such as multiple choice quizzes, essays or literacy skills assignment, and e-learning modules whether provided by textbook publishers or developed by academics. Subjects without practical components were not included in this data collection and analysis.

Data Analysis

Quantitative data analysed in institutional groupings, were presented as mean ± standard deviation, and analysed using two-tailed student's t-test (Microsoft® Excel software). Statistical significance was determined at the 5% level.

Results

With the underlying assumptions and limitations of the study in mind, the results suggest, that broadly first year biology subjects focus on understanding of biological content (100%), developing skills such as accurately collecting and interpreting data and drawing conclusions (92%) and communicating these results in the form of a scientific report (95%) (Table 2). To a lesser extent, other forms of communication are developed; for example, oral presentations and posters, with 41% of universities including these as learning outcomes. Interestingly, 34% of universities list quantitative skills (QS, referring to the application of mathematical and statistical thinking in a given context (Matthews, Adams, & Goos, 2010) as a learning outcome for biology and in most cases this referred to statistical analysis. A very small percentage (5%) of universities included skills in communication for diverse audiences and purposes.

Critical thinking as developed by critically evaluating information from a range of sources is listed as a learning outcome for 68% of universities, problem solving 22% and the ability to work in a team 57%. 'Design and plan an investigation' is listed as a learning objective in 24% of university subject descriptions where it is made clear that this is a student-driven open inquiry, otherwise 57% state only that students will conduct an experiment or undertake a laboratory task or gain experience in the use of scientific equipment.

Table 2: The percentage of first year biology subjects that specify learning outcomes (Generalised Scientific Skills, GSS) that aligned with Aspirational Scientific Skills (ASS). * denotes that unless the subject description specifically made reference to an open inquiry planned and executed by students, then 'conduct an experiment' was taken to mean guided-inquiry

Aspirational Skills Set (ASS)	**Generalised Skills Set (GSS) %**
Understanding Science	
An understanding of scientific method	47
Understand scientific knowledge is dynamic	3
Role and relevance of science	19
Scientific Knowledge	
Understand and integrates key concepts/models/theories	100
Knowledge in at least one other discipline	3
Inquiry and Problem Solving	
Critically evaluate information from a range of sources	68
Apply scientific method	54
Be able to problem solve	22
Design and plan an investigation - Open Inquiry	24
*Conduct an Experiment or Laboratory Task – Guided Inquiry	57
Select appropriate methods & tools to conduct investigation	0
Collect and accurately record data	92
Use appropriate representations of data	92
Interpret data and draw conclusions	92
Use QS skills for evaluation	34
Communication	
Communicate information & findings/report writing	95
Multimodal forms of communication	41
For diverse audiences & purposes	5
Personal and Professional Responsibility	
Able to work independently	19
Self-directed learning	11
Able to work in team	57
Practise ethical conduct	34
Follow safety regulations	41

Comparison of Assessment Components

Assessment components for G08 universities grouped according to subject themes, Cell Biology including genes, form and function – 'CB' and Evolution, Ecology & Diversity – 'EED' are shown in Figure 1. The average percentage weight ± standard deviation for practical (P), final exam (E) and other (O) are shown for CB and EED. There was no statistical significant difference between any assessment component in CB compared to EED. It is clear that the final exam is between 40-60% of the final subject score, and forms a significant part of assessment for first year biology subjects.

Assessment components for G08 and IRU universities grouped according to subject themes CB and EED are shown in figure 2. There was no statistical significant difference between any assessment component in CB compared to EED across the two university groupings. The practical assessment component is between 20-30% for G08 and IRU universities.

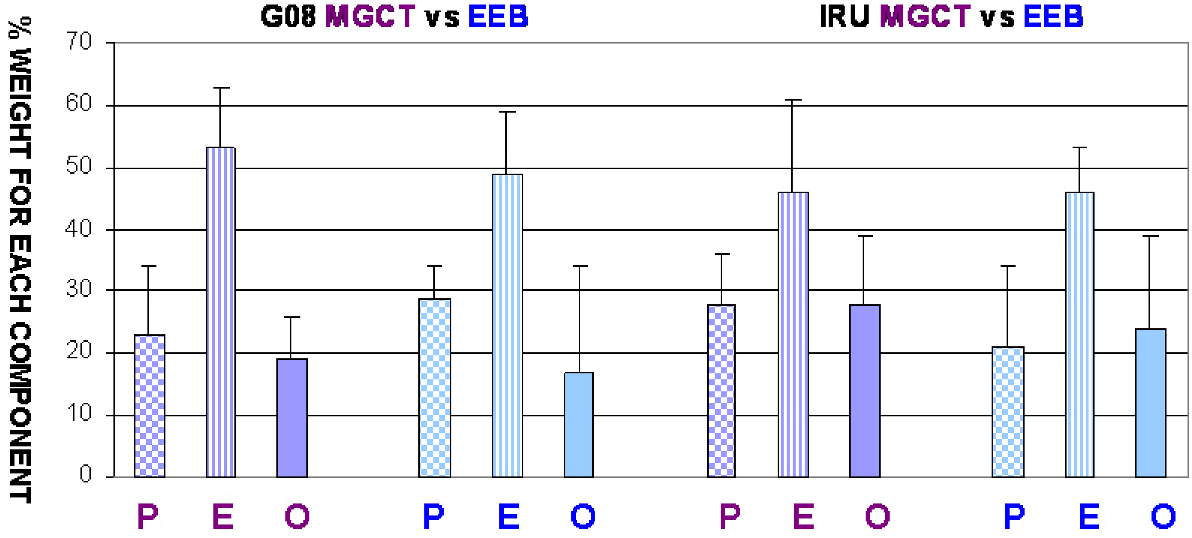

Figure 1. Proportion of assessment allocated to different components, Practical (P), Final Exam (E) and Other (O). Data is expressed as mean ± standard deviation and based on institutional groups, G08 (Group of Eight) and IRU (Innovative Research Universities) and subject themes MGCT (Molecules, Genes, Cells and Tissues) and EEB (Ecology, Evolution and Biodiversity).

Prior Knowledge

No Biology subject at first year level across the tertiary sector lists senior secondary school biology as a pre-requisite. One university requires a pass in year twelve English, and two universities require a pass in year twelve chemistry. 31% of universities assume year twelve level knowledge in chemistry or mathematics.

Discussion

In this study we compared the learning objectives proposed in the draft Australian national senior biology curriculum (ACARA, 2012), to the Threshold Learning Outcomes for Science Graduates (Jones et al., 2011) – we have called this alignment, the Aspirational Skill Set (ASS). The rationale for this alignment was based on the fact both documents are underpinned by a constructivist view of learning (Phillips, 1998). These documents also include learning objectives that specifically consider the nature of science and scientific inquiry skills as an equally important component to traditional curricula based on 'science knowledge'. The similarities in the learning objectives between the two documents underscore the importance of developing scientific inquiry skills for students and graduates in this new era.

Scientific inquiry, a component of scientific literacy, has been variously defined (Wenning, 2007) and for our purposes refers to the specific skill set listed under Inquiry and Problem Solving in ASS (see Table 2). The Australian curriculum has an emphasis on inquiry skills for secondary students. ‘Select appropriate methods & tools to conduct investigation’ relates to students being able to design an investigation and select the most appropriate techniques and tools necessary to address a particular research question (ACARA, 2012; Jones, Yates, & Kelder, 2011). This learning outcome is dependent on students having knowledge of a discipline to some extent, to select appropriate methods and tools. Its inclusion as a specific learning outcome appears to address an aspect of the mechanics of ‘problem solving’. ‘Select appropriate methods & tools to conduct investigation’ is not listed as a learning outcome for any first year biology subject. However, our data shows first year biology courses across the tertiary sector purport to provide students with opportunities to develop scientific inquiry skills and almost all universities surveyed incorporate some form of experimentation allowing students to collect, present, interpret and communicate their findings. From conversations with first year biology co-ordinators, most of these activities are guided inquiry and take place in purpose-built laboratories or in the field. Only a quarter of universities examined incorporate activities where students independently formulate their own questions and perform a full inquiry cycle. It should be noted that most students will undertake more comprehensive scientific training in later years of their courses, therefore we do not consider the lack of ‘select appropriate methods and tools’ in learning outcome statement at first year level of concern

However, it is important to continue providing appropriate opportunities for students to engage in laboratory activities as students consistently value these experiences (Deacon & Hajek, 2011) and they have been shown to positively impact on their achievement in science courses (Lee, Lai, Yu, & Lin, 2011; von Secker & Lissitz 1999). The Australian curriculum has an emphasis on inquiry skills but it is not explicit about recommending open or guided inquiry. If the former style of inquiry is favoured by secondary educators, once the curriculum is implemented, inclusion of open inquiry opportunities in first year biology may need to be addressed to ensure students with a senior biology background are able to build on and develop their inquiry skills. However, open inquiry has been shown to be ineffective (Mayer, 2004; Kirschner, Sweller, & Clark, 2006) and to have unintended outcomes of increasing gaps between students from different demographic profiles (Von Secker and Lissitz; 1999) which could have important implications for transition as the diversity of students’ backgrounds enrolling into universities increases.

Quantitative skills (QS) have been identified as a skill set required for science graduates, with QS referring to the application of mathematical and statistical thinking in a given context (Matthews et al., 2009). Yet, very few first year biology subjects list QS as learning outcomes in their handbook descriptions. Descriptive statistics, defined as a summary of observed data presented in numerical or graphical form (Anderson, Sweeney, & Williams, 1994) is in wide use in first year biology subjects and listed as ‘Collecting and presenting data’. However, what is less clear is whether inferential statistical methodology is used to interpret, validate data or draw conclusions but given the limited resolution of our data this cannot be determined.

It has been argued that graduates who have acquired a range of skills will have access to broad employment opportunities (Goodrum & Rennie, 2007). The inclusion of collaborative and communication skills in both the ASS and broadly across the tertiary sector, along with inquiry skills addresses the changing nature of the workplace. It is now widely accepted that many adults will make multiple career choices over their life spans (Drucker, 2007; Zunker, 2008) stressing the importance of graduates developing generic skills and life-long learning. The range of communication options offered by first year biology subjects is varied from written work (report and/or essay) in the majority of cases to oral presentations and posters also offered in just over half the subjects surveyed. Opportunities for all students to develop communication skills need to be addressed at first year undergraduate level and whether biology, some or all other first year subjects need to do so requires further investigation.

Opportunities to develop collaborative skills are reported in approximately 60% of subjects surveyed. Research in the social sciences has shown that groups of individuals engaged in problem-solving are more effective than individuals working alone and the effectiveness of the group increases with its diversity of members (McCleod, Loebel, & Cox, 1996; Guimera, Uzzi, Spiro, & Amaral, 2005). These are strong arguments for encouraging group work, and the development of group-work skills are considered essential for preparing students for the workforce where they will probably work in teams (Goodrum & Rennie, 2007; Wood, 2009).

Scientific literacy is multifaceted and has been previously defined (Goodrum & Rennie, 2007). One important component of this definition is 'nature of science' or as described in our Aspirational Scientific Skills 'understanding science' has received significant attention in both the ACARA and LTAS documents and refers to the epistemology of science, the development of scientific knowledge, science is a human enterprise embedded in culture and science as a way of knowing.

An important concept described in both the National Biology Curriculum and Threshold Learning Outcomes is the 'Understanding scientific knowledge is dynamic' requires further explanation. This learning outcome is about understanding that scientific knowledge is created by consensus within a group of scientists, is re-evaluated when subsequent findings become available, involves critique and uncertainty and therefore is dynamic. While 'understanding of scientific method' is highlighted as a learning outcome in biology subjects at a significant number of universities, both 'understanding scientific knowledge is dynamic' and 'the role and relevance of science (or science as a way of knowing and science is a human enterprise embedded in culture)' are not addressed to any appreciable extent.

This may be a consequence of the lack of pre-requisites for first year biology at the majority of Australian universities but does not exclude the possibility for teaching the relevance of biology to the lives of our students. First year biology serves as a pre-requisite for second year subjects and many majors in the life sciences; for example a pass in first year biology forms part of twenty-nine majors at the University of Melbourne and thirty-six at Flinders University. Between 40-60% of entry level students have not studied biology previously. Therefore first year serves to provide a knowledge baseline for students to progress in their courses as well as to introduce life science methodology. Given the varied choice of subjects in second year, first year biology appears to emphasise baseline knowledge for the breadth of disciplines in the life sciences. 'Other' assessment is made up of MCQ/e-learning modules which generally contribute to 'understanding science' and supplement lecture and practical activities; however the resolution of our data is limited to make any further comment.

The strong focus on 'scientific knowledge' is evident by its listing as a learning outcome for all biology subjects at all institutions, as well as the weighting of the final exam from 40-65% in assessment components across the sector. While we are aware exams may assess different levels of understanding using Bloom's taxonomy of cognitive skills as an example

(Krathwohl, 2002), we did not explore this any further. However, in a recent survey of exams for 500 different first year biology courses, most questions were rated Bloom's level 1 and 2 (Zheng, Lawhorn, Lumely, & Freeman, 2008).

Given that large undergraduate classes of biology are now a common feature of most universities (from around 800 – 2000 students), that the final exam weightings comprise a large component of assessment in these subjects, and the requirement for baseline knowledge in life science generally, we speculate the level of cognitive skills assessed in final exams may be similar to those reported by Zheng et al. (2008) for American universities.

While acquisition of scientific knowledge is also an important learning outcome in the ASS, 'knowledge in at least one other discipline' receives very little attention in first year biology. Despite the changing context of higher education, and the growing emphasis on the interdisciplinary nature of successfully funded scientific research (Tytler & Symington, 2006), the focus on single discipline subjects occurs at most universities. This reflects the continued compartmentalisation of disciplines and the broad lack of pedagogical collegiality among academics (Kezar, 2005) due in part to the focus academics must apply to their research output (in terms of grant success and publications) which provides the basis for their recognition and advancement. If teaching were more highly rewarded, it is assumed, academics at the same institution would work more closely together (Asmar, 2011).

More importantly however is the fact that first year biology is taken by a large number of students and for a significant number it is their only science subject. As mentioned currently 40-60% of students have little or no prior knowledge in biology. If the national curriculum for science subjects is effective in inculcating inquiry-oriented skills in senior secondary students, then students without prior study in biology, or particularly without combinations of senior secondary science subjects, are likely to be at a disadvantage. The positive effect of prior study, in combinations of, for example biology and chemistry, has been previously established (Bone & Reid 2011).

Conclusions

Students whether at universities classified as research intensive or not, both in the United Kingdom or Canada are aware of the research activities at their institution but very few as undergraduates have the opportunity to participate (Turner, Wuetherick, & Healey, 2008). It has been suggested that the relationship between teaching and research needs to be enhanced and one approach to achieve this integration is to increase inquiry-based instruction in higher education (Brew, 2003).

Broadly, first year biology subjects do offer experiences to develop a range of inquiry skills, including the opportunity to participate in practical classes offering a well-known and successful strategy to develop these skills. One notable difference, however, is in the need to shift from knowledge acquisition *per se* to science as a community of practice. While quantitative, generic and communication skill development occur to some extent, these areas need addressing.

Overall first year biology subjects will build on the skills that pre-tertiary students bring with them when the national senior biology curriculum is fully implemented. However if secondary schools choose to focus on open inquiry methods, then given the status of current curricula, universities will not build on the skills developed at secondary level, and curriculum developers need to aware of this potential difference. In addition, there may be a delay in achieving full implementation of this new Australian curriculum, particularly since the emphasis on inquiry skills, we assume, will require professional development of secondary school teachers and perhaps development of new resources. During the interim, we argue strongly for maintaining the laboratory practical in first year biology and a review of curricula, to augment the alignment of the learning outcomes in the two sectors in order to enhance student transition.

The alignment of the biology curricula offered in the two sectors has the potential to improve the opportunities for success in higher education among entry level students with diverse backgrounds when there is better integration between two sectors operating independently. Addressing the gaps and strengthening the similarities identified in this study between the Australian senior curriculum and first year biology will in the long term help maintain consistency in educational standards and allow tertiary educators to be poised and ready to welcome the entry-level students who have experienced this new coursework at secondary level.

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APPENDIX 1

Threshold LOs for Science	National Curriculum LOs for Scientific Inquiry Skills (Draft May 2012)	Aligned LOs (ASS)
Understanding Science 1.0 Demonstrate a coherent understanding of science by:	**Science as a Human Endeavour** .	
1.1 Articulating the methods of science and explaining why current scientific knowledge is both contestable and testable by further inquiry 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.	Highlights the development of science as a unique way of knowing and doing, the communication of science ideas, and the role of science in decision making and problem solving. In particular, this strand develops both students' understanding of science as a community of practice and appreciation that science knowledge is generated from consensus within a group of scientists and is therefore dynamic and involves critique and uncertainty. It acknowledges that in making decisions about science practices and applications, ethical and social implications must be taken into account.	An understanding of scientific method Understand scientific knowledge is dynamic
1.2 Explaining the role and relevance of science in society. 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	Through science, humans seek to improve their understanding and explanations of, and ability to predict phenomena in, the natural world. Since science involves the construction of explanations based on evidence, science concepts, models and theories can be changed as new evidence becomes available, often through the application of new technologies. Science influences society by posing, and responding to, social and ethical questions, and scientific research is itself influenced by the needs and priorities of society.	Role and relevance of science

students and academic colleagues; the social, environmental, technological, industrial and military sectors; and the world-wide community of scholars and others.		
Scientific knowledge 2. Exhibit depth and breadth of scientific knowledge by: 2.1 demonstrating well-developed knowledge in at least one disciplinary area 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.	**Science Understanding** Understands and integrates appropriate science concepts, models and theories to explain and predict phenomena, and applies those concepts and models to new situations.	Understand and integrates key concepts/models/theories
2.2 demonstrating knowledge in at least one other disciplinary area.		Knowledge in one other discipline
Inquiry and Problem Solving 3. Critically analyse and solve scientific problems by:	**Scientific inquiry skills** concerned with evaluating claims, investigating ideas, solving problems, reasoning, drawing valid conclusions and developing evidence-based argument by:	
3.1. Gathering, synthesising and critically evaluating information from a range of source Gathering and synthesising information: Science graduates will be able to identify, access, select and integrate information. Critically evaluating information: It is important that science graduates are able to assess the validity of the information that they gather in the context of their knowledge and understanding of science as described in TLO 1.1. Range of sources: This term is used to indicate that information can be gathered from traditional sources (including books, refereed papers and journal articles, conference presentations, seminars, lectures and colleagues) as well as non-traditional sources (including non-refereed articles, reports, 'grey literature' and electronic posts). It also could include information that is generated through experimentation or the analysis of existing	Evaluate processes, claims and conclusions by considering the quality of available evidence; and use reasoning to construct scientific arguments	Critically evaluate information from a range of sources

data.		
3.2 designing and planning an investigation 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.	Identify, research and construct questions for investigation, proposing hypotheses and predicting possible outcomes Design investigations, including: making decisions about the procedure to be followed, the materials required and the type and amount of primary and/or secondary data to be collected; *Conducting risk assessments; and considering ethical research*	Apply scientific method And be able to problem solve Design and plan an investigation
3.3 Selecting and applying practical and/or theoretical techniques or tools in order to conduct an investigation Selecting and applying: Through their undergraduate training, science graduates will have some knowledge of the most appropriate techniques to use to solve different types of problems. Practical and/or theoretical techniques: It is recognised that practical, experimental and field techniques will vary from one area of science to another. Science graduates will be able to use practical techniques that are appropriate for their disciplinary area, and will have an appreciation of the techniques used in other areas of science. They will be prepared to work in the office, the laboratory or the field, as appropriate to their disciplinary area. Tools: The tools of science might include instruments, apparatus, mathematical and statistical approaches including modelling, or information and communication technologies.	Conduct investigations, including using equipment and techniques safely, competently and methodically for valid and reliable collection of data	Select appropriate methods and tools to conduct investigation
3.4 Collecting, accurately recording, interpreting and drawing conclusions from scientific data 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.	Represent data in meaningful and useful ways; organise and analyse data to identify trends, patterns and relationships, and recognise uncertainty and limitations in data; and select, synthesise and use evidence to construct and justify conclusions Select, construct and use appropriate representations to communicate conceptual understanding, solve problems and make predictions *Under mathematical skills expected:*	Collect and accurately record data Use appropriate representation of data Interpreting data and drawing conclusions Use QS skills for evaluation

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.	In gathering and recording numerical data, students are required to make measurements with an appropriate degree of accuracy and to represent measurements using appropriate units, and, as appropriate, to specify confidence intervals to indicate accuracy.	
Communication 4.0 Be effective communicators of science by; 4.1 communicating scientific results, information, or arguments, to a range of audiences, for a range of purposes, and using a variety of modes.	Communicate to specific audiences and for specific purposes using appropriate language, nomenclature, text types and modes, including scientific reports	Communicate information and findings/report writing Be able to use multimodal forms of communication for diverse audiences and purposes
Personal and Professional Responsibility 5.0 Be accountable for their own learning and scientific work by: 5.1 being independent and self-directed learners 5.2 working effectively, responsibly and safely in an individual or team context 5.3 demonstrating knowledge of the regulatory frameworks relevant to their disciplinary area and personally practising ethical conduct	Conduct investigations using techniques, safely, competently and methodically for the valid and reliable collection of data	Work independently Self-directed learning Work in team Follow safety regulations and procedures Practise ethical conduct
SOURCE: Science Learning and Teaching Academic Standards Statement http://www.olt.gov.au/system/files/resources/altc_standards_SCIENCE_240811_v3.pdf	**SOURCE: Draft senior secondary Australian Curriculum- BIOLOGY** http://www.acara.edu.au/curriculum/draft_senior_secondary_australian_curriculum.html	