THE STATE OF QUANTITATIVE SKILLS IN UNDERGRADUATE SCIENCE EDUCATION

FINDINGS FROM AN AUSTRALIAN STUDY
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Quantitative Skills (QS) in Science: Curriculum model for the future

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Quantitative Skills in Science: **Curriculum Models for the Future (*QS in Science*) project**

The *QS in Science* project raises alarm bells for the higher education sector. Amid the approaching accountability agenda of the government and the calls for more and better qualified science graduates, this report highlights a serious gap in undergraduate science education. We can all appreciate discipline differences within science and across science and mathematics; however, this report exposes just how detrimental the influence of disciplinary isolationism is for preparing science graduates with the necessary quantitative skills.

Mathematicians, physicists, chemists and biologists, for example, generally object to each other's interpretations of the same list of techniques or items from a text-book. However, there is nothing explicit as to what the various protagonists do mean by particular quantitative skills, and how students would display their particular understanding of them.

How is service teaching meant to work in such an environment? Everyone knows that it doesn't work well, but in a new standards based environment people are going to start asking why. What is required is that providers and customers communicate via a shared understanding of each other's requirements and capabilities. However, the case studies in this report reveal that the organizational structures in universities do not foster this common understanding. So we have heads of departments, associate deans teaching and learning, deputy vice-chancellors teaching and learning, layers of organisational structure, none of which seemingly are tackling the problem.

There are 'graduate outcomes', 'national standards' and 'institutional attributes' all of which have honed in on the idea that a science degree develops quantitative skills. There is no sense that these worthy instruments are talking about the same thing, and no evidence that they give any guidance to the many innovations undertaken within faculties and departments in relation to teaching quantitative skills. The study finds no evidence-based evaluations of these many innovations; little to articulate their goals and nothing to say what exactly has been achieved.

Indeed, the study points out what most people already suspect, that curriculum redesign involving quantitative skills is often regarded as driven by the politics of student load redistribution and/or 'teaching efficiencies', inhibiting serious consideration of the significant educational issues.

If ever there was an issue that required faculty and university level leadership it is the teaching of quantitative skills. For those leaders, this report should be their starting point.

Professor John Rice
Executive Director, Australian Council of Deans of Science

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Executive Summary

The project, *QS in Science: Curriculum Models for the Future*, responded to the call for action to address the inadequacy of quantitative skills (QS) among science students and graduates. The *QS in Science* project espouses development of QS as a key learning outcome through embedding QS in undergraduate science programs in a 'whole of program' approach.

A year and half into the project, our findings affirm that the challenges faced by the higher education sector regarding QS in science are serious and deep-seated, with profound influence on the program structures of science undergraduate courses. Seven key findings verify that these challenges are substantial.

Key Findings

1. Lack of shared meaning for QS. Academics agreed that QS are essential learning outcome for science graduates, however evidence highlighted that academics possessed differing, and often vague, notions of what specific QS were needed.

2. Lack of communication about QS across disciplines. Organisational structures and processes for science and mathematics academics to meet and discuss QS were not evident.

3. Lack of curricular leadership for QS. Despite agreement of QS being an essential learning outcome, there was limited evidence of leadership taking responsibility for the achievement of QS as a learning outcome across the degree program.

4. Lack of evaluation and evidencing of QS curricular learning outcomes. In Australia there was no evidence of science specific, program level evaluation activity for QS.

5. Lack of QS reform efforts when organisational restructuring is occurring. Where institutional restructures and redundancies ran in parallel to curricular review processes, academics were less inclined to address the QS issue.

6. Lack of connection between attributes, outcomes and standards. Despite having national standards, institutional attributes and program level graduate outcomes, the influence on curricular design to build QS was not evident beyond generic statements.

7. Lack of knowledge and adaption of QS educational resources. Academics tended to develop their own QS resources, largely reacting to basic deficiencies in numeracy skills, duplicating existing resources unknowingly.

Recommendations

The key findings presented in the previous section offer opportunity in the form of identified challenges that when addressed will allow the sector to move forward with improving QS of graduating science students. The recommendations therefore respond to these key findings.

1. Formulate a shared meaning for *QS in science*. This will necessarily involve the provision of effective forums in which to open discussion between mathematicians and statisticians, and discipline scientists.

2. Development and maintenance of effective communication channels across and within disciplines. An effectual mechanism for communication must be established and maintained so that discussion can continue as the needs for *QS in science* evolve. This is probably as much about developing a culture of communication across disciplines as it is about the existence of the mechanism for communication.

3. Fostering of curricular leadership in QS. This leadership needs to be at the forefront of the development of whole-of-program approaches to QS in science.

4. Development of an evaluation framework for QS. This is essential so that individual institutions can determine how their curriculum should change to meet the needs of the science community. It will also have benefits in terms of the ability of institutions to meet government reporting requirements.

Introduction

Why focus on Quantitative Skills (QS) in Science?

The lack of quantitative confidence and preparedness among secondary school students is presenting significant challenges to the tertiary sector, particularly for science-based disciplines that rely on quantitative competency. Students entering science programs have weaker foundations in, and stronger negative beliefs toward mathematics, but at the same time advances in science and technology require more complex quantitative knowledge and skills. Undeniably, science curricula must evolve to ensure the preparedness of university graduates. Despite the obvious needs, individuals and institutions are struggling to understand how to achieve this in practice and are faced with increasing challenges in embedding QS in undergraduate science programs.

Throughout this project and this report, **QS are defined** as the ability to apply mathematical and statistical thinking and reasoning within a given external context.

Literature Review

Why QS in undergraduate science?

The Group of Eight report, Review of Education in Mathematics, Data Science and Quantitative Disciplines (Brown, 2009), is another in a long line of high-profile reports which identify a looming crisis in Australian education at all levels. Not only are secondary school students holding negative views of quantitative subjects, they are also underperforming in mathematics and science (Thomson, Wernert, Underwood & Nicholas, 2009). This issue is not limited to Australia, as evidenced by a recent UK report that stated, 'Science examination standards at UK schools have eroded so severely that the testing of problem-solving, critical thinking and the application of mathematics has almost disappeared … urgent action is required before it is too late' (Fazackerley & Richmond, 2009, p. 20). However, there is widespread agreement that QS are essential for graduate competence and preparedness in science (AAAS - American Association for the Advancement of Science, 2009 ; AAMC – American Association of Medical Colleges, 2009; Bialek & Botstein, 2004; National Research Council, 2009; National Research Council Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century, 2003; Rubinstein, 2009).

The need for universities to graduate more students who are ready to enter professions requiring science and mathematics is well-acknowledged globally (Roberts, 2002; Obama, 2009). However, declining enrolments in STEM are also well-documented in Australia (Ainley, Kos & Nicholas, 2008; Brown, 2009), the USA (Augustine, 2007; National Research Council Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century, 2003) and the UK (Fazackerley & Richmond, 2009; Koenig, 2011). Compounding the challenge for universities are the rapid changes in science resulting from technological advances in recent decades that require scientists with more interdisciplinary knowledge and greater levels of quantitative skills, including in the life and biomedical sciences (AAAS - American Association for the Advancement of Science, 2009 ; National Research Council Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century, 2003).

With declining enrolments and increasing demand from stakeholders, institutions are feeling the pressure to attract and retain more science students. Variations in academic preparedness and the overall diversity of students will continue to increase, particularly in light of the Bradley Review (2008). At one end, students are entering with weaker foundations in mathematics and greater fears of quantitative subject matter. At the other end, industry is demanding science graduates with greater quantitative skills. Caught in the middle, universities are struggling to raise science students to an appropriate level of quantitative competency in a three year Bachelor of Science program. Amid the myriad of 'calls for action', it is clear that science and mathematics departments will need to work across traditional disciplinary boundaries to address this issue.

The changing face of higher education in Australia requires a change in the way QS are delivered to the modern student cohort. Wood and Solomonides (2008) argue that when teaching mathematics, a context-based approach produces graduates who are more workplace-ready. Thus, many academics seeking to engage students in learning QS favour a context-based approach (Matthews, Adams & Goos, 2009). While placing material in context may be a useful motivator, it is also widely recognised that the contextual nature of the problems requiring QS poses additional challenges for many science students (LeBard, Thompson, Micolich & Quinnell, 2009; Tariq & Jackson, 2008). However, in science the context is inescapable. Used properly this should provide an advantage in terms of engaging students. Probably the most powerful way to demonstrate the importance of QS is through embedding within discipline-specific subjects. Communication between disciplines is essential for this delivery method to show success. Matthews et al. (2009) make it quite clear that the responsibility for teaching QS must be shared between mathematics and science disciplines, which is a view supported by professional bodies. For example, the Board of Life Sciences of the US National Academies, in the executive summary of Bio2010 (National Research Council Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century, 2003), writes:

'It is important that all students understand the growing relevance of quantitative science in addressing life-science questions. Thus, a better integration of quantitative applications in biology would not only enhance life science education for all students, but also decrease the chances that mathematically talented students would reject life sciences as too soft.'

Project aims

What did the QS in Science team set out to achieve?

This project addressed the challenge of embedding QS in undergraduate science programs and proposed four outcomes listed in Table 1.

Table 1. Outcomes and aims of the project.

Outcome 1: Curriculum Structures	International benchmarking of undergraduate science curriculum structures that effectively integrate QS.
Outcome 2: Model for Curricula Change in Higher Education	A model for institutional curriculum change processes based on four phases: need, vision, implementation and evaluation.
Outcome 3: Framework for Academic Change	A framework for cross-disciplinary academic collaboration, supporting adaption, adoption and evaluation of educational approaches/resources.
Outcome 4: High Profile Dissemination Activities	A symposium in 2012, a special issue with a high rated journal, and the development of an interdisciplinary Australian '*QS in Science*' network

Methodology
How did the QS in Science team achieve their aims?

A case study methodology (Yin, 2003) has been utilised to achieve Outcomes 1 and 2. We selected universities as case studies using the following sampling criteria:

1. The need for change in the undergraduate science curriculum had been identified, particularly the need to better enhance the QS of science students.
2. An institution was recognised as having well-integrated QS, without necessarily having completed a curriculum reform process.

Thirteen case studies from 11 universities across Australia (including Go8, regional and multi-campus) and two comparable universities from the USA with an established record of building QS of science students were completed.

The primary sources of data were:

1. Interviews with key stakeholders at each institution, including Associate Deans (Learning & Teaching), science program coordinators, subject coordinators for large, compulsory/highly recommended subjects, and other key administrators within science.
2. Document analysis, including program booklets, catalogues, curriculum documents, assessment tasks, teaching activities and previous evaluation results.

Interviews were conducted by project team members following a process of training the team to interview effectively and consistently. A semi-structured interview guide was developed. Shaped around Fullan's model for educational change and tailored to discuss QS in science as a program-level learning outcome, the guide was refined as the interviews progressed. In total, 38 interview sessions were conducted and audio recorded with 36 being transcribed (two sessions had too much background noise to be accurately transcribed). All transcribed interviews were then sent to interviewees for validation and approval for inclusion in the study. No interviewees declined involvement although a few did edit their transcripts. Only their edited transcripts were included in our analysis.

Through analysis of data collected, using data analysis software QDA Miner, distinctive factors characterising the change in curricula structures were identified and documented. Each case study was documented and made public with input from those interviewed.

Model for curricular change
How did the QS in Science team frame their study?

Fullan's (1983, 2007) framework for understanding large-scale educational change was designed from research into primary and secondary education systems. However, his model can readily be adapted to the tertiary sector. Fullan's initial model (1983) for large-scale educational change was built around four key stages, and was essentially linear in nature: (1) The Change – A new model or program; (2) Factors Affecting Implementation (both planned and unplanned); (3) Implementation - Its Use in Practice; and (4) Outcomes – Achievement, attitudes, etc. His refined model (2007) is more fluid and cyclical, and also features the role of individuals in the change process, including the importance of collaboration for embedding positive and sustainable change. Fullan's model centres on a system level while incorporating the needs and roles of people as change agents. We have adapted and visualised Fullan's framework for curriculum renewal (see **Figure 1**).

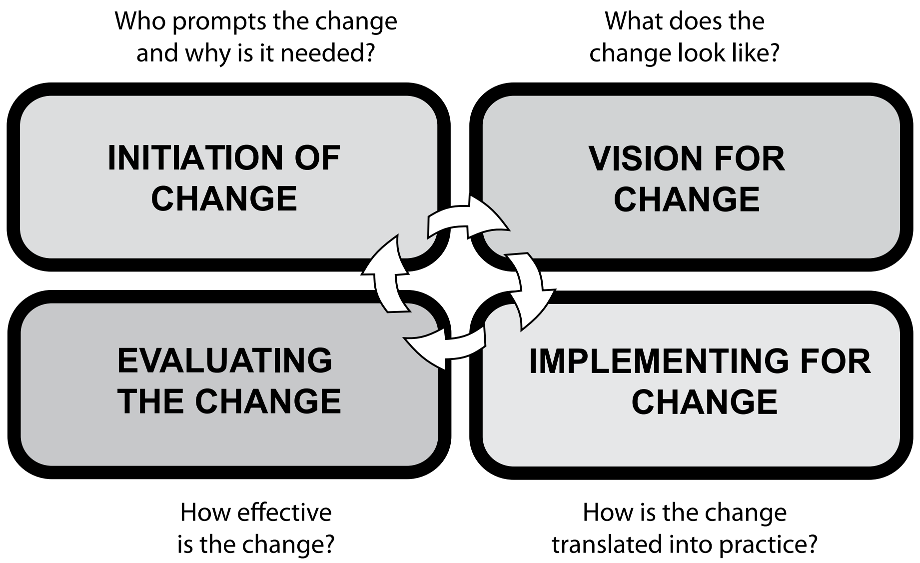

Figure 1: Conceptual framework based on the work of Fullan (2007).

Study participants

Who was involved in the QS in Science project?

A cascading approach to identifying key interviewees was utilised, whereby the Science Associate Dean Learning and Teaching (ADLT) (referred to as *L&T leaders*) or equivalent was contacted. The ADTL was asked to recommend a few lecturers (*teaching academics*) who were working to build QS in their units. A total of 48 academics (**Table 2**) from science and mathematics disciplines (**Table 3**) were interviewed in 38 interview sessions.

Table 2: Interviewee by role from participating universities.

University	Learning and Teaching leader	Teaching academic	Total interviewees
University of Sydney	1	1	2
University of Melbourne	1	2	3
University of Western Sydney	1	2	3
University of Wollongong	1	4	5
James Cook University	1	3	4
Curtin University	1	0	1
Monash University	1	2	3
La Trobe University	1	3	4
Macquarie University	1	2	3
University of Queensland	1	2	3
Queensland University of Technology	1	3	4
University of Maryland*	2	1	3
James Madison University*	4	6	10
TOTAL	**17**	**31**	**48**

*Dean of Science also interviewed. Learning and Teaching leader refers to ADTL; Teaching academic refers to those teaching into the science program.

Table 3: Interviewee by discipline from participating universities.

University	Science	Mathematics	Total
University of Sydney*	1		2
University of Melbourne	2	1	3
University of Western Sydney	3		3
University of Wollongong	5		5
James Cook University	3	1	4
Curtin University		1	1
Monash University	1	2	3
La Trobe University	2	2	4
Macquarie University *	2		2
University of Queensland	1	2	3
Queensland University of Technology	3	1	4
University of Maryland	3		3
James Madison University	10		10
TOTAL	**36**	**10**	**46**

*Data excludes a participant whose interview was not transcribed.

Outcomes

What did the QS in Science team find?

Case Studies

Whole of curriculum perspective on QS across science

Data from the 12 universities (**Appendices 1-12**) revealed that a whole of curriculum perspective on QS is something that has been rarely considered. The main reason for this lies in the inherent interdisciplinary nature of QS – applying mathematics to various science disciplines. This runs counter to the current model of science higher education where science is presented in a highly modularised form and taught within a traditional disciplinary-dominant set of units. This modularisation tends to reinforce the preparation of content and resources in isolation, with little or no interdisciplinary consultation taking place.

All faculties/schools offering science programs were acutely aware of the diversity of prior mathematical knowledge and attitudes towards mathematics of its entering science students. Some institutions responded to this by either glossing over or avoiding any numerical calculations that were required in their units. This impaired the development of a systematic approach to developing QS across the curriculum. Many science faculties also have no tradition of discussing, planning or evaluating the whole of the undergraduate curriculum within or across their departments/schools, with collegiate involvement from mathematicians/statisticians in any whole of curriculum discussions being not evident.

The main findings from the case studies, when considering QS from a whole of curriculum approach, can be summarised as follows:

1. There is no pattern for how the universities studied are implementing QS across the science curriculum.
2. Catering for the diversity of student cohorts in terms of their mathematical abilities impacted on the design of science curricula with different institutions implementing various methods to overcome this range of mathematical ability.
3. Science and mathematics academics and departments struggle to collaborate effectively on the learning and teaching issue of building QS for science students.
4. Resources to build QS tend to be developed reactively by teaching academics, in isolation from what is happening in the broader curriculum or what is available from other institutions.

Curricular models

Approaches to incorporate QS across science

The 13 case studies highlighted the tremendous variation in the curricular approaches. Overall, QS could only be identified in a few units across the curriculum. A significant factor is the choice and flexibility inherent in science programs. Focusing largely on life sciences disciplines, four models emerged, each describing a curricular approach to the development of mathematical knowledge.

Table 4 below summarises the themes that emerged in each model as well as stating which discipline is teaching QS. More details can be found in **Appendix 13**. Some distinctive features of the identified models are:

The **hybrid model** combined the inclusion of distinctly mathematical and/or statistical units with the embedding of QS components in the first year of a degree program. This model typically involved the mathematics and/or statistics units being taught by staff in the mathematics department, with further development of QS taking place in other discipline units. This was evident in the first year of the degree program only.

Table 4: Four curricular models for QS in science showing percentage of case studies by year level.

Curricular Model	Who is teaching QS?	1st year	2nd year	3rd year*
Unit Model	Mathematics ** teaches mathematics unit(s)	23%(3)	15%(2)	0
	Discipline teaches mathematic unit(s)	0	15%(2)	0
	Cross-disciplinary co-taught mathematics-science unit(s)	8%(1)	8%(1)	0
Embed Model	Mathematics teaches QS component in discipline unit(s)	0	8%(1)	8%(1)
	Discipline teaches the QS component in discipline unit(s)	8%(1)	31%(4)	54%(7)
Hybrid Unit + Embed Model	Mathematics teaches mathematics unit(s) + discipline teaches embedded QS component	38%(5)	0	0
	Mathematics teaches mathematics unit(s) + cross-disiciplinary co-taught mathematics-science unit(s) + discipline teaches embedded QS component	15%(2)	0	0
	Mathematics teaches mathematics unit(s) + mathematics teaches QS component in discipline unit(s)	8%(1)	0	0
QS Silent	No QS identified	0	23%(3)	38%(5)

*USA institutions have 4 year degree programs. For the purposes of this study, years 3 and 4 are classified as 3rd year.
**For the sake of the brevity any reference to mathematics includes statistics

The **embedded model** engaged students in QS in context-based learning experiences, mostly provided by the relevant science-based discipline academics. In the **unit model**, specific units were dedicated to building mathematical/statistical knowledge. Units co-taught by mathematicians and scientists to build QS specifically were emerging in a few universities.

Perhaps the most disturbing model in terms of fostering QS in students is the **QS silent model**. In five of the 13 case studies, no units could be identified as requiring QS in the later years of a science degree. One possible reason for this could be the difficulty in identifying units with QS due to the highly flexible nature of some science courses.

Analysis of interviews

Quantitative overview of qualitative data

1. Overview of quantitative analysis of interviews

A total of 48 academics, identified as either teaching academics working to build QS or Learning and Teaching leaders of science curriculum were interviewed in 38 interview sessions. The findings suggest that both the leaders and academics can speak to the four themes (initiation, vision, implementation and evaluation). However, within each role, evaluation is clearly the area focused on least with teaching academics not discussing vision for change as much as Learning and Teaching leaders. **Figure 2** below highlights the evaluation issue, though we note that the majority of the interviewees were lamenting the lack of evaluation.

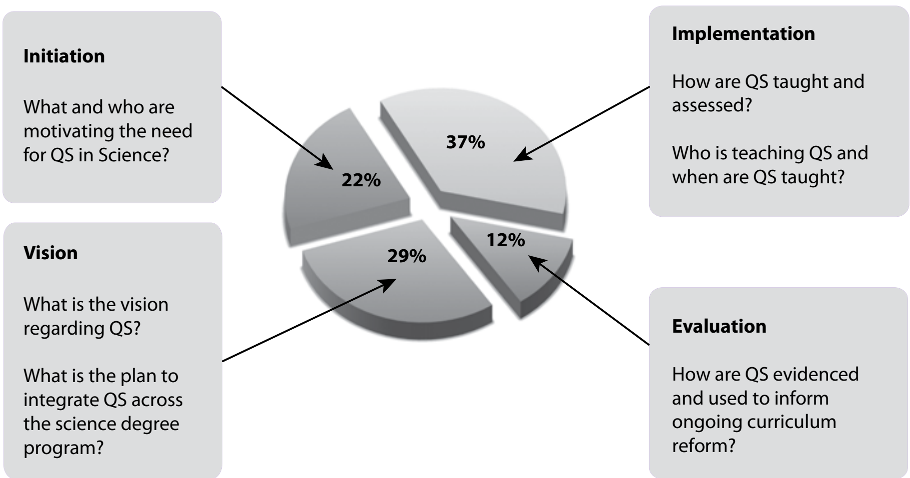

Figure 2: Code frequency of Fullan's four themes for educational change.

The roles of both *Learning and Teaching leaders and teaching academics* in implementing QS contain all four elements of Fullan's model as shown by **Table 5**, which displays the percentage of data coded by theme and role. Not surprisingly, teaching academics perceive the implementation of QS as their major responsibility, in reply to both senior management directives and student capabilities. *Learning and Teaching leaders* also believe they have a role to play in implementing QS but at the institutional level by providing resources, for example, to ensure that changes do take place. Evaluation of the effectiveness of programs where QS have been included has not received much attention as yet.

Table 5: Codes based on Fullan's model of educational change, *within* roles of interview participants.

Elements of Fullan's model	Learning and Teaching Leader	Teaching Academic
Initiation	24%	23%
Vision	31%	24%
Implementation	34%	40%
Evaluation	11%	13%
Total	100%	100%

Table 6 displays the coding themes and the number of times each of these themes was coded as well as how these themes overlapped. A glance at the numbers by theme highlights that much attention is being given to implementation and that interviewees were able to discuss challenges, particularly in relation to implementing QS and how QS were progressing from high school into first, then second and then third year of university.

Interviewees identified a number of challenges with QS. According to the data, Progression and Quantitative Skills were commented upon most often. A lack of a shared meaning as to what constitutes QS makes the teaching of these skills problematic, which the data suggest, could result from the ineffective relationships that exist between science and mathematics academics in trying to reach agreement about what QS are required, who should teach these skills and in what contextual setting students should be exposed to these skills. This dilemma is further aggravated when the diversity of students' mathematical backgrounds is taken into consideration.

The analysis confirms that implementing QS successfully across science curricula is very challenging for academics. The findings indicate that the difficulties identified are seriously ingrained, which significantly impacts on the effective planning and provision of learning environments that promote QS throughout science curricula.

Table 6: Code occurrences displaying raw numbers for each theme in bold and percentage of overlap in coding.

THEME	Initiation	Vision	Implementation	Evaluation	Progression	Quantitative skills	Resource	Strategy	Teaching	Math/Science relationship	Challenges
Initiation	**155**	12%	6%	5%	3%	3%	3%	33%	3%	3%	9%
Vision		**209**	6%	2%	7%	8%	2%	4%	9%	5%	16%
Implementation			**258**	2%	20%	18%	11%	16%	19%	9%	20%
Evaluation				**84**	2%	2%	1%	4%	1%	4%	5%
Progression					**180**	16%	4%	9%	12%	11%	26%
Quantitative skills						**173**	17%	7%	24%	9%	24%
Resource							**142**	8%	15%	5%	8%
Strategy								**95**	25%	9%	3%
Teaching									**166**	30%	18%
MS relationship										**89**	20%
Challenges											**252**

Key findings

Thematic analysis of data

1. Lack of shared meaning of QS

Building QS across the undergraduate science curriculum is inherently an interdisciplinary educational endeavour of institutions. However, it is this characteristic that makes determining what QS are needed in science curricula so challenging as opportunities to discuss and debate the meaning of QS were not evident. More detail is available from **Appendix 14**, page 68.

2. Lack of communication about QS across disciplines

Opportunities for academics teaching into the science program to meet and discuss QS across the curricula were not evident. In addition, evidence was found that suggests scientists have more negative views than mathematicians of the interdisciplinary relationship between departments. More detail is available from **Appendix 15**, page 69.

3. Lack of curricular leadership for QS

Despite QS being either implicitly or explicitly articulated among graduate outcomes, there is no evidence of program-wide frameworks to support these outcomes.

4. Lack of evaluation and evidencing of QS in curricular learning outcomes

In Australia, there was no evidence of science specific, program level evaluation although all institutions in the study had QS as a curricular learning outcome. The quality assurance agenda of the government is another cause for concern given the lack of evaluation. Overseas exemplars could offer some guidance. Much curriculum reform is occurring without a framework. More detail is available in **Appendix 16**, page 70.

5. Lack of QS reform efforts when organisational restructuring is occurring

The cycle of constant organisational change further complicates the already deep-seated challenges facing QS, an issue of educational change. The confusion between educational change and organisational change had added a sense of risk when trying to address the QS issue.

6. Lack of connection between attributes, outcomes and standards

Despite recent efforts to state sector-wide outcomes, institutional attributes and program level graduate outcomes, their influence on curricular design, teaching practices and student learning is questionable. There was no evidence of a shared vision for QS beyond generic statements. More detail available in **Appendix 17**, page 71.

7. Lack of knowledge and adaption of QS educational resources

Academics develop their own QS resources with little attempt to find existing material that could fit their needs. This could be caused or instigated by the lack of curricular framework for a 'whole of program' approach, and a lack of infrastructure for QS related teaching and learning.

Resources

Practical tools and references

Online resources

Project website

One of the significant resources to come out of the project is the user friendly website at www.qsinscience.com.au, a hub of project information and activities, which to date has received over 4000 hits. One of the main features of the website is the twelve online university case studies (**Figure 3**). The website is designed to be dynamic with updates and new information added on a regular basis.

Figure 3: Snapshot of website – case studies and links page.

Curricular mapping tool

The team has developed a tool that creates a visual image that highlights the 'QS critical pathway' of students within a major in the science curriculum (**Figure 4**). In the opinion of one reference group member this simple visual can provide significant curricular information and the template will be a good resource for other groups to map out 'critical pathways' in their majors for QS or other learning outcomes such as writing and teamwork. This template was developed in an easy to use format (PowerPoint) along with a short online instructional video, which demonstrates its use. The video is available from the following link which is also on the *QS in Science* website http://www.youtube.com/user/qsinscience.

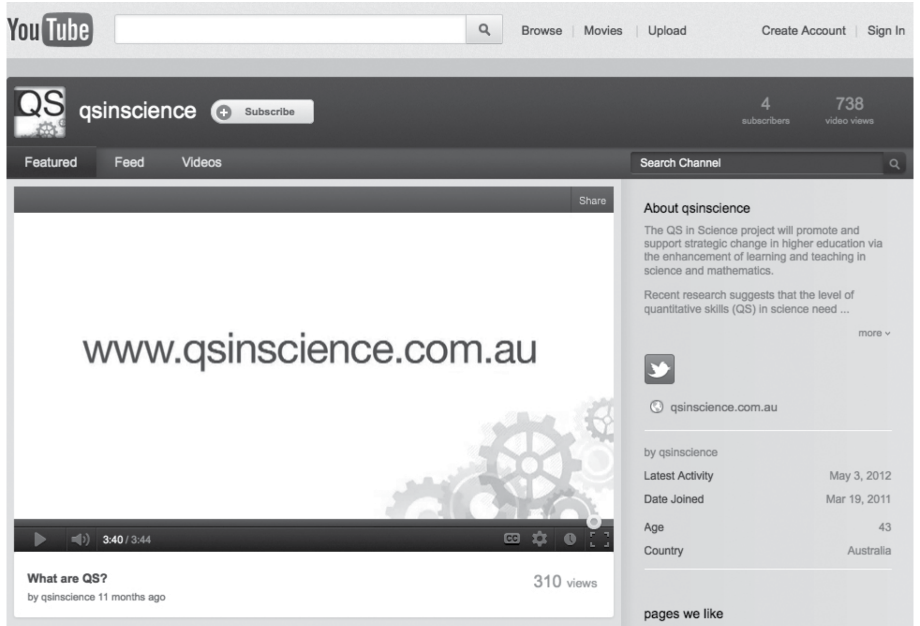

Figure 4: Snapshot of the curricular mapping tool video available on YouTube.

Academic resources
Reference sharing website

Published and unpublished project papers, talks and other *QS in science* relevant resources gathered by team members are made available via the *QS in Science* Mendeley reference sharing website (**Figure 5**) at www.mendeley.com/groups/1442913/quantitative-skills-qs-in-science

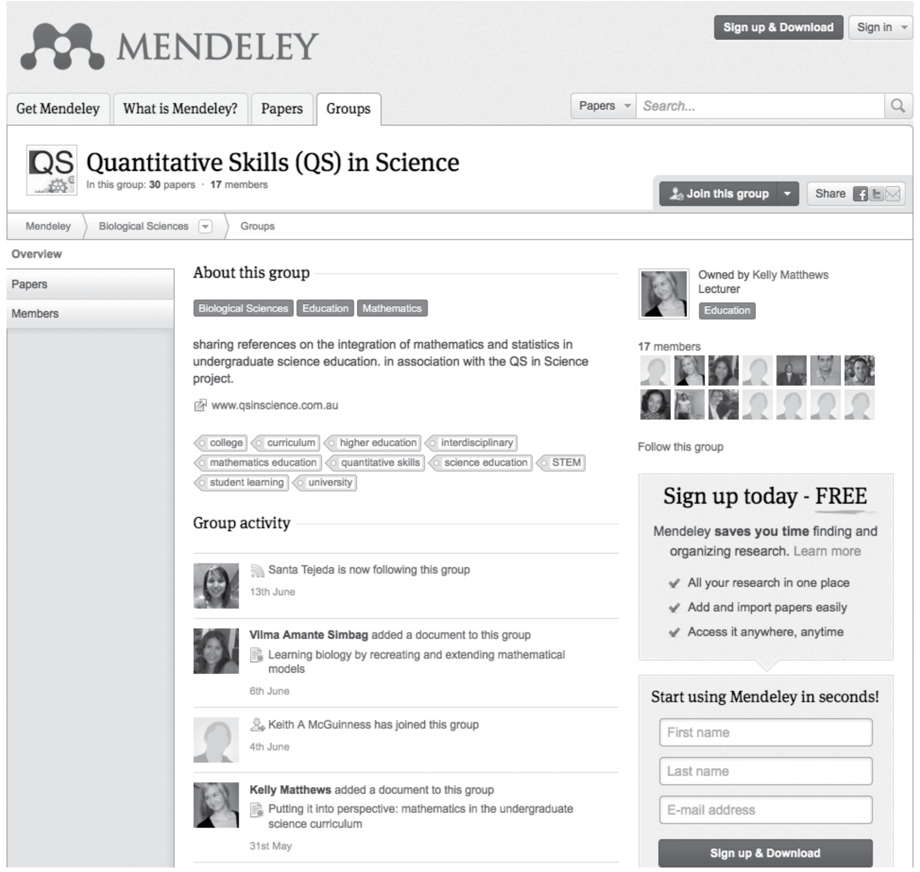

Figure 5: Snapshot of the *QS in Science* reference sharing website.

Journal special addition

The *QS in Science* team, in collaboration with *The International Journal of Mathematics Education in Science and Technology* (iJMEST; **Figure 6**), is inviting submissions for a Special Issue entitled Quantitative skills in science: integrating mathematics and statistics in undergraduate science curricula, which is due for publication in September 2013.

Figure 6: An *iJMEST* special edition on QS will be published in September 2013.

Recommendations

QS Phase 2 Proposals

Our examination of *QS in Science* curricula uncovered the challenges stated on pages 14-15. Lack of communication and shared meaning, and lack of a whole program approach, all too important in developing and providing students with the needed QS in science, stood prominently in our list. However, we believe that it is not all bad news for QS in science, hence our project strives to go further than raising issues. As we rigorously analysed our data and formed conclusions we focused on recommendations for action; actions for the future that will build on the outcomes of our project. We believe that our project is positioned to bring the QS challenge to the surface and engage the science higher education community in planning for future action.

In this section we identify a list of proposed projects, which address some of the major challenges that we raised. Below are the project names and aims. Details are available as appendices to this report.

1. Acquiring a shared meaning of QS (See Appendix 18, page 72**)**

Project name: The Rosetta Stone of QS: Translating what quantitative skills are needed for science graduates.

Project aim: This project aims to engage mathematicians, statisticians and life scientists in conversations and activities to articulate, define and converge on what QS actually are, the relationship between QS as perceived by mathematicians and statisticians, and QS as perceived by life scientists.

2. Identifying and bridging the QS gap from high school mathematics to university (See Appendix 19, page 73)

Project name: Transition: QS from secondary school to first year university.

Project aim: This project aims to address issues concerning QS in secondary school and how well this prepares students for first year university science. Answers to questions such as what QS were acquired in secondary school, are these QS enough to cope with what is required in first year, and how do universities build on these acquired QS, will be documented.

3. Evaluating assessment activities across the year levels (See Appendix 20, page 74)

Project name: Assessment of QS learning in science.

Project aim: This project aims to focus on evaluation of assessment activities designed to measure students' QS in a science program as well as how QS are built across the year levels.

4. Evaluating QS as a program-level learning outcome in science (See Appendix 21, page 75)

Project name: QS Assessment in Science: Engaging academics in developing, assessing and interpreting data on program level learning outcomes.

Project aim: This project aims to bring together academics to develop a program level assessment framework for QS in the sciences, to pilot the evaluation framework and to interpret results though benchmarking. Further, the project aims to engage academics in the collection of data that is reliable and useable as a means to influence curriculum development and teaching practices.

5. Applying the *QS in Science* approach to exploring other program-level learning outcomes (See Appendix 22, page 76)

Project name: Writing Skills in Science: Curriculum models for the future.

Project aim: Writing Skills (WS) have been identified as essential for science graduates, however the teaching and assessing of writing within the undergraduate science curricula are presenting numerous challenges. Adopting the successful *QS in Science* project methodology, this project seeks to engage academics in a process of identifying curricular 'critical pathways' that build the WS of science students, which can then be shared across the sector.

Dissemination activities

We have strived for engaged dissemination throughout the implementation of this project, and as such identified dissemination activities as a primary outcome. We believe that our active, engaged dissemination is a key component of the project and is of utmost importance to the project team as we aim to enhance the QS of science students in Australia.

Online engagement
Since 21 December 2010 the *QS in Science* website has had over 4000 visits. The interest has come from Australia (about 65 per cent), followed by the United States (14 per cent), the United Kingdom (3 per cent) and across other parts of Europe, Asia and Africa (18 per cent). The cluster map in **Figure 7** indicates the world-wide interest in this project. In addition, the website provides regular updates on the progress of the project.

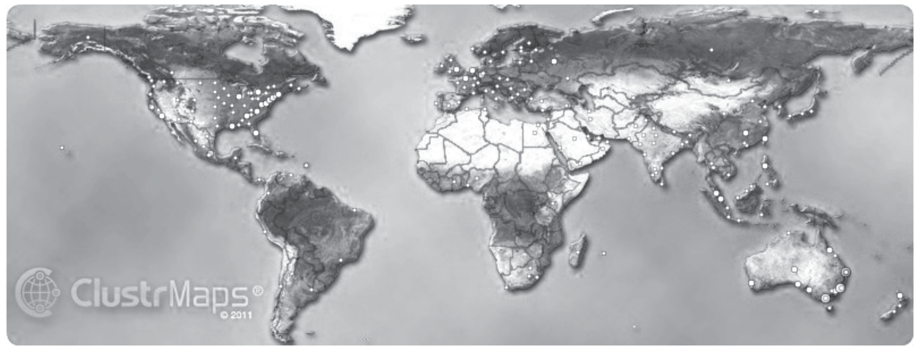

Figure 7: Cluster map indicating the international interest in the *QS in Science* project.

Face to face activities

The project team has been actively engaged with QS colleagues and other parties in conferences, workshops and meetings where QS issues have been raised and discussed. A number of such dissemination activities have occurred in the last one and a half years and such activities will continue until 2013 as shown in the dissemination activity plan for 2012–2013 **(**see www.qsinscience.com.au for details**)**.

Presentations and publications

The *QS in Science* team has given a number of presentations and written conference papers and journal articles in 2011 while a series of *QS in Science* papers are being prepared for 2012 and 2013 including a special issue of *International Journal of Mathematics Education in Science and Technology* (iJMEST) devoted to *QS in science*.

Conclusion

The *QS in Science* project outcomes were set out to describe and disseminate knowledge, experience and expertise on how universities are responding to the challenges around QS. In the process of achieving these outcomes, key findings that highlight the major issues hindering the effective implementation of QS were identified. These findings indicate that the development of QS in science graduates suffers because of a **lack of communication between academics**, leading to a fragmented/isolationist approach in solving curricular issues. Science faculties have **no tradition of discussing, planning or evaluating the whole of the undergraduate curriculum**. A complex learning outcome, such as QS, has no forum for broader discussion within science faculties or departments. In addition, the **general confusion about what constitutes educational change** versus organisational change has severe implications.

Communication, or rather **lack of communication**, is the major drawback in implementing QS across the science curriculum. Invisible barriers appear to prevent interdisciplinary discussions taking place, with little or no cross-disciplinary consultation evident. Academics from both the science and mathematics disciplines have difficulty in coming to a shared meaning of what QS really are and what each discipline requires and is able to provide. There was little evidence of opportunities or willingness on the part of academics teaching into science programs to meet with colleagues and discuss QS across the curriculum.

Institutional policy also plays a major role when considering QS. Graduate outcomes explicitly or implicitly citing QS impact on course structure, as will the recently announced national standards for science graduates. **Frequent organisational change** complicates educational change as staff become concerned about what is required of them and their course structures as they navigate through organisational change.

Further, the **interdisciplinary nature of QS** – applying mathematics to various science disciplines – runs counter to the current model of science higher education where science is presented in highly modularised form and taught within a traditional disciplinary-dominant set of subjects. Add to this the increasing diversity of prior mathematical knowledge of entering science students, and the QS challenges are exacerbated.

However, we believe that projects like ours can change the above scenarios in not so distant future. We feel we are making a substantial and critical contribution to solving this serious problem facing the science higher education sector. We are linking with colleagues through our dissemination activities and we want to carry on with this endeavour through our Recommendations (**Page 20**). These are actions for the future that will build on the outcomes of our project. We offer this report so others can build and extend our work to further improve QS in science.

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Project Team

The project team comes from mathematics, science and education disciplines and each member is committed to enhancing *QS in science*.

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Appendix 1

Case Study: Curtin University (Perth, Australia)

Curtin University http://www.curtin.edu.au/ is a public, multicampus university and a member of the Australian Technology Network of Universities. http://www.atn.edu.au/ It became a university in 1987 and is now Western Australia's largest university. Curtin University has five faculties and in 2009 the university had 44,500 students (including offshore students) of which 7,660 were in Science and Engineering.

Science at Curtin: Science is located in the Faculty of Science and Engineering. The Bachelor of Science (BSc) is a three year program in which each student must complete a major and has the opportunity to combine two majors.

Mathematics requirements for entry into Science: Students enrol in a particular stream; some have a mathematics prerequisite, for example, general science, and some have no mathematics prerequisite.

The Curtin case study gives an overall view of the Bachelor of Science (BSc).

Initiation of Change

"Who prompted need for QS in science and why?"

The main push for change came from the Dean of Science as a result of the very large number of BSc programs, including different science degrees in the same discipline. This was assisted by an initiation of change at the university level as discussed in by Oliver, et al. (2010), which created the right climate for review and change in science.

Vision for Change

In 2006 the Dean of Science released a discussion paper which outlined some models for the unification of the BSc programs. A uniform model has now been adopted, with several sets of patterns for first year, each of which prepares students for a related set of majors and allows students to easily take a double major.

"What do QS in Science look like?"

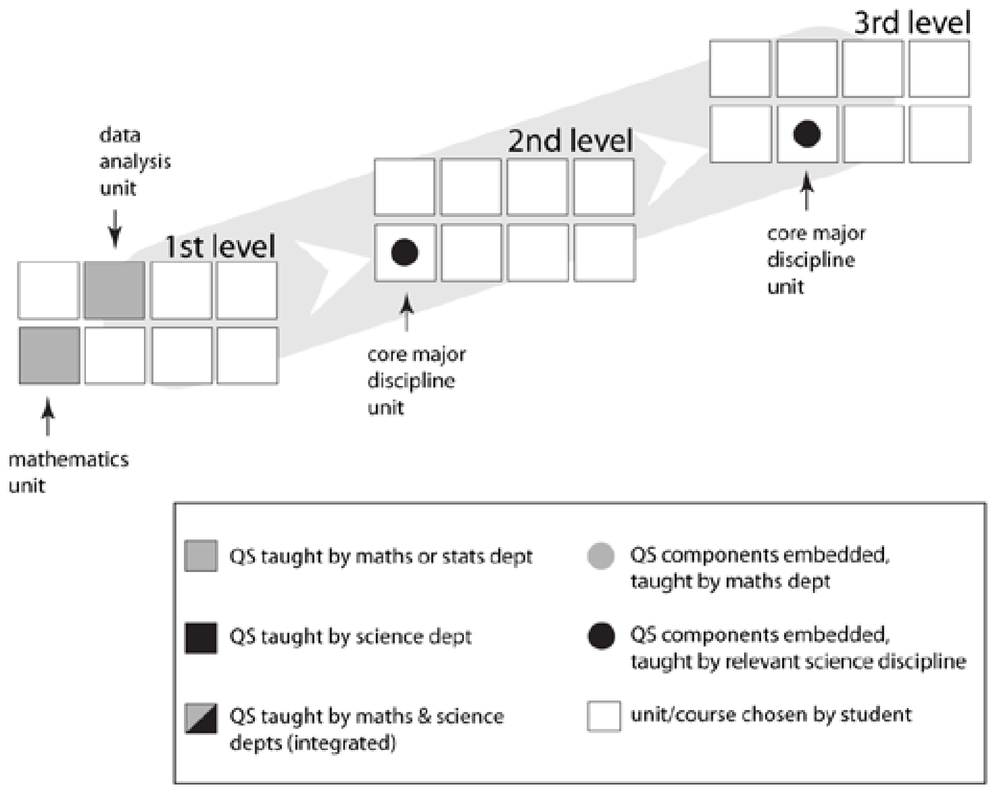
Curtin has graduate attributes which are embedded in the courses. There is an overarching set of graduate attributes for science, and these have been articulated in the context of the relevant discipline for each major. Every course and every major at Curtin has been curriculum mapped.

Implementing for Change

"How is need for QS in Science translated into practice?"

The BSc at Curtin allows students to major in many different science disciplines. Students choose from four themes. Each theme is a structured program for first year which prepares them for a broad area of study without locking them into one particular discipline. Each first year is structured to cover various basic skills.

Curriculum Structure for building QS



1st level features a data analysis unit and a mathematics unit, regardless of the theme that the student has chosen.

2nd level features at least one unit of the student's chosen discipline each semester.

3rd level features at least one unit of the student's chosen discipline each semester.

Extra Curricular QS: None.

Interdisciplinary QS: The Dean of Science is ensuring cross disciplinary communication by the use of cross disciplinary committees.

Evaluating the Change

"How effective has the change to build QS in Science been?"

There are unit evaluations such as Curtin's online student feedback system, the eVALUate unit survey, but these do not give a holistic view and the Course Experience Questionnaires will not evaluate the new degrees for a couple of years. The board of examiners will have a role in evaluation, and it will be easier in the future as several boards are being replaced by a single board of examiners.

Thanks to Professor Jo Ward, Dean of Sciences and Head of School of Science at Curtin University for collaborating with us to document this case study.

This case study is up to date as of October 2011. The interview to gather this data was conducted in July 2011.

Appendix 2

Case Study: James Cook University (Queensland, Australia)

James Cook University (JCU) is a multicampus university that has been in operation since 1961. It is located in tropical north Queensland with approximately 19,000 students enrolled in various undergraduate and postgraduate programs. James Cook University is a member of the Innovative Research Universities, a consortium of seven universities across Australia.

Science at JCU: The Faculty of Science and Engineering offers a Bachelor of Science (BSc) program with 16 majors. The entry requirement for the BSc at James Cook is a rank of 16 out of a possible 25, with 1 being the highest rank. There is an annual intake of approximately 300 students into the BSc program.

Mathematics requirements for entry into Science: The BSc requires Mathematics B for entry. This is a calculus-based secondary school unit.

The JCU case study focuses on the Marine Biology major in the BSc.

Initiation of Change

"Who prompted need for QS in science and why?"

JCU began a Curriculum Refresh of the BSc in 2009. This project received government funding and when complete, will have impacted on all disciplines across JCU.

The ensuing discussions by science academic staff highlighted the need for improvement in the development of quantitative skills (QS) of science students. Many students entering first year had poor QS with the level of QS not significantly improving by third year. This situation was perceived to have deteriorated over a period of several years preceding the Curriculum Refresh initiative.

Vision for Change

"What do QS in Science look like?"

James Cook University has institutional graduate attributes. Each unit within the BSc program lists the 'graduate qualities' developed within that unit. However, these are not mapped directly to the graduate attributes.

Implementing for Change

"How is need for QS in Science translated into practice?"

The BSc program allows students great flexibility in designing their course of study. Thus it is difficult to identify 'QS pathways' that build on the knowledge gained from the core level one mathematics unit.

Curriculum Structure for building QS: In the diagram, the critical pathway for building QS is shown for the Marine Biology major.

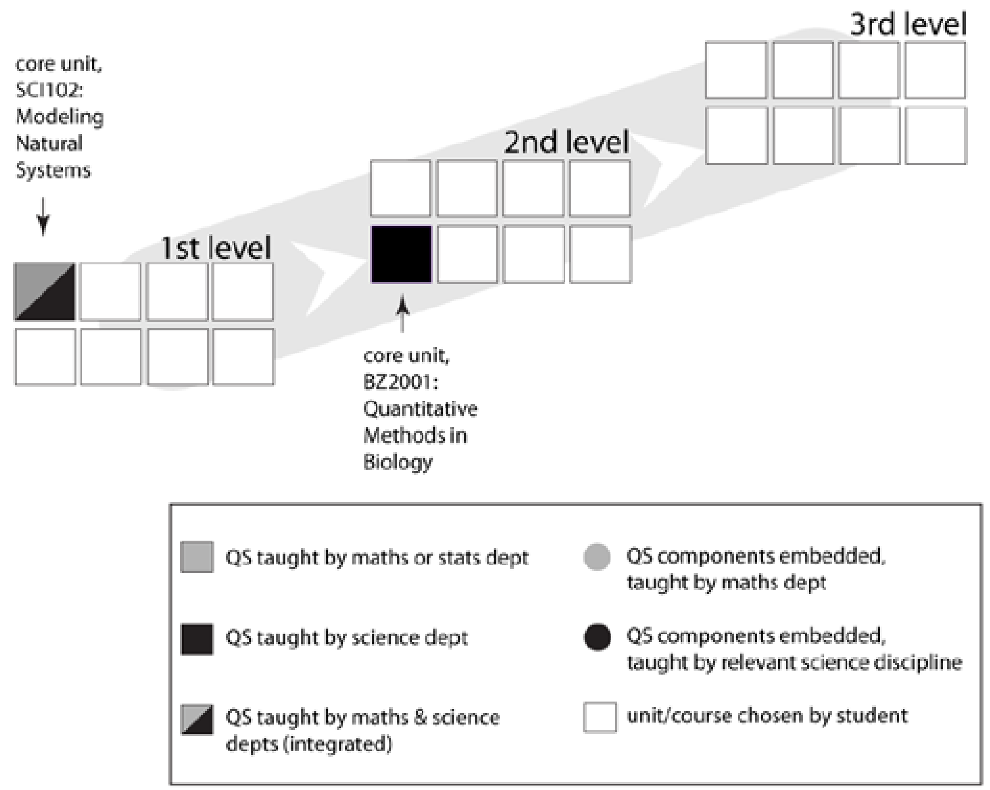
1st level features the core unit SC1102 Modeling Natural Systems.

2nd level features the core unit BZ2001 Quantitative Methods in Biology.

3rd level features a range of units that can embed QS.

Extra Curricular QS: Students who do not have the required secondary school Mathematics B background are required to complete the bridging mathematics unit MA1020 Preparatory Mathematics. This unit does not contribute in terms of credit towards any of the BSc majors except the BSc (General). This unit is taught by mathematics academic staff.

Interdisciplinary QS: Academic staff across all the science disciplines at JCU were involved in the discussions prompted by *Curriculum Refresh*. These discussions have incurred informally as no formal mechanisms are in place to promote cross-disciplinary collaboration in building QS in science students.



Evaluating the Change

"How effective has the change to build QS in Science been?"

Institutional standardized evaluation procedures are in place at JCU, including general unit and teaching surveys.

Evidence of QS learning outcomes: Implementation of the new science curriculum is occurring over a three year period, beginning with the first year units in 2010. No formal evaluation procedures concentrating on the development of QS are yet in place. However, the SC1102 project team has evaluated the outcome of this new unit – leading to a paper published in the 2011 Australian Conference on Science and Mathematics Education (ACSME) Proceedings.

Thanks to the following people at James Cook University for collaborating with us to document this case study:

Orpha Bellwood, Senior Lecturer in Marine Biology, School of Marine and Tropical Biology
Yvette Everingham, Senior Lecturer in Statistics, School of Engineering and Physical Sciences

Emma Gyuris, Senior Lecturer in Environmental Science, School of Earth and Environmental Sciences

Betsy Jackes, Associate Dean Teaching and Learning, Faculty of Science and Engineering and Adjunct Associate Professor, School of Marine and Tropical Biology.

If you have any questions or comments on the James Cook University case study, you are welcome to contact them directly.

This case study is up to date as of September 2011. The interviews to gather this data were conducted in August 2011.

Appendix 3

Case Study: La Trobe University (Victoria, Australia)

La Trobe University is a multicampus university based in the state of Victoria, Australia with approximately 30,000 students enrolled across a range of undergraduate and postgraduate programs. Established in 1967, La Trobe is a member of the Innovative Research Universities, a consortium of seven universities across Australia.

Science at La Trobe: The Faculty of Science, Technology and Engineering offers a Bachelor of Science (BSc) program with 20 majors. The program has an average annual intake of 250 students. The entry requirement for the BSc at the Melbourne campus is an ATAR of 65 (admissions ranking from 0-100, with 100 the highest rank).

Mathematics requirements for entry into Science: The BSc requires Mathematical Methods (a calculus-based high school subject).The BBiolSc has no mathematics prerequisite from secondary school.

The La Trobe case study focuses on majors in the biological sciences (in either the BSc or the BBiolSc).

Initiation of Change

"Who prompted need for QS in science and why?"

At the institutional level the Design for Learning project spawned university wide review of curriculum.

This provided the opportunity for a review of both the BSc and BBiolSc degrees, which prompted discussion among biological sciences academics on the skills expected of graduates and documentation of QS with which students entered third year units. There was a perception amongst staff that the standard of QS in the first year cohort was dropping.

Vision for Change

"What do QS in Science look like?"

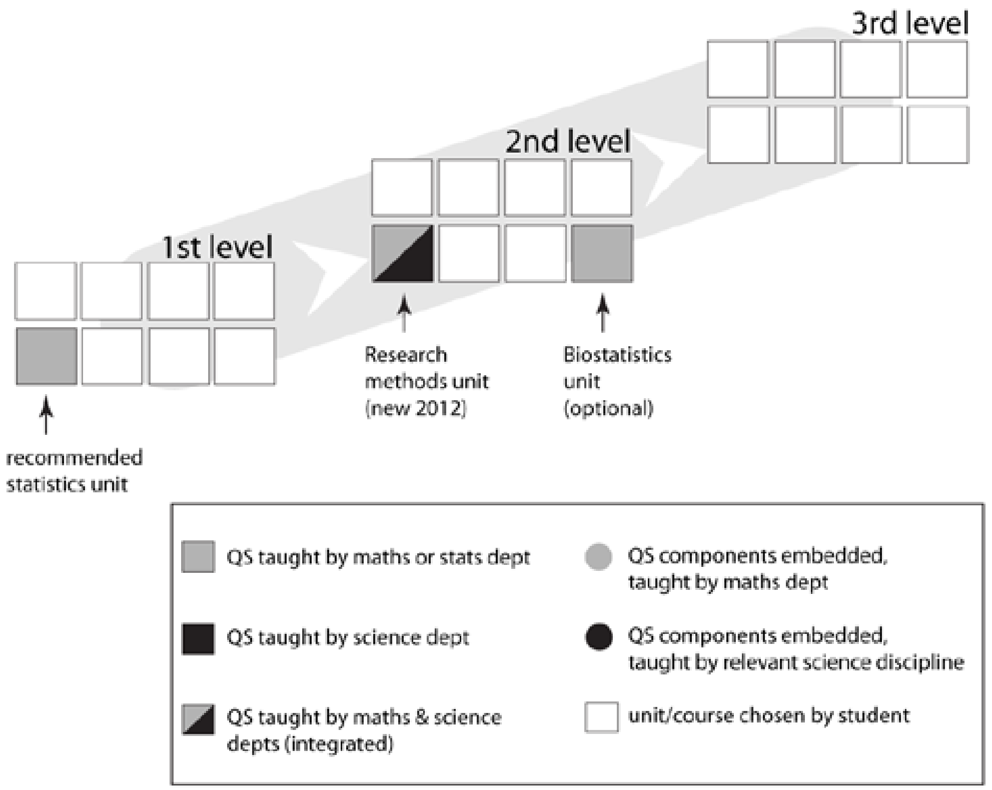
La Trobe University has institution-wide graduate capabilities.

The Faculty of Science, Engineering and Technology has developed its own set of graduate capabilities for programs in science with quantitative literacy listed as one of four such capabilities. Within the biological sciences departments, QS requirements of graduates are being mapped.

Implementing for Change

"How is need for QS in Science translated into practice?"

The biological science majors can build on the statistical knowledge provided in level one units. However, the flexible nature of the degree program, especially in the second and third years enables students to mix and match, making it difficult to identify the 'QS pathways' within majors.



Curriculum Structure for building QS: The diagram shows the 'critical QS pathway', highlighting the requisite units for the major.

1st level features a choice of recommended statistics units. STA1DCT, Data-based Critical Thinking, is an option for students without high school mathematics. The second unit is the revised STA1LS, Statistics for Life Sciences, and is an option for students regardless of mathematics background.

2nd level features (from 2012) a new unit, BIO2POS: Practice of Science, that will be co-taught by a statistician and ecologist and focuses on research methods. It is compulsory for zoology, genetics and botany students. The unit STA2ABS, Applied Biostatistics, is also an option for students in the biological sciences.

3rd level features QS components embedded in a range of units such as ZOO3EPA, ZOO3EPB, BOT3FEB and BOT3ESE.

Extra Curricular QS: A current faculty pilot project features a Curriculum Fellow from mathematics who is collaborating with colleagues across first year biology, chemistry and physics to develop a diagnostic mathematics test and subsequent program to support students with weak mathematical knowledge. The pilot project aims to contextualise the mathematical knowledge within the science disciplinary context to draw explicit links between the mathematics and its applications in the science units.

Interdisciplinary QS: The current curricular reviews across science have sparked conversations across disciplines. However, there are no formal structures or mechanisms that facilitate or promote cross-departmental planning around building QS.

Evaluating the Change

"How effective has the change to build QS in Science been?"

Institutional standardised procedures are in place at La Trobe University, including general unit surveys.

Evidence of QS learning outcomes: To date there has been no formal evaluation on the effectiveness of the changes in the curriculum to build QS.

Thanks to the following people from the Faculty of Science, Technology and Engineering at La Trobe University for collaborating with us to document this case study:

Elizabeth Johnson, Associate Dean Academic

Deborah Jackson, Curriculum Fellow

Luke Prendergast, Senior Lecturer in Statistics, School of Engineering and Mathematical Sciences

Michael Clarke, Associate Professor Zoology, Zoology Department Head

If you have any questions, comments or thoughts on the La Trobe University case study, you are welcome to contact them directly.

This case study is up to date as of September 2011. The interviews to gather this data were conducted in May 2011.

Appendix 4

Case Study: Macquarie University (New South Wales, Australia)

Macquarie is a multicampus university based in Sydney, Australia. It was established in 1964 with an enrolment of approximately 35,000 students in 2009.

Science at Macquarie: As of 2008, the Faculty of Science offers a Bachelor of Science (BSc) with 25 majors. The three year degree has an average intake of 300 new students and is described as a *'general degree program, which offers maximum flexibility'.* The Faculty of Science also offers a range of more structured, named degrees in specific areas of science.

Mathematics requirements for entry into Science: For entry into the BSc, mathematics is not a prerequisite, although it is considered assumed knowledge.

The Macquarie case study focuses on majors in the biological sciences.

Initiation of Change

"Who prompted need for QS in science and why?"

At the institutional level, organisational restructures in the past five years along with university wide curriculum reviews have catalysed change.

In the biological sciences this prompted departmental discussions about what discipline specific capabilities where required of students. Quantitative skills (QS) were identified as a desired capability and an area of weakness for many science students. New academics to the department recognised the increasing reliance on QS in their own research, which influenced their ideas of desirable graduate capabilities and curriculum design. The need for competent honours and PhD students was also a motivation to better build the QS of students in the biological sciences majors.

Vision for Change

"What do QS in Science look like?"

University-wide graduate capabilities were identified at Macquarie in 2008.

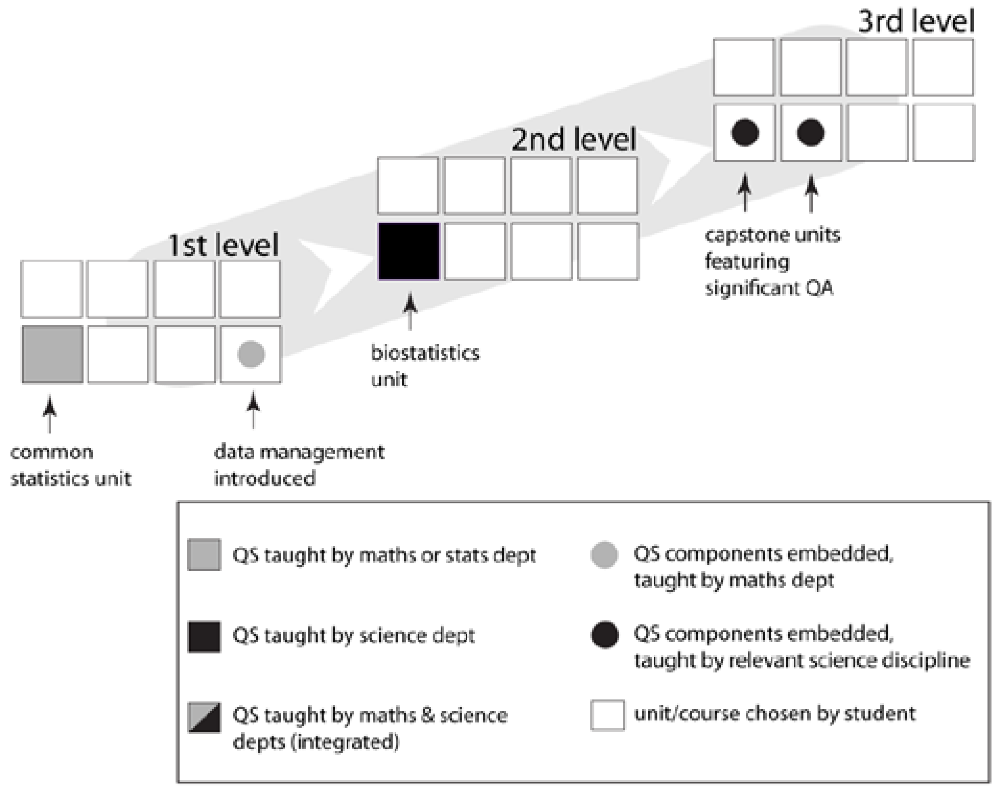
The BSc at Macquarie does not have program specific graduate capabilities, as the degree program model is decentralised to the major-level. Each major is expected to have a list of graduate capabilities.

In the biological sciences, quantitative skills (QS) have been identified as a graduate capability. The department articulated specific QS competencies across five areas: basic mathematical skills; data management; study design (experimental); statistics; advanced statistics/mathematics. Specific topics for each of the areas were then mapped to the current units offered to students by the Department of Biological Sciences.

Implementing for Change

"How is need for QS in Science translated into practice?"

The biological sciences majors incorporate QS into many units, as evidenced by the curriculum mapping documentation. However, the flexible nature of the degree program enables students to mix and match units.



Curriculum Structure for building QS:

The diagram, a visual overview of the curriculum structure, highlights the 'critical pathway' in the major where QS are substantially incorporated into units that are required or highly recommended. The remainder of the units are highly variable as students select their units.

1st level features a common statistics unit taught by the Department of Statistics, taken by students across of disciplines and recommended as prerequisite for many 3rd year biological sciences units. Data management is introduced into a core biological sciences unit. The mathematics department and the faculty office are discussing the possibility of an interdisciplinary science-mathematics unit.

2nd level features a biostatistics unit built around experimental design in science. At 2nd year, there is an expectation that QS are incorporated into units offered by the Department of Biological Sciences.

At 3rd level, as part of capstone course requirements, students select a unit from a choice of five (with four featuring significant quantitative skills components). At 3rd year, there is an expectation that QS are incorporated into units offered by the Department of Biological Sciences.

Extra Curricular QS: Macquarie is in the early stages of QS in Science curriculum change, however there is the Numeracy Resource Centre that provides institutional support for the development of basic mathematics via student drop-ins and workshops.

Interdisciplinary QS: There are no formal structures or mechanisms that facilitate or promote cross-departmental planning or ongoing communication around building QS in the BSc.

Evaluating the Change

"How effective has the change to build QS in Science been?"

Institutional standardised evaluation procedures are in place at Macquarie, including general unit surveys.

Evidence of QS learning outcomes: In the Faculty of Science, and in the biological sciences majors, there has been no formal evaluation on the effectiveness of the changes in the curriculum to build QS.

Thanks to the following people at Macquarie University for collaborating with us to document this case study:

Kelsie Dadd, Associate Dean Learning and Teaching

Belinda Medlyn, Senior Lecturer in Ecophysiology, Department of Biological Sciences

Paul Smith, Professor in Mathematics, Head of Department, Department of Mathematics.

If you have any questions, comments or thoughts on the Macquarie case study, please contact them directly.

This case study is up to date as of August 2011. The interviews to gather this data were conducted in May 2011.

Appendix 5

Case Study: Monash University (Victoria, Australia)

Monash University, founded in 1958, is a public, multicampus, research intensive university. As of 2010 Monash had approximately 60,000 students with roughly 30% being enrolled in postgraduate programs.

Science at Monash: The Faculty of Science has seven schools offering an array of programs to about 3,500 undergraduate students. It has an average annual intake of about 800 students into the Bachelor of Science (BSc) at its main campus, Clayton, where it has 20 areas of study, five of which are under the Faculty of Science and the rest taught across other faculties.

Mathematics requirements for entry into Science: The Bachelor of Science does not have any mathematics prerequisites but students must enrol in a level one mathematics or statistics unit in first year. Monash offers different pathways for students with varying high school mathematics backgrounds.

The Monash case study focuses on the Biological Sciences major in the BSc.

Initiation of Change

"Who prompted need for QS in science and why?"

In the Faculty of Science the Associate Dean, Education, together with the education committee, initiates five-yearly reviews. In recent years, the BSc at Monash has undergone some changes in order to address the declining quantitative skills among graduates, and students' under preparedness for tertiary level of mathematics (Varsavsky, 2010).

Prior to year 2000 there were stringent mathematics requirements for the BSc These were believed to have partially caused the drop in the number of students doing the BSc. One strategy used by the Faculty to alleviate this drop was to provide different compulsory level one mathematics and statistics units for students with different high school mathematics backgrounds. In recent years, however, the need for Monash BSc graduates to be more quantitative resurfaced.

Vision for Change

"What do QS in Science look like?"

In 2007 a set of graduate attributes for the BSc was developed ahead of the university-wide more generic graduate capabilities. Among the BSc graduate attributes is quantitative literacy, described as students' ability to collect, organise, analyse and interpret data meaningfully using mathematical and statistical tools as appropriate to the discipline of specialisation. For biological sciences majors it means developing problem solving, data analysis and presentation skills and being able to conduct activities such as survey, inventory and measurement of biodiversity in the ecosystem.

Implementing for Change

"How is need for QS in Science translated into practice?"

The biological sciences majors are expected to embed QS into biology units starting from first year. However, the flexible nature of the degree program, especially in the second year, enables students to mix and match.

Curriculum structure for building QS: Monash biological sciences majors.

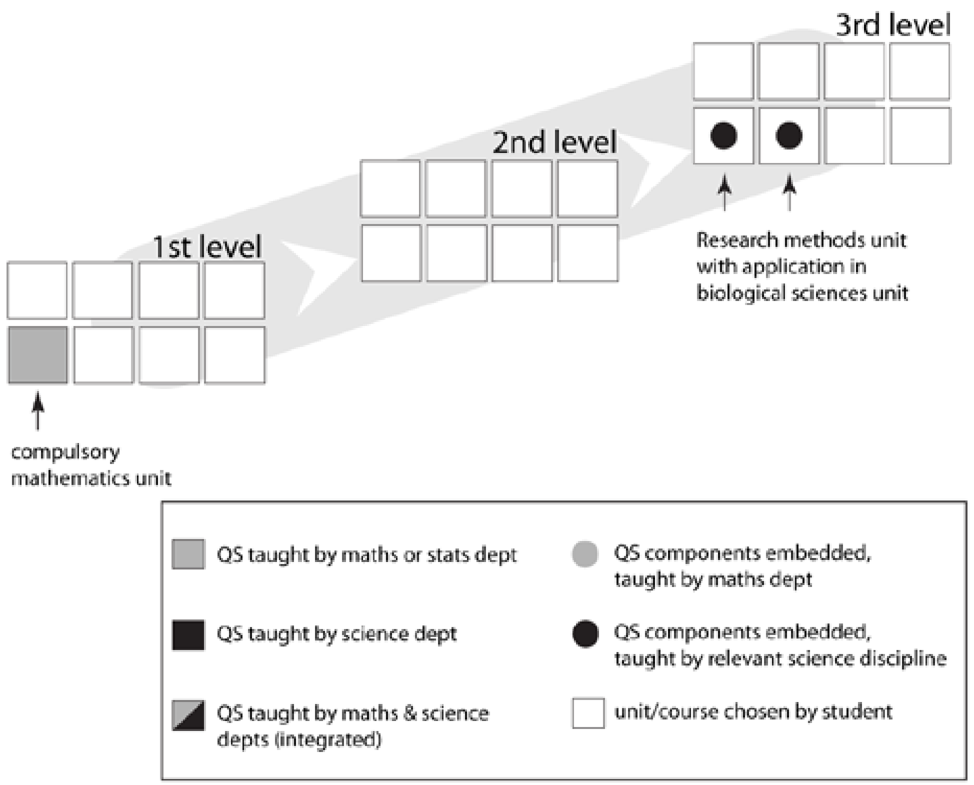
The diagram is a visual overview of the curriculum structure. This diagram highlights the 'critical pathway' in the majors where QS are substantially incorporated into units that are required or highly recommended. The remainder of the units are highly variable as students have choice in selecting their units.

1st level features a range of maths and statistics units that students can choose from depending on their high school mathematics background. Most students doing biological sciences majors opt for STA1010 which builds on high school mathematics, or SCI1020 that does not require previous mathematics. Students with high school mathematics can also opt for MTH1020.

2nd level does not have a required QS unit although 1st level and 2nd level breadth of study across disciplines could have varying levels of QS content.

3rd level features a core level-three unit, BIO3011,

Extra Curricular QS: The Mathematics Learning Centre provides institutional support for the development of basic mathematics via drop in support and tutorials.



Interdisciplinary QS: There are no formal structures or mechanisms that facilitate or promote cross-departmental planning or ongoing communication around building QS in the BSc.

Evaluating the Change

"How effective has the change to build QS in Science been?"

Institutional standardised evaluation procedures are in place at Monash, including student general unit surveys. There is no formal instrument for program level evaluation however, there is a regular program/course review every five years conducted by the Faculty of Science through the education committee, lead by the Associate Dean, Education. The BSc will undergo another review in 2012.

Thanks to the following people at Monash for collaborating with us on this case study:

Cristina Varsavsky – Assoc Professor, School of Mathematical Sciences; Assoc Dean Education, Faculty of Science

Gerry Rayner – Lecturer, School of Biological Sciences, Faculty of Science

Dianne Atkinson – Asst Lecturer, School of Mathematical Sciences, Faculty of Science.

If you have any questions, comments or thoughts on the Monash case study, please contact them directly.

This case study is up to date as of September 2011. The interviews to gather these data were conducted in May 2011.

Appendix 6

Case Study: University of Melbourne (Victoria, Australia)

The University of Melbourne is a multicampus university based in Melbourne, Australia. It was established in 1853, and is the 2nd oldest university in Australia with a strong focus on research. There are approximately 36,000 students enrolled, both undergraduate and postgraduate.

Science at Melbourne: The Bachelor of Science (BSc) is one of six new-generation degrees at Melbourne started in 2008. The three-year degree program 'provides flexible pathways' with students selecting from 36 possible majors that can lead directly to employment or further graduate studies in engineering, medicine and other graduate health vocation programs, veterinary science, education and scientific research in a range of fields. The degree program is housed within the Faculty of Science, although four faculties contribute to the numerous majors on offer. In 2011, the entry score for the BSc was 85 out of a possible 100. Further details on the degree program are outlined in this Information Day video.

Biomedicine at Melbourne: The Bachelor of Biomedicine is one of the six new-generation degrees at Melbourne started in 2008, and is essentially a more structured science degree with an emphasis on biomedical science. The program enrols approximately 450 students per year, who can go on to professional health degrees, or on to do postgraduate studies in biomedical research. The program attracts high-achieving students with an entry rank of 98.45 (top 1.5th percentile) in 2010. The Faculty of Medicine, Dentistry and Health Sciences has oversight for the program, although the Faculty of Science contributes substantially. Further details on the degree program are outlined in this Information Day video that specifically discusses the increasing relevance of QS in Biomedicine.

Mathematics requirements for entry into Science and Biomedicine: Both degree programs require Maths Methods, which is a calculus-based high school subject.

The Melbourne case study focuses on two degree programs: the BSc with a focus on the Biological Sciences majors and the Bachelor of Biomedicine.

Initiation of Change

"Who prompted need for QS in science and why?"

At the institutional level the Melbourne Model was introduced in 2008 with the introduction of six new-generation degrees. The new Melbourne degrees are intended to align more closely with degrees internationally, in Europe (Bologna process) and the United States, that emphasise a more general undergraduate degree that leads to specialised postgraduate qualifications.

A 2010 Australian Universities Quality Agency (AUQA) audit, which focused in on the BSc, captured the ongoing review process and discusses the departments that teach into the Life Sciences majors. Questions such as *'why they were doing what they were doing'* were asked with some academics in the life sciences indicating that students were graduating under-prepared for the quantitative requirements of the disciplines.

In the Bachelor of Biomedicine, the switch to the Melbourne Model prompted discussions around the program structure and desirable outcomes. The broader environmental phenomena influenced thinking on the curriculum. Advances in the field of biomedical sciences and the recognition of the increasing need to apply mathematics and statistics influenced thinking around the need for QS.

Vision for Change

"What do QS in Science look like?"

The University of Melbourne has institutional graduate attributes. The BSc at Melbourne has further contextualised the institutional graduate attributes, and these appear in their handbook and feature statements that assume QS:

- understand the principles of sound project and experimental design, including data analysis;
- apply outstanding analytical, quantitative and technical skills to problem solving and, where relevant, design.

The Bachelor of Biomedicine has adopted the BSc attributes and the QS that underpin the above statements.

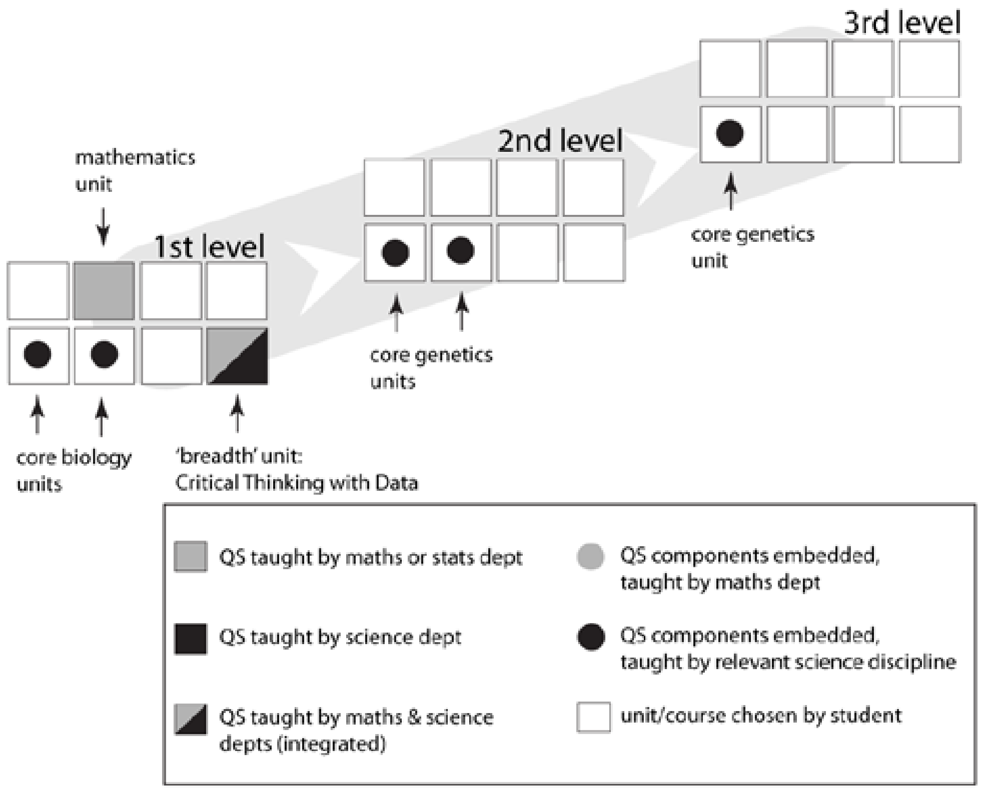
Neither program has explicitly articulated QS standards or mapped them to the curriculum. However, curriculum mapping of graduate attributes is underway in the life science majors in the BSc.

Implementing for Change

"How is need for QS in Science translated into practice?"

The BSc. The BSc has no core, shared units in the degree program. There are 18 life sciences majors in the BSc that incorporate QS via core biology units. However, the plethora of majors and the flexible nature of the degree program enable students to mix and match units in the life sciences majors.

Curriculum Structure for building QS: The BSc, life sciences majors with a focus on the genetics major in 2nd and 3rd year. The diagram shows the 'critical QS pathway', highlighting the requisite units for the major.



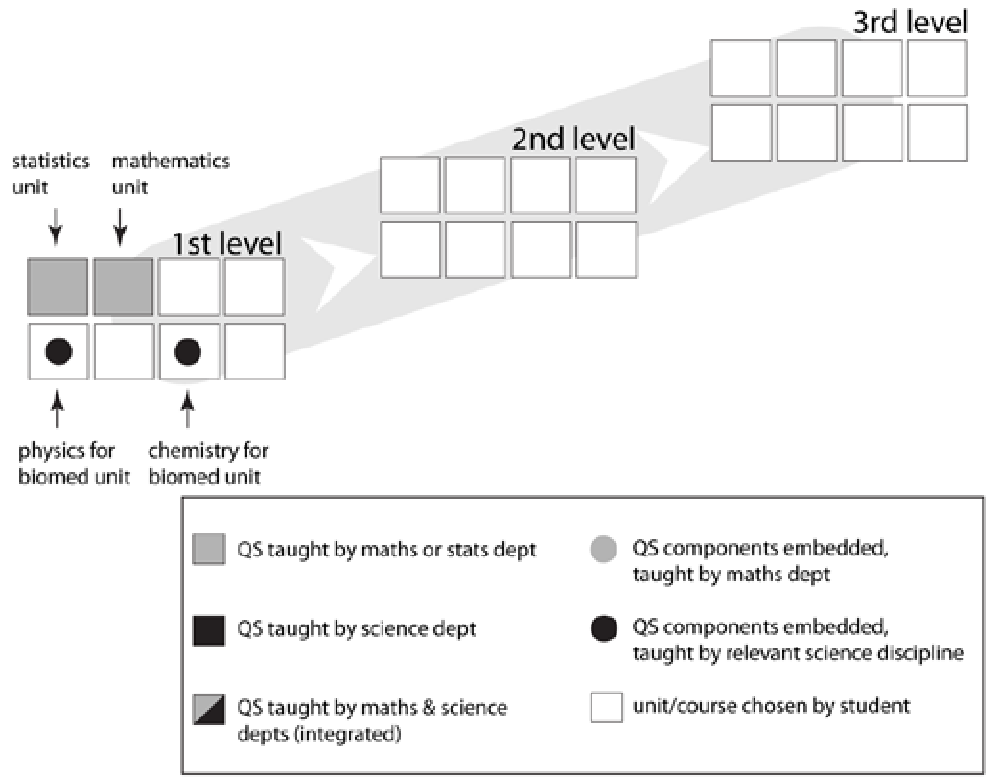
1st level features—for the 18 life sciences majors—two core biology units that both include substantial elements of embedded QS, which are taught by biologists. Prior to the Melbourne Model these majors listed a statistics unit—taught by the statistics department—as prerequisite for upper level units. This was dropped for a range of reasons. All science students enter with a calculus-based mathematics requirement. It is common for life science major students to choose a mathematics or statistics unit in their first year, and also other science units in which students' QS are further developed. In addition, a university-wide 'breadth' unit was introduced in 2008, Critical Thinking with Data, that is available to all students.

2nd level features core units in the more specific majors, which varies given the need for QS in the discipline. In the genetics, QS is further embedded in the core units.

3rd level features core units in the genetics majors that further embed QS in the context of the discipline.

The BSc has no core, shared units in the degree program. There are many life sciences majors in the BSc that incorporate QS via core biology units. However, the plethora of majors and the flexible nature of the degree program enable students to mix and match units in the life sciences majors.

Curriculum structure for building QS: The Bachelor of Biomedicine is a far more structured degree program than the BSc.



1st level features a philosophy of building a strong mathematical and statistical knowledge base along with chemistry and physics units that are underpinned by QS. There are three mathematics units (Calculus 1, Calculus 2 and Linear Algebra) with students required to complete one based on their level of high school mathematics and level of proficiency. The statistics unit is designed around experimental design and data analysis with biomedical examples.

2nd level features two required block units that represent 50% of second level units. These units are inherently interdisciplinary although the QS requirements are not substantial. A goal is to introduce some mathematical modelling. Students can select three science units and one 'breadth' unit.

3rd level features two required biomedicine units although these do not have substantial QS components at present. Students have options to select units based on their major within the program along with 'breadth' units.

Extra Curricular QS: The University of Melbourne has a well-resourced Mathematics and Statistics Learning Centre that provides institutional support for the development of mathematical and statistical knowledge via drop-ins to compliment units run by the mathematics and statistics departments. They also offer enrolment advice for mathematics and statistics units. The Statistical Consulting Centre coordinates the university-wide 'breadth' unit, Critical Thinking with Data, and has developed a series of real world, online case studies that are included in various units called Realstat. Contact Sue Finch for access to Realstat.

Interdisciplinary QS: The University has a hierarchy of committees that focus on curriculum and teaching/learning. At the degree program level, which is cross-faculty, there is a 'Course Committee'.

The overlap in the BSc and the Bachelor of Biomedicine has resulted in a single 'Course Committee' for the two degree programs. At the Faculty level in Science, there is an 'Undergraduate Programs Committee' which can propose the approval of new units to the 'Course Committee'.

Evaluating the Change

"How effective has the change to build QS in Science been?"

Institutional standardised evaluation procedures are in place at the University of Melbourne, including general unit surveys and the Melbourne Student Experience Survey.

Evidence of QS learning outcomes: To date there has been no formal evaluation on the effectiveness of the changes in the curriculum to build QS or other science-specific graduate attributes, in either the Bachelor of Biomedicine or the life science majors in the BSc.

Thanks to the following people at the University of Melbourne for collaborating with us to document this case study, both in the Bachelor of Biomedicine and the majors in the BSc:

Mark Hargreaves, Professor of Physiology and Director of the Bachelor of Biomedicine until 25 Sept 2012
David Williams, Professor of Physiology and Director of the Bachelor of Biomedicine from 25 Sept 2012
Michelle Livett, Associate Professor of Physics and Director of the Bachelor of Science
Deborah King, Director of the Maths and Stats Learning Centre
Dawn Gleeson, Associate Professor of Genetics
Mary Familari, Lecturer in Biology
Sue Finch, Statistical Consultant, Statistical Consulting Centre, Department Mathematics and Statistics

If you have any questions or comments on the University of Melbourne case study, you are welcome to contact them directly.

This case study is up to date as of October 2011. The interviews to gather this data were conducted in May 2011 with further communications in September 2011.

Appendix 7

Case Study: The University of Queensland (Queensland, Australia)

The University of Queensland (UQ) is based in Brisbane, Australia with approximately 40,000 students enrolled across undergraduate and postgraduate programs. Established in 1909, UQ is a member of the research-intensive Group of Eight universities in Australia and a member of the global Universitas 21.

Science at UQ: The Faculty of Science offers a Bachelor of Science (BSc) program with 20 majors along with a series of smaller, more structured named degree programs and a suite of dual degree programs. The BSc has an average annual intake of 1,000 students. The entry requirement for the BSc is an overall position of 10 (OP; range of 1-25 with 1 being the top rank).

Mathematics requirements for entry into Science: The BSc requires Mathematics B or equivalent, which is a calculus based high school mathematics unit. Queensland has three mathematics units, Mathematics A (basic unit), Mathematics B and Mathematics C (advanced mathematics taken in parallel to Mathematics B).

The UQ case study focuses on the Biomedical Sciences major in the BSc.

Initiation of Change

"Who prompted need for QS in science and why?"

At an institutional level, a cycle of review for generalist degrees occurs every seven years. This prompted a substantial review of the BSc in 2007 leading to sweeping changes to the program from 2008. The review documentation was compiled into a single, publically available document. A report on the UQ BSc Review process was published on the Australian Universities Quality Agency good practices website.

During the institutional review process for the BSc, QS were recognized as a core attribute for UQ science students. Inspired by *BIO2010*, building QS across all majors in the BSc became a stated goal for the curriculum. In the biomedical sciences, the belief that QS were an essential attribute was widely accepted.

Vision for Change

"What do QS in Science look like?"

At an institutional level, university-wide graduate attributes were first developed in 1996 with a series of reviews and subsequent modifications.

The BSc Review, building on the university-wide graduate attributes, established a set of science-specific graduate attributes, listed on page 247 of the BSc Review document.

More broadly, the 2006 BSc Review committee listed12 recommendations, the first three of which explicitly addressed QS in Science:

1. Development of a proposed structure that focuses more on the quantitative and information aspects of science, in which all students are required to take the courses (i) Foundations of Science (SCIE1000) and (ii) Analysis of Scientific Data and Experiments (STAT1201).

2. A concerted effort to teach a range of courses in a more interdisciplinary manner, rather than as isolated entities.

3. Strong recognition that mathematics, physics, chemistry and biology are enabling sciences and this is reflected in the expectation that all students who graduate with a UQ BSc will have achieved a level of competence in all of these areas.

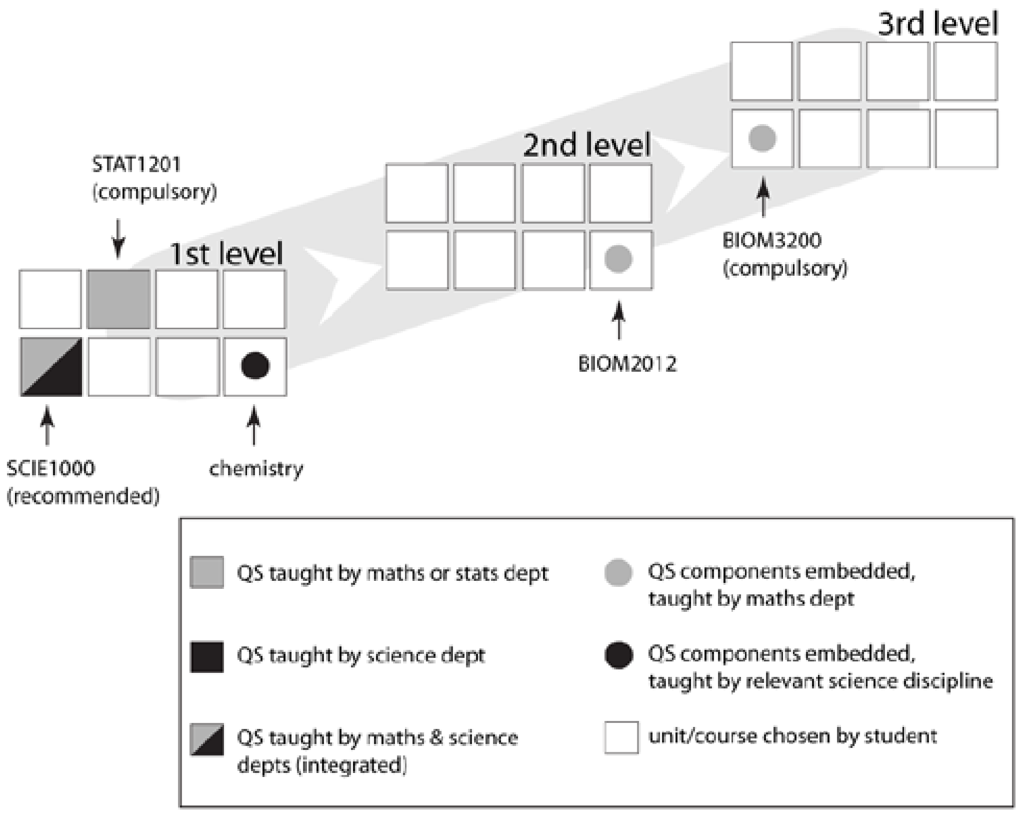
In the Biomedical Science major, a team of academics drafted a set of major specific attributes that explicitly included QS, which are listed on page 252-253 of the BSc Review document.

Implementing for Change

"How is need for QS in Science translated into practice?"

The Biomedical Science major in the BSc has a common first year followed by some core units in second and third year.

Curriculum structure for building QS: In the following diagram, the critical pathway for building QS is shown for the BSc Biomedical Science major.



1st level features a highly recommended interdisciplinary science-mathematics unit, SCIE1000: Theory and Practice in Science, introduced in 2008. Statistics is a compulsory unit for all BSc students. Prerequisites for the major include chemistry, which relies on a high level of QS, and two biology units, neither of which relies heavily on QS. The first year study planner is posted online.

2nd level features a breadth of choice with the philosophy that QS will be embedded in the biomedical units. From 2011, QS is explicitly incorporated into one of the core units, System Physiology, with a statistics academic teaching into the unit.

3rd level features a breadth of choice with the philosophy that QS will be embedded in the biomedical units. A capstone unit is required for all Biomedical Science majors in the BSc and includes a substantial QS component.

Extra Curricular QS: The university has support available for BSc students needing assistance in QS-related learning:

- The First Year Learning Centre (FYLC) is run by the School of Mathematics and Physics and is open to assist students in all first year units taught by the department.
- Peer Assisted Study Sessions (PASS) are offered in first year statistics, chemistry and biology. They offer students additional weekly study sessions facilitated by 2nd and 3rd year students.

Interdisciplinary QS: Sporadic, individual interdisciplinary collaboration is common at UQ. However, the concept of systemic adoption is now gaining ground and being explored through an initiative of the Faculty of Science.

Evaluating the Change

"How effective has the change to build QS in Science been?"

Institutional standardised evaluation procedures are in place at UQ, including general unit surveys.

Evaluation of QS specifically has been under-taken at a few levels

Unit level: QS in level one interdisciplinary unit (SCIE1000: Theory & Practice in Science)

Research investigating the impact of learning mathematics in the context of science was completed during the first iteration of the unit (Matthews, Adams and Goos, 2009). Evaluation of SCIE1000 among biology students was conducted by Matthews, Adams, & Goos (2010) (see Figure 2).

Program-level: QS learning outcomes in the new BSc

A research project into the implementation of capstone units in biomedical science (publications in progress) has resulted in a benchmarking project across UQ and Monash. This involves the administration of the Science Students Skills Inventory (SSSI) which explores graduating students' perceptions of their attainment of science specific learning outcomes including QS (Matthews & Hodgson, 2011).

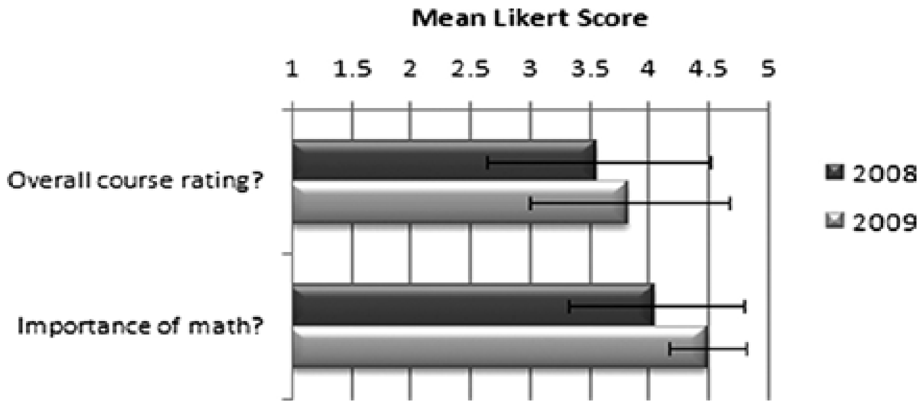


Fig 2. Biology student perceptions of SCIE1000 in 2008 and 2009 on a 5-point Likert scale with standard deviation. The first survey question was, Think about your whole experience in this course. Overall, how would you rate this course? (1-poor, 5-outstanding). The second survey question was, How important do you think mathematics is in science? (1-not at all important, 5-very important). Source: Matthews et al. (2010).

References

Matthews, K., E. , Adams, P., & Goos, M. (2010). Using the principles of BIO2010 to develop an introductory, interdisciplinary course for biology students. *CBE—Life Sciences Educatio, 9* (Fall 2010), 290–297. doi: 10.1187/cbe.10–03–0034

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Thanks to the following people at the University of Queensland for collaborating with us to document this case study:

Peter Adams, Associate Dean Learning and Teaching, Faculty of Science

Jon Curlewis, Assoc Prof, Biomedical Science, School of Biomedical Sciences, Faculty of Science

Michael Bulmer, Senior Lecturer in Statistics, School of Mathematics and Physics, Faculty of Science

If you have any questions, comments or thoughts on the UQ case study, you are welcome to contact them directly.

This case study is up to date as of August 2011. The interviews to gather this data were conducted in May 2011.

Appendix 8

Case Study: University of Sydney (New South Wales, Australia)

The University of Sydney is a research-intensive institution in Sydney, Australia. It was established in 1850, is the oldest University in Australia and is a member of the research-orientated Group of Eight. In 2009, the University enrolled approximately 48,000 students in both undergraduate and postgraduate programs.

Science at Sydney: The Faculty of Science administers the large, broad and flexible Bachelor of Science (BSc), which has an average annual intake of 2,000 students. The BSc had an entry cut-off of 84.50 in 2011 (out of a possible 100, with 100 being the highest ranking). The BSc offers over 30 majors.

Mathematics requirements for entry into Science: There is no mathematics requirement for entry into the BSc.

The University of Sydney case study focuses on majors in the life sciences.

Initiation of Change

"Who prompted need for QS in science and why?"

At the institutional level, an ongoing graduate attributes project, led by staff from the centralised Institute for Teaching and Learning, has prompted policy change across the institution.

In the Faculty of Science, external drivers around national policy in higher education have prompted further activity towards changing curricular and assessment practices. The Learning and Teaching Academic Standards project and subsequent articulation of National Science Threshold Learning Outcomes has further prompted change to better articulate and document learning outcomes and standards at the University of Sydney.

QS are viewed as an inherent characteristic of a scientist, and the need to transition undergraduates into honours in science prompts QS activity in the life science majors in the BSc at the University of Sydney.

Vision for Change

"What do QS in Science look like?"

There are established university-wide graduate attributes which are framed around the 'Sydney Graduate' with five clusters of more specific attributes.

The University-wide attributes have been articulated into Faculty of Science statements of attributes around the five clusters. Although QS are not explicitly stated, the statements implicitly assume QS. These statements were ratified by the faculty following industry consultation. A mapping exercise within the Faculty of Science involved unit coordinators identifying which of the five cluster areas they teach in their unit, however this occurs at the generic level of the five cluster areas of attributes and is not science specific.

The School of Biological Sciences utilises the Faculty of Science statements of attributes.

Implementing for Change

"How is need for QS in Science translated into practice?"

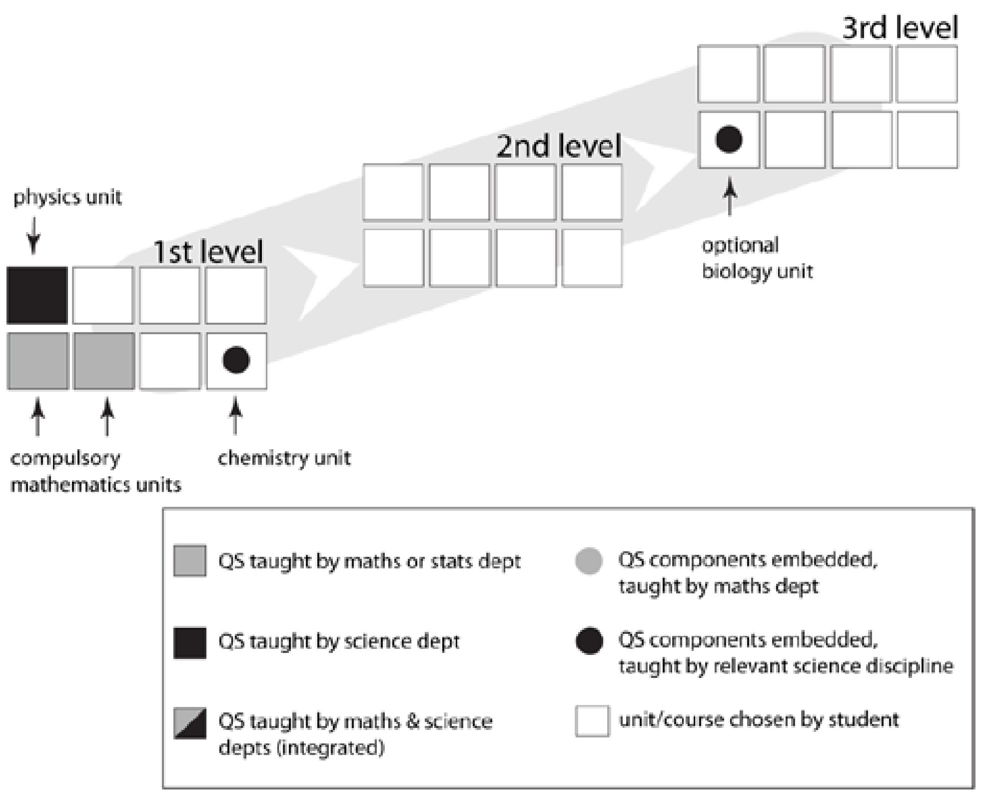
The biological science majors can build on the mathematical and statistical knowledge provided in the compulsory level one units. However, the flexible nature of the degree program, especially in the second and third years, enables students to mix and match, making it difficult to identify the 'critical QS pathway' within the majors.

Curriculum structure for building QS: The diagram shows the 'critical QS pathway', highlighting the requisite units for the major. In the biological sciences majors the inclusion and development of QS occurs at the level of the individual major and varies considerably.

1st level features a philosophy of building foundation knowledge in the 'enabling sciences', including physics, chemistry, mathematics and biology. The only compulsory unit is mathematics, where a selection of units is on offer to accommodate for the range of prior mathematics knowledge. Mathematics for Life Sciences is a unit tailored for BSc life science students, and is one of the options available.

2nd level features more specialised units where QS can be applied in context. Plant PhysiCAL was developed for plant biology specifically to build the QS of students. The interactive, online modules are offered as supplementary support for students, and are an example of context specific QS embedded in upper level life science units.

3rd level features more specialised units where QS can be applied in context.



Extra Curricular QS: There is a Mathematics Learning Centre to support the mathematics units, although it is limited to 'eligible students'.

Interdisciplinary QS: There is currently a project, the Sydney Scientists, which is bringing together teaching teams from the four first year units to discuss commonality across the units in terms of graduate attributes. However, the focus is on mapping writing and communication skills with QS to a lesser extent.

Evaluating the Change

"How effective has the change to build QS in Science been?"

Institutional standardised evaluation procedures are in place at the University of Sydney, including general unit surveys.

Evidence of QS learning outcomes: No science specific, program level evaluation procedures are in place at present, although conversations are beginning to explore standards based assessment around science graduate attributes.

Scholarship of Teaching and Learning activities at the University of Sydney have focused on numeracy in science, and the transfer of mathematical knowledge into a science context. A list of references is provided below.

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Thanks to the following people at the University of Sydney for collaborating with us to document this case study:

Charlotte Taylor, Associate Dean Learning and Teaching in the Faculty of Science
Rosanne Quinnell, Senior Lecturer in the School of Biological Sciences
Leon Poladian, Associate Professor in the School of Mathematics and Statistics

If you have any questions, comments or thoughts on the University of Sydney case study, you are welcome to contact them directly.

This case study is up to date as of September 2011. The interviews to gather this data were conducted in May 2011 with further communications in August 2011.

Appendix 9

Case Study: University of Western Sydney (New South Wales, Australia)

The University of Western Sydney (UWS) is a multicampus university based in the Greater Western Sydney area of Australia. Established in 1989, it now has a student enrolment of approximately 40,000 and offers a range of undergraduate and postgraduate programs.

Science at UWS: The College of Health and Science offers a Bachelor of Science (BSc) in seven disciplines and a general BSc. The average annual intake of students is 300 with numbers varying across each of the eight degree programs. The entry score for each of these three-year degree programs is estimated to be at least 70 out of a possible 100 across all campuses offering the BSc.

Mathematics requirements for entry into Science: There are no specific mathematics prerequisite requirements for entry into any of the BSc degree programs.

The UWS case study focuses on the Chemistry major in the BSc.

Initiation of Change

"Who prompted need for QS in science and why?"

In 2010 the project Reconceptualising Science was launched as a response to the continued international debate around tertiary science curricula and teaching. This ambitious project sought to remodel all of the science degree programs to reflect an evidence and inquiry based curriculum. To achieve this, a whole of degree program approach to the curriculum was adopted.

The ensuing discussions among academic staff highlighted the need for quantitative skills (QS) skills to be embedded throughout the BSc, as staff perceived that incoming students' ability to use QS was poor, with this lack of ability continuing into third year.

Vision for Change

"What do QS in Science look like?"

The University of Western Sydney has institutional graduate attributes.

The BSc at UWS has contextualized the graduate attribute generic skill of 'numeracy' that incorporates QS, as follows:

- Displays appropriate skills in gathering and critically analysing information that is required for solving scientific problems
- Displays appropriate numerical and statistical skills for a professional scientist, in the context of their chosen scientific discipline(s).
- Integrates theoretical and practical knowledge to analyse and solve complex and novel scientific problems.

Other UWS BSc graduate attributes have been articulated and mapped to the UWS graduate attributes and the ALTC Threshold Learning Outcome statements. Further 'drilling down' is occurring with a 'whole of degree program' curricula mapping exercise is underway to map QS skills across the entire curriculum.

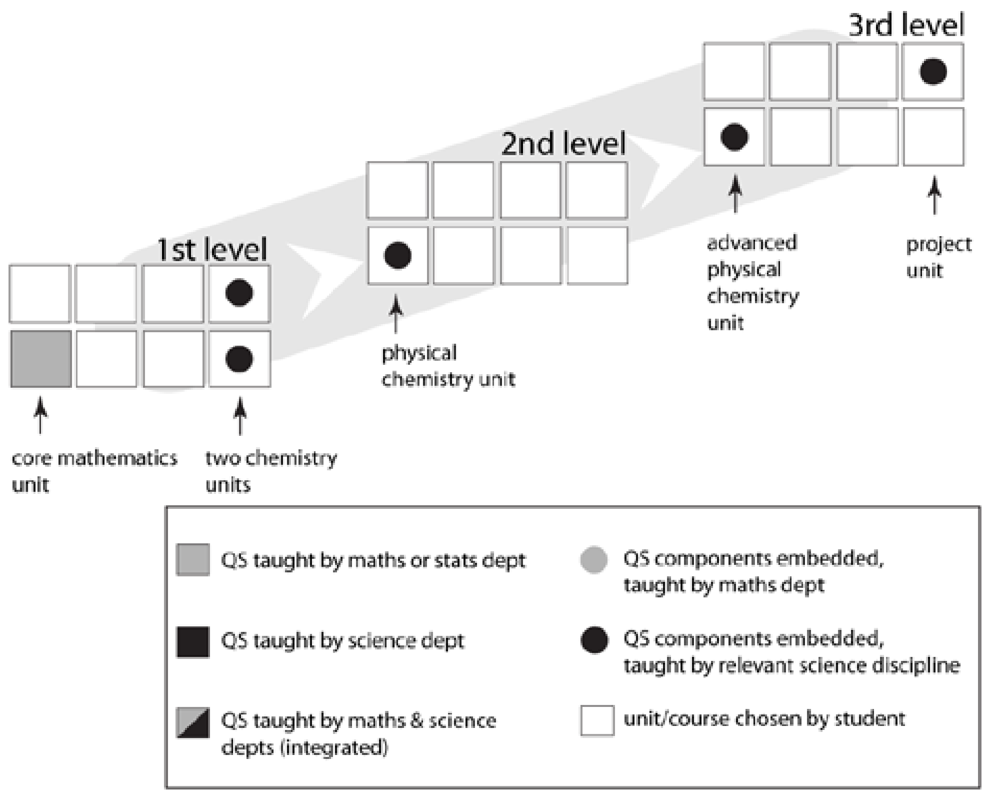
Cross departmental discussions between chemists and mathematicians has led to further articulation of QS in first year chemistry.

Implementing for Change

"How is need for QS in Science translated into practice?"

The BSc (Chemistry) offers students a choice between two calculus based mathematics units at the first year level. This knowledge is built upon in varying degrees in the subsequent compulsory chemistry units.

Curriculum structure for building QS: The Chemistry major at UWS has QS embedded throughout its program.



1st level features a choice of two units from 2012, Analysis of Change, or Mathematics 1A. Both units are calculus based, and assume that students are proficient in algebraic manipulation. Students complete two chemistry units (Essential Chemistry 1 and Essential Chemistry 2).

2nd level features a number of chemistry units that rely on QS. In particular, the units on physical chemistry are heavily QS oriented.

3rd level features a capstone unit Science Research Project that most students choose to do. The expectation is that the students have acquired a sufficient level of competence in QS to undertake the analysis usually required in such capstone units.

Extra Curricular QS: Currently UWS has a Student Learning Unit that provides both mathematical and statistical support to (mostly) first-year students. In 2011, UWS funded the establishment of the Mathematics Education Support Hub (MESH), which will provide both 'just-in-time' and 'just-for-me' help for both staff and students. The support provided by this centre will be tailored specifically to the mathematical and statistical needs of disciplines across the university by way of drop-in centres, online tutors, on-campus tuition and an extensive array of online resources.

Interdisciplinary QS: The university has a hierarchy of committees that focus on curriculum and teaching/learning. Due to a planned restructure which will take effect in 2012, the current suite of committees is under review.

This science curricula review has promoted collaboration between science and mathematics staff that has resulted in a shared understanding of the content and pedagogy of the compulsory mathematics unit and the QS requirements of later stage science units.

Evaluating the Change

"How effective has the change to build QS in Science been?"

Institutional standardised evaluation procedures are in place at the UWS, including general unit and teaching surveys.

Evidence of QS learning outcomes: The proposed BSc courses will not be implemented until 2012. At present there are no plans to evaluate the success or otherwise of the changes made, but it is envisaged that this will be part of the next phase of this extensive curriculum review.

Thanks to the following people at the University of Western Sydney for collaborating with us to document this case study on the development of the Bachelor of Science program.

Pauline Ross, Assistant Associate Dean Academic (Health)
Joanne Chuck, Senior Lecturer in Biology, School of Natural Sciences

Sebastian Holmes, Lecturer in Biology, School of Natural Sciences

Roy Tasker, Associate Professor of Chemistry, School of Natural Sciences.

If you have any questions or comments on the University of Western Sydney case study, you are welcome to contact them directly.

This case study is up to date as of September 2011. The interviews to gather this data were conducted in May 2011.

Appendix 10

Case Study: University of Wollongong (New South Wales, Australia)

The University of Wollongong is a public, multicampus university with approximately 26,000 students. It has nine faculties and offers 30 degrees across its campuses in Australia and overseas.

Science at Wollongong: The Faculty of Science consists of three schools of roughly equal size: Chemistry, Biology, and Earth and Environmental Sciences. The Faculty offers a range of three and four year science degree programs. The most general is the three year Bachelor of Science (BSc) with an average annual intake of 260 students. The entry requirement for the BSc is an ATAR of 75 (admissions ranking from 0-100, with 100 the highest rank).

Mathematics requirements for entry into Science: Mathematics is not required for entry into the BSc although it is assumed knowledge. Students without at least HSC Band 4 Mathematics or equivalent are required to take a mathematics unit (usually MATH151) in the first year.

The Wollongong case study focuses on Bachelor of Science majors in the Biological Sciences.

Initiation of Change

"Who prompted need for QS in science and why?"

At Wollongong each degree program is reviewed every five years, with the reviews run by the relevant faculty education committee. Strategies around the enhancement of QS outcomes have largely occurred independent to cyclical reviews of degree programs and have been driven by the needs of individual disciplines.

Vision for Change

"What do QS in Science look like?"

The University of Wollongong has identified institutional Graduate Qualities, which have been further contextualised at the faculty level.
The Science Graduate Qualities assume quantitative skills (QS) with statements such as '*Scientific approach to the acquisition, analysis, and interpretation of data.*'

Currently, staff within the faculty are mapping graduate qualities across the science curriculum.

Implementing for Change

"How is need for QS in Science translated into practice?"

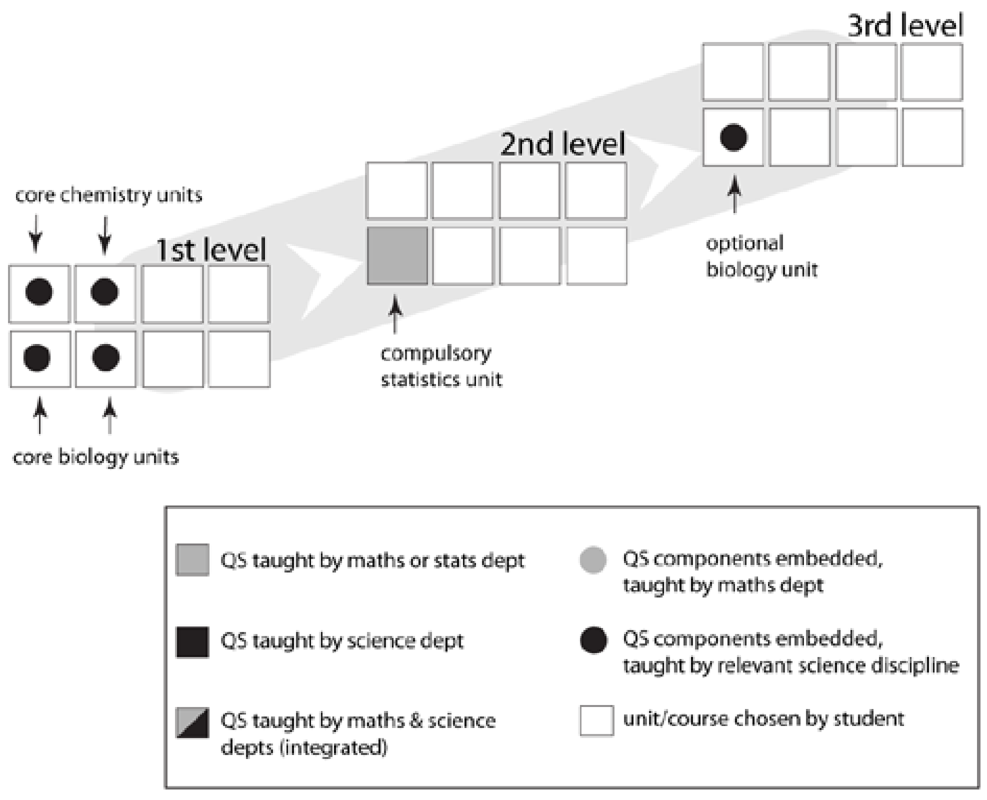
Curriculum structure for building QS: Students enrolled in the major are expected to have either completed secondary school mathematics, or to complete an equivalent unit when they begin their study at Wollongong. QS are embedded within level 1 discipline units. A QS pathway exists through a level 2 statistics unit followed by the embedding of QS components in level 3 biological sciences units.

1st level features a mathematics unit taught by mathematicians for those whose mathematics on entering university is not up to the required standard. QS components are embedded within compulsory chemistry units in both semesters with specific QS resources and QS components embedded within compulsory biology units in both the first and second semesters.

2nd level features a compulsory unit: Statistics for the Natural Sciences STAT252 taught by the School of Mathematics and Applied Statistics.

3rd level There is QS component embedded within the optional ecology unit BIOL355.

Interdisciplinary QS: The need to address QS of students across science has sparked cross discipline conversations. However, there are no formal structures or mechanisms that facilitate or promote cross-departmental planning around building QS.



Evaluating the Change

"How effective has the change to build QS in Science been?"

Institutional standardised evaluation procedures are in place at Wollongong, including general unit surveys.

Evidence of QS learning outcomes: To date, in the Faculty of Science, and in the biological science majors, there has been no formal evaluation on the effectiveness of the changes in the curriculum to build QS.

Thanks to the following staff at the University of Wollongong for collaborating with us to document this case study:

Paul Carr, Associate Professor and Associate Dean Teaching and Learning, Faculty of Science

Glennys O'Brien, Senior Lecturer, School of Chemistry, Faculty of Science

Kristine French, Professor of Ecology, and Director of Janet Cosh Herbarium, School of Biological Sciences, Faculty of Science

Tracey Kuit, Lecturer, School of Biological Sciences, Faculty of Science

James Wallman, Senior Lecturer, School of Biological Sciences, Faculty of Science

If you have any questions or comments on the University of Wollongong case study, you are welcome to contact them directly.

This case study is up to date as of September 2011. The interviews to gather this data were conducted in May 2011.

Appendix 11

Case Study: James Madison University (Virginia, USA)

James Madison University (JMU) is based in Virginia, United States of America with approximately 20,000 students enrolled across undergraduate and postgraduate programs. Established in 1908, JMU is often cited as one of the top public universities in the USA.

Science at JMU: The College of Science and Mathematics offers a Bachelor of Science (BSc) program with majors in biology, chemistry, geology, mathematics and physics. The college has an average annual intake of about 700 students. The entry requirement into JMU is based on the SAT Reasoning Test with scores ranging from 600 (lowest) to 2400 (highest) across three sections, each weighted at 800 points. In 2010, the SAT mean entry score was 1146 based on only two sections, mathematics and verbal reasoning (1600 being the highest possible outcome).

Mathematics requirements for entry: JMU requires high school level mathematics usually including two years of algebra and a year of geometry. Mathematics entry requirements are linked to the SAT which has a dedicated section on mathematics.

The JMU case study focuses on the Biology major.

Initiation of Change

"Who prompted need for QS in science and why?"

At an institutional level, a cycle of review for academic programs occurs roughly every seven years. There are several other factors at JMU that have led to a focus on the development of learning outcomes and the evaluation of the program in light of those learning outcomes.

1. The State of Virginia requires evaluation of programs at the level of learning outcomes.
2. A revision of the general education program in 1997. This program is split into 'clusters' with Cluster Three, The Natural World, providing all JMU students the opportunity to develop problem-solving skills in science and mathematics. For this cluster learning objectives were formulated around skills rather than content.
3. Following discussion amongst academic staff in biology around the year 2000 there was an application for an NSF grant to revitalize core courses– at this time there was a realisation that it was necessary to have learning outcomes to guide the redevelopment.
4. At annual 'retreat days' (faculty planning meetings) the academic program sometimes features. For example, in the recent past a review of the upper division curriculum in light of assessment data was the focus of one retreat day.

Vision for Change

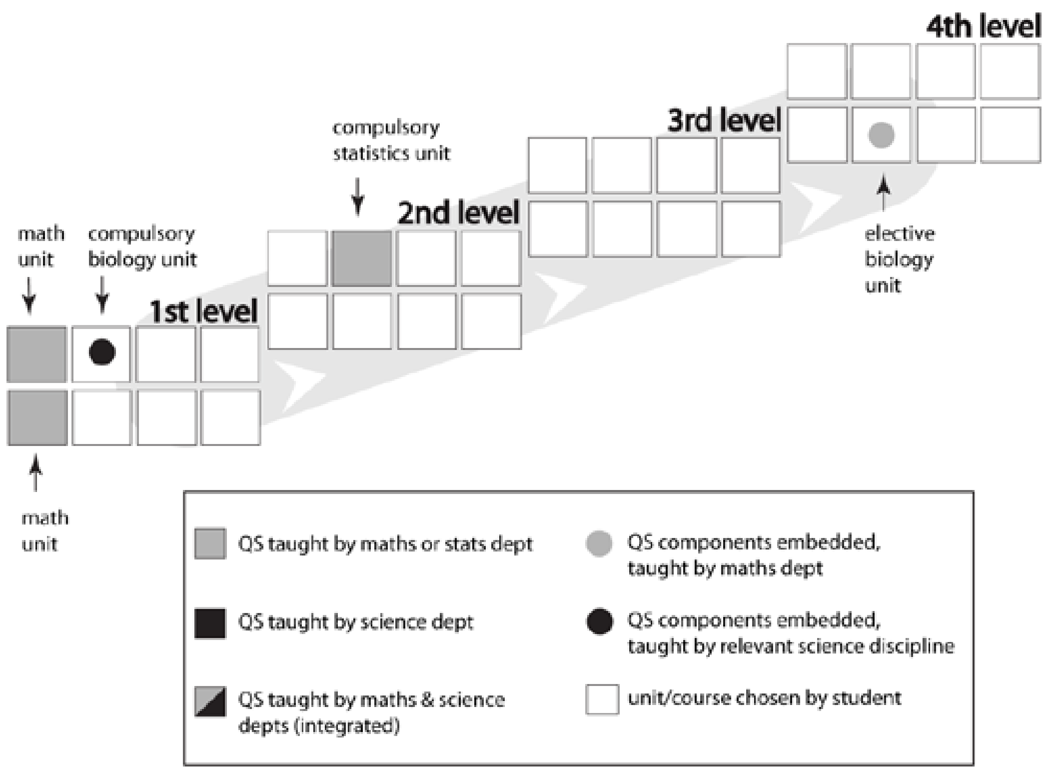
"What do QS in Science look like?"

Institutional graduate attributes are not a feature at institutions in the USA. Skill objectives for both biology majors and students in the general education program are listed in this publication (see table 1 on page 19).

Implementing for Change

"How is need for QS in Science translated into practice?"

The major in biology offers considerable structure in the first two years of the program. The final two years offer students greater flexibility. Comprehensive advice for students studying biology is given here: http://www.jmu.edu/catalog/10/programs/biology.html.



1st level features up to two core mathematics units (depending on the background of the student) taught by the mathematics department. The unit BIO124, Ecology and Evolution, offers a QS experience taught by biology academics.

2nd level features one core statistics unit taught by statisticians from the mathematics department.

3rd and 4th levels feature flexibility of choice with students able to select units which embed QS.

Extra Curricular QS: There is no specific extra curricular QS program, however students are encouraged to participate in research, and this may provide the opportunity for enhancement of QS.

Interdisciplinary QS: There is an interdisciplinary program with biotechnology which offers students the opportunity to develop interdisciplinary QS.

Evaluating the Change

"How effective has the change to build QS in Science been?"

JMU has a well-developed program for evaluation of its programs (in the USA this is called assessment). The Center for Assessment and Research Studies provides the university with this service. The regime of assessment is across both the general education program and the disciplinary majors. Assessment day is a prominent feature in the cycle of evaluation, each student being tested multiple times throughout their study, using the same instrument, in order to determine the effectiveness of the programs at JMU. The center provides resources that can be used to aid in the development of effective assessment. Information about the Quantitative Reasoning test (QR) and Scientific Reasoning Test (SR) is available from Madison Assessment. These tests form the basis on which the natural world cluster in the general education program is assessed. Furthermore, the extent to which the assessment of the natural world cluster can be used to assess the outcomes of the biology major has been explored in this publication. Included in the publication are examples of the questions in each of the QR and SR tests.

Thanks to the following people at JMU for collaborating with us to document this case study:

Dr Carol Hurney, Executive Director, Center for Faculty Innovation, Department of Biology.

Dr Donna Sundre, Executive Director of the Center for Assessment and Research Studies.

Dr Patrice Ludwig, Lecturer in Biology, Department of Biology.

A/Prof Janet Daniel, Associate Professor in Biology, Department of Biology.

Dr Judith Dilts, Associate Dean and Professor of Biology, Department of Biology.

Dr David Brakke, Dean, College of Science and Mathematics.

Prof Bruce Wiggins, Professor of Biology, Department of Biology.

If you have any questions, comments or thoughts on the JMU case study, you are welcome to contact them directly.

This case study is up to date as of January 2012. The interviews to gather this data were conducted in October 2011.

Appendix 12

University of Maryland (Maryland, USA)

The University of Maryland is a public research university located in the city of College Park in the US state of Maryland. It was founded in 1856 and has an enrolment of over 37,000 students.

Science at UMD: The College of Computer, Mathematical and Natural Sciences, offers a Bachelor of Science (BSc), a four year program, with majors and minors in atmospheric and oceanic science, astronomy, computer science, computer engineering, geology, mathematics, physics, physical sciences, biochemistry, biological sciences, chemistry, and environmental sciences & policy – biodiversity and conservation. There are almost 4,900 students doing majors in science.

Mathematics requirements for entry into Science: Three years of high school mathematics, including Algebra I or Applied Math I & II, formal logic or geometry and Algebra II are required for all science majors. Students with majors in biology, biochemistry, and chemistry are expected to have completed four years of high school mathematics, including precalculus.

The UMD case study focuses on the BSc biological sciences major.

Initiation of Change

"Who prompted need for QS in science and why?"

Efforts to increase the quantitative training of biological sciences students have arisen organically from the changing landscape of scientific research–over the last few decades biology has evolved from a largely descriptive field to one that is increasingly interdisciplinary and quantitatively rigorous. Newly hired biological sciences faculty members in fields such as bioinformatics, theoretical ecology, and computational neuroscience reflect this increased quantitative emphasis. At the same time, the department of mathematics has recruited a cohort of faculty members who are focused on biological problems. There was a growing feeling within biological sciences faculty that students enrolled in upper-level courses did not show the degree of sophistication in quantitative reasoning that would be expected given the students' previous mathematical and statistical coursework. The creation of learning outcomes and ongoing curriculum discussions inspired faculty members to consider solutions to their frustrations with the unmet analytical demands and the lack of QS of the students.

Vision for Change

"What do QS in Science look like?"

There are six program outcomes for the biological sciences. Two of these outcomes relate to quantitative skills:

- students should demonstrate an ability to use and apply quantitative methods, especially: interpretation of graphical or tabular data; expression of physical, chemical, or biological process in mathematical form; solving equations to determine the value of physical, chemical, or biological variables.
- students at the lower level should have a basic understanding of how to express questions as a hypothesis, how to design a test of a hypothesis, and how to gather and analyse simple data.

The vision was also informed by the report '**Bio 2010:** Transforming Undergraduate Education For Future Research Biologists'.

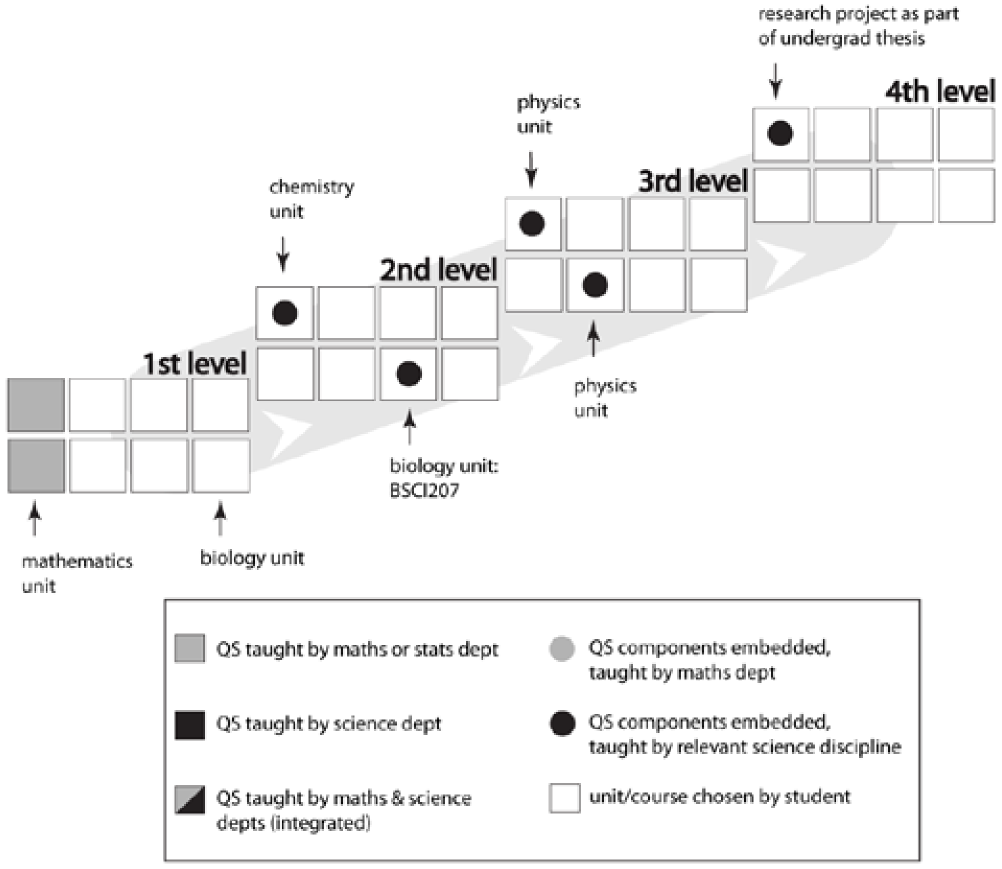
Implementing for Change

"How is need for QS in Science translated into practice?"

The implementation had three major components: (1) revision of the mathematics sequence taken by biology students to be more biologically relevant, (2) embedding basic mathematical content into introductory biology units for both majors and non-majors, and (3) creation of an upper-level, quantitatively intensive unit in mathematical biology.

Strategies to embed mathematical and statistical content into biology units included: creation of a series of online modules, MathBench; development of a highly quantitative third semester introductory biology unit (BSCI 207); and an upper-level mathematical biology unit that allows students to develop sophisticated quantitative approaches to authentic biological problems.

Curriculum structure for building QS: The diagram below shows the critical pathway for building QS in the Biological Sciences major.



1st level features a common sequence of compulsory introductory and supporting units. This includes two mathematics units, MATH130 or MATH140 and MATH131 or MATH 141. A grade of C or better is required for these units. The first semester also includes an introductory biology unit with strong QS component.

2nd level has a highly quantitative biology unit, BSCI207, which focuses on the integration of the physical and the natural sciences and a highly quantitative chemistry unit in the second semester. Level two also includes other QS support units.

3rd level features two semesters of physics, which has a strong QS emphasis. This sequence is currently being revised to have a stronger biological emphasis.

4th level features an undergraduate research project as part of an optional undergraduate thesis and/or an upper-level QS course. Students can choose statistics (taught by a statistician), mathematical biology (taught by a biologist), or advanced mathematics (taught by a mathematician).

Extra Curricular QS: UMD has Math Success, a program run by the Department of Mathematics, that offers undergraduate mathematics tutoring and workshops for students enrolled in introductory courses such as MATH 130 and 131.

Interdisciplinary QS: An interdisciplinary group, including mathematicians, was formed around the time BIO 2010 was released. The group continues and meets once a semester. Biology and mathematics faculty worked together to create material for MATH 130 and 131. A similar collaboration is underway between physics and biology faculty members, as part of a four institution collaboration to create interdisciplinary, competency-based courses for premedical students (Project NEXUS).

Evaluating the Change

"How effective has the change to build QS in Science been?"

Anecdotally the new calculus sequence is a success. Evaluation of the students coming out of the new calculus sequence is just beginning. Assessment of whether or not students have a better mastery of the application of mathematics in biology will be done as part of the campus required learning outcomes assessment.

Formal assessments of learning gains of students using MathBench in introductory biology indicate that students show a higher level of QS, more confidence in solving mathematical problems, and an increased appreciation for the importance of mathematics in biology (Thompson et al. 2010, CBE-Life Sciences Education 9, 277-283).

Thanks to the following people at the University of Maryland for collaborating with us to document this case study on the development of the Bachelor of Science program:

Joelle Presson, Assistant Dean, College of Computer, Mathematical, and Natural Sciences
Robert Infantino, Associate Dean, College of Computer, Mathematical, and Natural Sciences, and Senior Lecturer, Department of Biology
Todd Cooke, Professor of Biology; Director of Integrated Life Sciences, Living-Learning Program in the Honors College, Department of Cell Biology and Molecular Genetics, College of Computer, Mathematical, and Natural Sciences.

If you have any questions or comments on the University of Maryland case study, you are welcome to contact them directly.

This case study is up to date as of December 2011. The interviews to gather this data were conducted in October 2011.

QS Quantitative Skills in Science
Curriculum models for the future

Curricular models for QS in Science

Kelly Matthews[1], Peter Adams[1], Carmel Coady[2], Leanne Rylands[2], Shaun Belward[3], Nancy Pelaez[4], Katerina Thompson[5], Vilma Simbag[1] and Mark Parry[6]

Overview

There is an increasing focus on mathematics and statistics in undergraduate science education as the scientific community calls for graduates with greater levels of quantitative skills (QS). How are undergraduate science curricula designed to build QS? What role do mathematicians and scientist play in equipping science undergraduates with quantitative knowledge and skills?

Methodology

Using a case study methodology, the paper draws on interview data (n=48) from 13 universities (11 in Australia and 2 in the United States) exploring how QS are incorporated into the undergraduate science curricula. Framed within a model for large-scale educational change based on the extensive work of Michael Fullan, this poster focuses on implementation and curricular approaches to building QS across the whole of the degree program.

Case Studies: Institutional Clusters

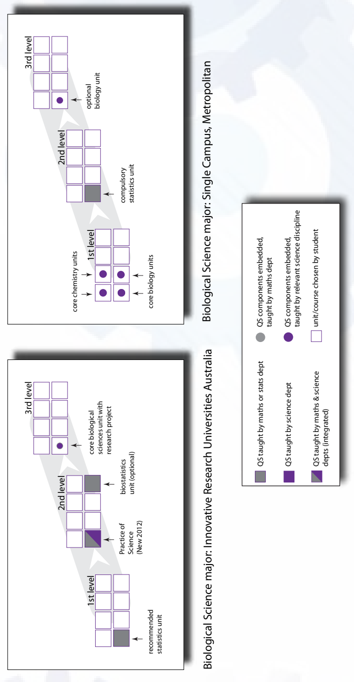
University clusters	# of universities	T&L leader*	Teaching academic**
Research-intensive^^	5^	6	8
Innovative Research Universities Australia	2	2	6
Australian Technology Network	2	2	3
Multi-campus, urban	2	2	4
Single campus, regional/ Metropolitan	2^	5	10
TOTAL	13	17	31

*T&L Leaders refer to Associate Deans (Teaching and Learning) or equivalent
**Teaching academic refers to those teaching into the science program
^Includes university from the USA
^^In Australia, these are the Group of Eight affiliated universities

Table: Institutional clusters

Mapping QS across the whole of the undergraduate curriculum

Interviewees were asked to identify QS taught within a given field of study in core units. The 'critical pathway' of QS were then mapped using a visual tool, which also highlighted who was teaching QS. The 13 curricular structures were then validated by feedback from the interviewees.



Biological Science major: Innovative Research Universities Australia
Biological Science major: Single Campus, Metropolitan

Where are QS taught and who is teaching QS?

Curricular Model	Who is teaching QS?	1st year	2nd year	3rd year*
Unit Model	Mathematics** teaches mathematics unit(s)	23% (3)	15% (2)	0
	Discipline teaches mathematic unit(s)	0	15% (2)	0
	Cross-disciplinary co-taught mathematics-science unit(s)	8% (1)	8% (1)	0
Embed Model	Mathematics teaches QS component in discipline unit(s)	0	8% (1)	8% (1)
	Discipline teaches the QS component in discipline unit(s)	8% (1)	31% (4)	54% (7)
Hybrid Unit + Embed Model	Mathematics teaches mathematics unit(s) + discipline teaches embedded QS component	38% (5)	0	0
	Mathematics teaches mathematics unit/s + cross-disciplinary co-taught mathematics-science unit(s) + discipline teaches embedded QS component	15% (2)	0	0
	Mathematics teaches mathematics unit(s) + mathematics teaches QS component in discipline unit(s)	8% (1)	0	0
QS Silent	No QS identified	0	23% (3)	38% (5)

*USA institutions have 4 year degree programs. For the purposes of this study, years 3 and 4 are classified as 3rd year.
**For the sake of brevity any reference to mathematics includes statistics

Table: Who is teaching QS across the year levels categorised into four curricular models

Preliminary Findings

The 13 case studies highlight the tremendous variation in the curricular approaches. Overall, QS could only be identified in a few units across the curriculum. A significant factor is the choice and flexibility inherent in science programs. Focusing largely on life sciences disciplines, we offer four models for cross-disciplinary curricular approaches to describe how mathematical knowledge is developed and then applied in science units.

Unit model
Approach where units are designed to build mathematical/statistical knowledge and QS. Emergence of cross-disciplinary co-taught units evident.

Embed Model
Approach where QS components are embedded into disciplinary based units, taught in context mostly by disciplinary academics.

Hybrid Model
Approach of having QS units and embedded components across the curricula. Standard 1st year approach where curricula is usually more structured with fewer electives.

QS Silent
QS cannot be identified. Challenge to identify core units as student choice increases with specialisation.

1 The University of Queensland, Australia; 2 University of Western Sydney, Australia; 3 James Cook University, Australia; 4 Purdue University, USA; 5 University of Maryland, USA; 6 Parryville Media, Australia

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QS Quantitative Skills in Science
Curriculum models for the future

The perspective of scientists and mathematicians on quantitative skills

Kelly Matthews[1], Peter Adams[1], Carmel Coady[2], Leanne Rylands[2], Shaun Belward[3], Nancy Pelaez[4], Katerina Thompson[5], Vilma Simbag[1] and Mark Parry[6]

QS in Science

Quantitative skills (QS) is the ability to apply mathematical and statistical thinking and reasoning in context. QS require some mathematical and statistical knowledge. Students are entering university with weaker foundations in mathematics, yet industry is demanding science graduates with greater QS.

Methodology

Data was gathered from 48 academics across 11 Australian and two US universities via interviews. Transcribed data was double-coded to broad themes. This poster draws on one of the broad themes: the interdisciplinary relationship of mathematics and science. It explores views of the 27 science and 8 mathematics academics who commented on interdisciplinary issues involved in building the QS of undergraduate science students.

> "I think part of the problem with mathematicians teaching mathematics is because they can't, even though they try to teach it in context, they can't, because they're not interested in that. You can give them examples, this is how we do (X), but they don't care. It's meaningless to them."
> **Scientist**

> "... we are teaching these students as a service course ... to make sure that we are giving them a course that is useful for them."
> **Mathematician**

The relationship - differing perceptions

Approximately one-third of the comments on the maths-science interdisciplinary relationship were positive. However, mathematicians were far more likely to comment positively (71%) compared to scientists (24%). While the numbers point towards differences in perspective, the quotes reveal some of the differences in thinking.

> "... we don't expose ourselves to potential embarassment ... when I can't even solve the equation myself."
> **Scientist**

> "The mathematicians are working really, really hard at developing and improving the preparatory mathematics subject. So that's one way in which our discipline contributes to the overall science program."
> **Mathematician**

> "We're asking mathematics to do a service and they don't want to do a service and of course they don't."
> **Scientist**

What QS are science and mathematics academics discussing?

Interviewees were asked to discuss QS topics specifically. There was a range of responses from basic numeracy through to complex modelling.

data analysis, ANOVA, hypothesis testing, exponential models, linear models, fractions, statistics, t-test, modelling, skill transfer, calculus, differential equations, basic skills, calculator use, percentages, equations, mathematics

Conclusion

Building QS across the undergraduate science curriculum, the application of mathematical and statistical knowledge in scientific contexts, is inherently an interdisciplinary educational endeavour. However, evidence suggests that scientists have more negative views of the interdisciplinary relationship between departments. This is confounded by varying notions of what QS are needed across disciplines and the lack of opportunities for ongoing communications across the disciplines on curricular issues, such as QS.

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QS Quantitative Skills in Science
Curriculum models for the future

The Stumbling Blocks in Integrating Quantitative Skills in Science

Kelly Matthews[1], Peter Adams[1], Carmel Coady[2], Leanne Rylands[2], Shaun Belward[3], Nancy Pelaez[4], Katerina Thompson[5], Vilma Simbag[1] and Mark Parry[6]

Overview

The science higher education community has acknowledged the essential role of quantitative skills (QS) in science curricula, but institutions are grappling with finding effective methods to integrate these skills across the curricula. What are the challenges facing institutions seeking to embed QS in science?

Methodology

Interview data from academic staff (n=48) in 11 Australian and 2 institutions in the United States were coded and analysed based on Michael Fullan's extensive work on large-scale educational change. The Universities involved in the study were diverse in terms of their student cohort, program structure and type of institution. This poster focuses on the challenges that emerged in regards to building the QS of undergraduate science students.

Findings

Three broad categories emerged:

1. student attitude towards mathematics and the mathematical background of students undertaking science courses
2. the mind-set of science and non-science academic staff teaching into science programs
3. the constraints of the various science program structures.

$$V=\sum\varepsilon_r(r-r_0)^2+\sum\varepsilon_\theta(\theta-\theta_0)^2+\sum\varepsilon_\chi(\chi-\chi_0)^2$$

Students backgrounds

The major themes identified were:

- Diversity of students' backgrounds in mathematics
- The relevance of the mathematics is questioned
- Students in science courses lack basic mathematical skills

> "We all struggle in various ways with the students not having numerical skills."

Academic staff

Comments tended to concentrate on:

- Lack of communication between scientists and mathematicians/statisticians
- Mathematicians/statisticians lack scientific knowledge
- Language is a barrier when trying to communicate mathematics/statistics in context

> "Across the curriculum there's no planning."

Program structure

The major issues raised here can be summarised as follows:

- Crowded curriculum
- Little collaboration between disciplines when designing courses
- Short timeframe to design programs
- Development of QS is not specifically addressed when designing programs
- Too much flexibility in the program

> "I think again, it does boil down to communication between say Mathematics and Biology. We have more to do with say, Chemistry, Physics, than we have to do with Maths."

Conclusion

Despite the differing types of institutions studied, similar themes emerged - communication, or rather, lack of communication across departments teaching into undergraduate science curricula. Opportunities for academics teaching into the science program to meet and discuss QS across the curricula were not evident.

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QS Quantitative Skills in Science *Curriculum models for the future*

Program Level Evaluation of Quantitative Skills: Anyone?

Kelly Matthews[1], Peter Adams[1], Carmel Coady[2], Leanne Rylands[2], Shaun Belward[3], Nancy Pelaez[4], Katerina Thompson[5], Vilma Simbag[1] and Mark Parry[6]

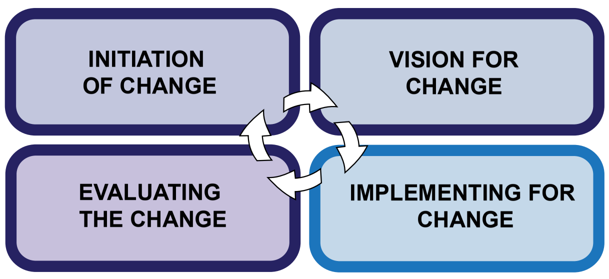
Overview

Quantitative skills (QS) are an essential graduate learning outcome. Science undergraduate curricular reform efforts are underway to better integrate, link and build QS to sufficient levels. On what evidence will the achievement of reform efforts be based and future curricular enhancements be made? Externally, shifting government quality assurance policies are focusing on graduate learning outcomes and seeking evidence of attainment. How will the science higher education sector respond to government calls for evidence?

Methodology

Using a case study methodology, the paper draws on interview data (n=48) from 13 universities (11 in Australia and 2 in the United States). The extensive work of Michael Fullan influenced the conceptual framework, offering a model for capturing educational change and curricular activity. This poster focuses specifically on evaluation.

Interviews were transcribed, entered into a qualitative software program and then coded by two researchers into themes based on the four overlapping, inter-related phases of Fullan's model.



Results for quantitative analysis

Only 11% of all the data coded fell into the theme of evaluation, which was the least discussed theme of Fullan's four phases. Analysis revealed that discussion of evaluation occurred largely in isolation from the other three phase: 5% overlap with *Initiation for Change* phase; and only 2% overlap with both the *Vision* and *Implementation* phases.

Emerging theme: international differences

In Australia, only generic evaluation instruments were mentioned: Course Experience Questions (CEQ); Graduate Destinations Surveys; Unit surveys. No science specific, program level evaluative tools were used. One institution in the United States was utilising a science-specific evaluative tool for assessing program level learning of QS (James Madison University).

Of the 11 Australian universities studied, most were in the initial phases of building QS across the curriculum. The analysis revealed:

- no evidence of any science specific, program-level evaluation framework
- confusion on how to go about gathering evidence of QS at the program level
- a small number of scholarship of teaching/learning projects into QS in science

The two international universities were further advanced in terms of identifying QS as a learning outcome, implementing curricular activities and then assessing their effectiveness in building students QS. The analysis revealed:

- an established evaluation framework in place based on existing government policies
- evidence of QS learning outcomes
- partnerships with higher education assessment researchers

Implications

In Australia, there was no evidence of science specific, program level evaluation activity or planning although all institutions studied had QS as a curricular learning outcome. This finding is disconcerting, particularly as much curriculum reform is occurring without a framework for gathering evidence as per quality enhancement cycles. The quality assurance agenda of the government is another cause for concern given the lack of evaluation. Overseas exemplars could offer some guidance.

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QS Quantitative Skills in Science *Curriculum models for the future*

The vision of QS in science through the lens of graduate outcomes

Kelly Matthews[1], Peter Adams[1], Carmel Coady[2], Leanne Rylands[2], Shaun Belward[3], Nancy Pelaez[4], Katerina Thompson[5], Vilma Simbag[1] and Mark Parry[6]

Overview

There is general agreement amongst the scientific community of the need for graduates with greater levels of quantitative skills (QS). What is the vision for QS and how are this shared across the higher education community? We specifically focus on vision through the lens of graduate outcomes. In particular, the extent to which opinion differs between teaching and learning (T&L) leaders and teaching academics on the value of graduate outcomes is explored.

Methodology

Using a case study methodology, the paper draws on data from 48 interviewees across 13 universities (11 in Australia and 2 in the United States) exploring how QS are incorporated into the undergraduate science curricula. Data was initially coded using the four themes from Fullan's model for educational change. A second level of coding was performed on data from the "vision" theme.

Country (total # universities in study)	University graduate outcomes[1]	Faculty graduate outcomes[2]	Discipline learning outcomes[3]
Australia (11)	11	9	6
USA (2)	N/A†	2	2

[1] For all universities in the study graduate outcomes can be found on the web. Note that link to QS is often implicit at this level.
[2] Most, but not all, faculty graduate outcomes can be found on the web.
[3] The existence of discipline learning outcomes was extracted from the interview data.
† These universities do not publish outcomes at the institutional level.

Table 1: The number of universities in the study that have statements regarding QS as an outcome at the university, faculty or discipline level.

Who is talking about graduate outcomes?

Roughly 25% of the interview data was coded as vision. Of this, 35% was coded as pertaining to graduate outcomes at either the university or faculty level, or as pertaining to discipline learning outcomes.

	Total # of people in study	# of people contributing statements coded as vision	# of statements coded as vision	# of people contributing statements coded as outcomes	# of statements coded as outcomes
T&L leaders	17	17	108	13	40
Teaching academics	31	23	81	15	27

Table 2: The number of people contributing statements coded as "vision" and then as "outcomes" and the number of statements coded in these categories.

What is being said about graduate outcomes?

Teaching and learning leaders

The breadth of faculty graduate outcomes allows different disciplines to go in different directions.

†External reports such those from the QAA and LTAS influence faculty level graduate outcomes.

Discipline level graduate outcomes offer the most to academics.

There is a contrast between preparing students for research and preparing them for employment.

There is some belief that by mandating QS as a faculty graduate outcome the disciplines will ensure they are part of the program in higher years.

†QAA: Quality Assurance Agency for Higher Education (UK). LTAS: Learning and Teaching Academic Standards Project.

Teaching academics

‡Assessing whether graduates have attained skill outcomes is difficult.

Faculty level graduate outcomes are not explicit in providing direction for QS in science.

‡Faculty level graduate outcomes are a "box-ticking" exercise.

Employers' endorsement of graduate outcomes is helpful.

Academics at the same institution interpret policy associated with graduate outcomes in opposing ways.

Some academics could not articulate their own faculty level QS graduate outcomes.

‡These comments also from T&L leaders.

Conclusion

Despite recent efforts to state sector-wide outcomes, institutional attributes and program level graduate outcomes, their influence on curricular design, teaching practices and student learning is questionable. There was no evidence of a shared vision for QS beyond generic statements.

1 The University of Queensland, Australia; 2 University of Western Sydney, Australia; 3 James Cook University, Australia; 4 Purdue University, USA; 5 University of Maryland, USA; 6 Parryville Media, Australia

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Project Name

The Rosetta Stone of QS: translating what quantitative skills are needed for science graduates

Project Aim

The QS in Science project found that quantitative skills are viewed as an essential learning outcome for science graduates and many institutions in Australia are attempting to build better QS in their science students. However, a major challenge emerged around the meaning of QS, with few able to articulate a clear answer to the question: what are the QS needed for students to be successful in science? While many are working feverishly to "fix the QS" problem, our understanding of QS is not clear and nor is it shared among academic staff. The inherent interdisciplinary nature of QS, building on mathematical and statistical knowledge that is then applied in varying scientific contexts, further complicates arriving at a shared meaning of QS. This project aims to engage mathematicians, statisticians and life scientists in conversations and activities to articulate, define and come to agreement on what QS actually are, the relationship between QS as perceived by maths/stats and QS as perceived by life scientists.

Project Outcomes

The project team will facilitate activities to engage the broader science and mathematics higher education community to produce:

1. A definition of QS in science shared broadly across the sector.

2. Standards of QS achievement at each year level in an undergraduate science degree program.

3. Translation of QS between mathematics/statistics and life sciences disciplines.

4. Case studies of exemplars in communicating QS as a graduate learning outcome to academics and students.

Project Team

First and foremost, team members should be passionate and inherently interested in contributing to student learning of QS. Willingness to collaborate with colleagues from different disciplines is also essential. Time and institutional support for team members must be available for this collaborative effort to take place.

The team should consist of members

1. from across disciplines (mathematics, statistics, science, higher education and life scientists)
2. in a position of overseeing a major (field of study) or degree program

QS Quantitative Skills in Science
Curriculum models for the future
QS Phase 2 Project
… advancing the QS agenda

Project Name

Transition: QS from secondary school to first year university

Project Aim

QS have been identified as essential for science graduates, but academics are finding it a huge challenge to build the skills they want among their students over the three years of a science program as they grapple with student diversity including the wide range of QS that students bring with them from secondary schools.

The ALTC project QS in *Science: Curriculum Models for the Future*, investigated QS in science bachelors degrees. However the connections between the QS that students bring to university and their performance in quantitative units were not part of the QS in Science project, hence it is the aim of this project to document and analyse factors surrounding this issue.

This project aims to provide information about issues such as what QS will students who have done some science and mathematics take with them to university; whether they will have experienced mathematics in the context of science; and what can be done to remedy any deficiencies at school, between school and university and in the first year of a science program.

Project Outcomes

The project team will facilitate activities to engage school and university stakeholders to produce:

1. A comprehensive map of where basic mathematical skills of relevance to science occur in school science and mathematics and whether students use these skills in university science.

2. The QS that various science academics assume from new students.

3. Recommendations for improvement in building QS at school and in first year across the sciences and for smoothing the school-university transition.

4. Dissemination of findings and recommendations in a useful and informative manner.

Project Team

A **mathematics** and a **science academic**, one or two **secondary education academics** specialising in science and/or mathematics, one or two **ADLTs** or **first year science coordinators** or **deans**, a **higher education researcher** with experience with science or mathematics.

Project Name

Designing assessment tasks: building QS learning in science

Project Aim

QS have been identified as essential for science graduates, but academics are finding it a huge challenge to build the skills they want among their students over the three years of a science program. We can expect this to become more of a challenge in the years ahead as the uncapping of places should mean more students enrolling in science programs, many with weak mathematical backgrounds. This will be compounded by the increasing proportion of secondary students taking no or low level mathematics in their last years at high school.

The ALTC project *QS in Science: Curriculum Models for the Future*, investigated QS in science bachelors degrees, without focussing on details of how the curriculum is delivered. This project aims to address some of these details by considering how assessment tasks can be designed to ensure students' ability in QS are measured as part of assessment in discipline based science units.

Project Outcomes

The project team will facilitate activities to engage school and university stakeholders to produce:

1. An analysis of current assessment approaches;

2. Case studies from units where QS in science are known to be addressed effectively;

3. Recommendations for improvement in designing of assessment items that measure QS in science students in both formative and summative roles;

4. Dissemination of findings and recommendations in a useful and informative manner.

Project Team

Mathematics and science academics (one or two of each), one or two ADLTs or first year science coordinators or deans, a higher education academic with experience in assessment.

QS Quantitative Skills in Science
Curriculum models for the future
QS Phase 2 Project
… advancing the QS agenda

Project Name

QS Evaluation in Science: engaging academics in developing, assessing and interpreting data on program level learning outcomes

Project Aim

QS have been identified as essential for science graduates and the QS in Science project highlighted the varying approaches being implemented to build QS across 10 Australian universities. While the need to gather evidence to inform ongoing curricular enhancements was acknowledged, none of the studied institutions had program level data of students' QS or a plan for how to go about gathering such evidence. As science reform efforts continue, data are needed for quality enhancement processes unfolding at the level of teaching/learning/assessment in disciplines and faculties. At the national level, shifting government policies towards quality assurance are demanding evidence of student learning outcomes. This project aims to bring together academics to develop a program level assessment framework for QS in the sciences, to pilot the evaluation framework, and interpret results though benchmarking.

Project Outcomes

The project team will facilitate activities to engage the broader science and mathematics higher education community to produce:

1. An Evaluation Framework for evidencing learning at the program level;

2. Case studies of pilots of the Evaluation Framework across several Australian degree programs;

3. Useful **report of evidence** of science students' QS benchmarked across several Australian degree programs and selected international univeristies;

4. Recommendations to the sector on furthering program level evaluation of graduate learning outcomes in science.

Project Team

Two or three **Science Associate Deans** (TL or equivalent); a **Higher Education Researcher** (science or assessment specialisation); one or two **Heads of Discipline**.

QS Phase 2 Project
… advancing the QS agenda

Use any graduate learning outcome in science – ethics, inquiry, oral communication

Project Name

Writing Skills in Science: Curriculum models for the future

Project Aim

Writing Skills (WS) have been identified as essential for science graduates, however the teaching and assessing of writing within the undergraduate science curricula are presenting numerous challenges. Adapting the successful *QS in Science* project methodology, this project seeks to engage academics in a process of identifying curricular 'critical pathways' that build the WS of science students, which can be shared across the sector.

Project Outcomes

1. **Curricular structures:** International benchmarking of undergraduate science curriculum structures that integrate scientific writing skills.
2. **Case studies:** Online institutional case studies of how WS are build in science degree programs.
3. **Standards framework:** A standards framework to articulate, clarify and communicate WS as a science learning outcome.
4. **High profile dissemination activities:** An international symposium in 2015, an edited book, the development of the *WS in Science* network via the *WS in Science* website.

Project Team

Managing team: passionate, dedicated academics with a broader curricular perspective and institutional support including scientists from a range of disciplines; a higher education researcher.

Consultant: science communicator

Evaluator: an active critical friend with expertise in the area of the WS in science.

Quantitative Skills in Science:
Curriculum Models for the Future (*QS in Science*) project

The *QS in Science* project team is to be congratulated for successfully working towards its overall aim of promoting and supporting strategic change in higher education through the enhancement of learning and teaching in the disciplines of science and mathematics, with a view to improving students' quantitative skills. The project team has done well in delivering all its outcomes within the timeframe originally proposed, and are to be commended on their engagement in and their collaborative approach towards analysing the considerable amount of qualitative data collected, and in delivering their extensive programme of dissemination activities. The outcomes of this project make fascinating reading and provide much 'food for thought'.

The project's well-designed website has provided an excellent means of showcasing the team's achievements, in particular the considerable number of case studies, with the short videos representing a particularly innovative way of promoting the project and disseminating its findings.

A particular strength of this project has been the inclusive approach adopted and the energy and commitment exhibited by, not only all members of the project team, but also by their partners in this enterprise.

As the external evaluator to the project I am delighted to have had this opportunity to work with such a capable, diverse, and talented project team. The project's findings will not only help address the challenges associated with embedding quantitative skills within science curricula but will also provide a framework which can facilitate academic change.

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