A STUDY OF THE AUSTRALIAN TERTIARY SECTOR'S PORTRAYED VIEW OF THE RELEVANCE OF QUANTITATIVE SKILLS IN SCIENCE

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The ability to apply mathematical and statistical thinking within context is an essential skill for graduate competence in science. However, many students entering the tertiary sector demonstrate ambivalence toward mathematics. The challenge, then, is to determine how science curricula should evolve in order to illustrate the integrated nature of modern science and mathematics. This study uses a document analysis to examine degree structures within science programs at a selection of Australian tertiary institutions. Of particular interest are the signals these degree structures send in terms of the relevance of the study of mathematics prior to entry to university and the quantitative content within.

Introduction

The increasing dependence of modern science on data, algorithms and models has resulted in a greater need for science graduates to achieve competency in Quantitative Skills (QS)[1]. This fact is acknowledged through publications such as the *Bio 2010* report from the National Research Council of the USA (NRC, 2003). More recently, the Learning and Teaching Academic Standards—Draft Science Standards Statement Consultation Paper, published by the Australian Learning and Teaching Council (ALTC, 2010), provides clear statements on learning outcomes for Australian science graduates. The document represents the opinion of academic scientists in Australia and details *threshold learning outcomes* that all recent graduates of science are expected to demonstrate. These are "minimum standards" and many are explicit regarding the use of QS.

[1] In this article the adjective "quantitative" is used to describe the fundamental skills that allow a scientist to use mathematical and/or statistical thinking and reasoning to gain understanding of scientific processes. In the context of primary and secondary education, the term "numeracy" has frequently been used in place of quantitative skills. For example, in The Report of the Numeracy Strategy Education Development Conference, published by the Australian Association of Mathematics Teachers (AAMT, 1997), numeracy is described as the ability to use mathematics to achieve some purpose in a given context.

Meeting the need for increased proficiency with QS is a considerable challenge for tertiary educators when one considers the environment in which these advances need to occur. The report by Brown (2009) details the downwards trend in the mathematical preparedness of students entering the sector. With students displaying weaker skills and increasingly negative feelings towards quantitative tasks, tertiary science educators are struggling to understand how best to foster the development of QS in science students.

The challenge for science and mathematics educators of how best to demonstrate the intimate relationship between the disciplines is a source of continuing conjecture and robust debate. 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 how to use mathematics skills favour interdisciplinary or integrated approaches because they involve context (see for example, Matthews, Adams and Goos (2009)). Similarly, Venville, Wallace, Rennie and Malone (2002) report that secondary school teachers employ these approaches to enhance pupil engagement in learning. While placing material in context may be a useful motivator, Tariq (2008) is one of many who report that the contextual nature of the problems in science requiring QS poses additional challenges for many students.

Despite the large body of literature discussing the teaching of QS to science students, there is still substantial confusion and variation in opinion regarding its importance. The negative attitude students display towards applying QS is perhaps reflective of a larger body of opinion in society that expresses confusion, or worse mistrust, when quantitative arguments are used to discuss issues in science. Undoubtedly there are many factors leading to this negative view of the quantitative nature of modern science. This publication considers the influence the Australian tertiary sector has on the perception of the importance of QS in science. The analysis uses publically available documents (internet web pages) which the institutions either contribute to, or publish themselves, regarding academic preparation for, and content within, science degree programs. Accessible information includes (i) science degree entry requirements; (ii) prerequisite or assumed knowledge requirements for subjects within the degree program; and (iii) subject or unit descriptions. Through these documents, it is possible to gain some insight into the portrayed value of proficiency with QS in science. This information is of interest and importance, not only to prospective science students, but also to secondary educators who have to grapple with this issue and frequently look to the higher education sector for leadership in terms of a consistent message that can help motivate themselves and their students. Furthermore, secondary teachers and guidance officers often advise students on subject choice in the later years of secondary school, and their views are heavily influenced by the content of these documents. Therefore, we explore the following research question:

> What is the apparent relevance of QS in Science in tertiary education, as portrayed by publically available documents?

We also briefly comment on the literature to illustrate some approaches to the delivery of QS to science students. Whilst not within the direct scope of the above research question, this allows conclusions to be drawn regarding alignment between the importance of QS in science as portrayed beyond the tertiary education sector, and efforts within institutions to embed QS in science.

Method

The study involved documenting four characteristics of the Bachelor of Science degree programs at a selection of Australian universities. These particular degree programs were chosen over other degree programs that may be labelled as science degrees, in order to maintain consistency through the study. The only exceptions to this protocol were in instances where a Bachelor of Science was not offered by particular institutions, but a Bachelor of Applied Science was in existence.

The universities chosen for the study were those that were reported to have had enrolments of greater than 1800 students in the natural and physical sciences in the year 2005 in a study commissioned by the Australian Council of Deans of Science; see Dobson (2007). This results in a sample of 17 tertiary institutions representing over 73% of the total cohort of students across Australia studying the natural and physical sciences in 2005. It is anticipated that the messages these institutions transmit have the greatest impact on the public perception of importance of QS in science.

The following characteristics were chosen as indicators of the publicly portrayed importance of QS in science:

1. Entry requirements requiring prior study in mathematics; and
2. Compulsory requirements for mathematics, statistics or QS within the degree program.

In addition to investigating these two factors in the context of science in general, they are also applied to study within a specific science major[2], chemistry. The decision to investigate a particular major arose for two reasons. Firstly, the requirements for prerequisite study for some majors may be different to the requirements for the science degree as a whole.[3] In this study we measure the publicly portrayed importance of prior knowledge of mathematics for success in a chemistry major as part of a science degree. Secondly, through subject sequences and prerequisite and assumed knowledge requirements, we wish to determine whether it is possible to observe development of QS through the major. Specifically, we investigate how deeply is it possible to observe *subjects that develop QS*[4] within the chemistry major.

Chemistry was chosen as an appropriate representative major for two reasons. Firstly, it is recognised that the variety of programs represented by the Bachelor of Science is considerable, so using minimum standards to measure the articulation of the importance of QS may be similarly varied. By focusing on the sequence of subjects that defines the chemistry major in each program (note that most Bachelor of Science degrees have such a major), some of the variability is removed. Secondly, we note that the Draft Science Standards Statement Consultation Paper, published by the ALTC (2010), has resulted in a corresponding document for the discipline of chemistry, titled

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[2] In this publication a major refers to a sequence of subjects that a student must complete as a part of a science degree, in order to be deemed proficient in the discipline area named as the major. Typically, a major represents about one third of the total number of subjects required for graduation with a science degree.

[3] For example, this frequently occurs in physics majors where successful completion of secondary school physics may be a prerequisite for the major, despite the absence of a physics prerequisite for entry in to the degree program itself.

[4] *Subjects that develop QS* are defined to be discipline-specific subjects that have mathematics, statistics or quantitative skills subjects, as either prerequisite, or assumed knowledge.

the Chemistry Academic Standards Statement—Consultation Phase published by the ALTC (2011). Similar to the overarching document it states very clearly that QS are essential for graduating chemistry majors.

Prior mathematics study required for entry into science degree programs

The requirements for prior study in mathematics for entry to a science program were identified using information from tertiary admissions centres in each state of Australia. These centres were used because many students prefer to access information regarding tertiary entrance requirements in one place. For example, the University Admissions Centre (UAC) in New South Wales "processes applications for admission to most undergraduate courses at participating institutions" (UAC About us, 2011a). In their first quarterly newsletter for 2011 (UAC, 2011b) they comment on their publication *University Entry Requirements 2014 Year 10 Booklet*, stating that:

> The booklet is a valuable tool for Year 10 students choosing their subjects for years 11 and 12. It shows all the prerequisites, assumed knowledge and recommended studies for university courses starting in 2014. Each Year 12 school in NSW and the ACT will receive four complimentary copies of the booklet in mid-May.

For the purposes of this study we report the occurrence of a secondary level mathematics subject as a prerequisite or assumed knowledge for entry into a science degree.

Compulsory mathematics, statistics, or QS subjects

Some science degree programs have compulsory mathematics, statistics or QS subjects embedded within their structure. Although many majors require some such subjects, we identified the minimum requirements within *any* major of the degree program, and report the minimum number of these compulsory subjects that must be completed to be awarded the degree.

Prior mathematics study for entry into the chemistry major

We report the percentage of first year chemistry subjects that have an explicit mathematics prerequisite, statement of assumed knowledge, or recommendation of previous study.

QS requirements within a program to satisfy chemistry major

For the chemistry major in each Bachelor of Science degree, we determine the percentage of chemistry subjects beyond first year that develop QS.

Results

A summary of the data collected is presented in Table 1. The institutions in the table are ordered according to enrolments in the natural and physical sciences in 2005, as presented in the table by Dobson (2007, p. 23). The institutions are labelled according to their affiliations; "G8" represents membership of the Group of Eight, "ATN" represents membership of the Australian Technology Network and "IRU" represents membership of the Innovative Research Universities.

Table 1. Summary of results showing entry requirements in mathematics, and compulsory mathematics/statistics/QS subjects for Bachelor of Science degrees, and prerequisite requirements for chemistry majors and higher level chemistry subjects.

University	Mathematics background from secondary school: P=Prerequisite A=Assumed	Compulsory mathematics /statistics/QS subject	Percentage of 1st year chemistry subjects in the chemistry major with secondary level mathematics as prerequisite or assumed knowledge	Percentage of 2nd and 3rd year chemistry subjects in the chemistry major with 1st or 2nd year mathematics/statistics/ QS subjects as prerequisites or assumed knowledge
University of Melbourne (G8)	P	0	33%	0%
University of Sydney (G8)	A	2	50%	33%
Monash University (G8)	None	1	0%	0%
University of Queensland (G8)	P	1	0%	0%
University of New South Wales (G8)	A	0	0%	38%
University of Western Australia (G8)	P	0	0%	0%
University of Adelaide (G8)	A	0	0%	0%
RMIT University (ATN)	None	1	0%	0%
Australian National University (G8)	None	0	0%	15%
Murdoch University (IRU)	None	0	0%	25%
Queensland University of Technology (ATN)	A	1	0%	0%
University of Technology, Sydney (ATN)	A	1	0%	8%
La Trobe University (IRU)	P	0	0%	0%
Curtin University of Technology (ATN)	P	1	0%	0%
University of Western Sydney	None	0	0%	12%
Griffith University (IRU)	P	1	0%	0%
James Cook University (IRU)	P	1	50%	0%

One immediate observation from the table is the dominance of the Group of Eight in terms of enrolments in the natural or physical sciences. Dobson (2007, p. 23) reports that these institutions account for the preparation of nearly half of Australia's science graduates. We anticipate that this group sends strong signals regarding the importance of QS in science.

Mathematics preparation from secondary school

The strongest signal in any of the four data categories was in the required mathematics background from secondary school. Twelve of the seventeen institutions include mathematics from secondary school either as a prerequisite or as assumed knowledge. This signal was almost uniform across the Group of Eight institutions with only two of the eight not requiring or assuming mathematics from secondary school for students in their science degree program.

Anecdotally there is some discussion around what many regard as the weaker message associated with the word "assumed" when it is used in place of "prerequisite".

Compulsory mathematics/statistics or QS subjects in science degrees

Eight of the 17 institutions in the table have a compulsory mathematics, statistics or QS subject within the Bachelor of Science. It is difficult to draw a conclusion from this statistic, except perhaps to observe that a significant number of institutions appear to believe that students enter their science programs with adequate QS preparation from secondary school for the needs of the full degree program. Development of QS within these programs must be facilitated solely within discipline-specific subjects, relying at most on previous secondary-level mathematics study.

QS in chemistry majors

The table shows some uniformity in the portrayal of the importance of QS within chemistry majors: very few subjects comprising chemistry majors appear to develop QS. That is, there is very little reliance on building QS through links between secondary school mathematics and first year chemistry, or through links between tertiary mathematics/statistics/QS subjects and higher-year chemistry subjects. Anyone using these measures alone may conclude that the relevance of QS to becoming a capable chemical scientist is quite tenuous.

Discussion

The data presented in Table 1 are revealing in terms of measuring *external perception* of the value of QS in science. This type of data represents information that is accessed by practicing secondary school teachers and guidance officers, as well as by budding science students and their parents when choosing senior secondary school. Some students may enjoy science, but experience anxiety towards mathematics, so any hint that the study of mathematics is unnecessary, or can be postponed until later, may result in poor subject selection in the senior school.

Misalignment of external perceptions with efforts towards increased understanding of the need for QS

Whilst being a credible measure of the *portrayed* importance of QS in science, the data accessed in this study and summarised in Table 1 are a crude measure of the *actual* relevance of QS in science. These data hide significant efforts in both secondary and tertiary education to demonstrate the links between mathematics, statistics and science.

Huntley (1998) explains that approaches to curriculum organisation that foster understanding of the intertwined nature of mathematics and science almost certainly involve *interdisciplinary* or *integrated* approaches. It is certainly the case that such approaches may not be revealed by the documents analysed in this study.

At the secondary level, Venville et al (2002) conclude that the authenticity offered by integrated or interdisciplinary approaches provides an opportunity to enhance pupil engagement with school, and that process and higher-level cognitive skills may be increased. Goos and Askin (2005) report on a problem-based Year 10 course at a Brisbane school that integrated mathematics and science. The course showed success with students empowered to make more effective decisions about future careers through an understanding of how mathematics and science are used in "real life" situations.

In the Australian higher education system, Bridgeman and Schmid (2010) report on an interdisciplinary approach in laboratory exercises in first year chemistry subjects at The University of Sydney, which facilitate the development of skills in statistical analysis in a science context. Similarly an interdisciplinary teaching intervention at The University of Queensland highlighting the links between mathematics and science is discussed in Matthews *et al*. (2009). The intervention, in the form of a first year subject, was designed to demonstrate the need for QS in modern science and to improve mathematics skills of students when applied in the context of science.

The preceding two paragraphs briefly touch on the literature revealing efforts to foster an understanding of the value of QS in science. The approaches adopted in these examples are not widely recognised outside science education, and often struggle to gain acceptance amongst educators themselves as Goos and Askin (2005) and Henderson, Beach, Finklestein and Larson (2008) discuss.

Perhaps one of the greatest barriers to the tertiary sector transmitting uniform signals regarding the importance of QS in science is a lack of understanding within the sector as to the most effective way to demonstrate the links between mathematics and science. Without continued efforts in these areas, tertiary science educators are unlikely to be able to meet the ambitious goals they have set themselves through the standards reported in the Learning and Teaching Academic Standards draft consultation paper published by the ALTC (2010).

Acknowledgements

Support for this publication has been provided by the Australian Learning and Teaching Council Ltd, an initiative of the Australian Government Department of Education, Employment and Workplace Relations. The views expressed in this publication do not necessarily reflect the views of the Australian Learning and Teaching Council.
The authors thank Mrs Leah Daniel for her assistance in sourcing the data for this study.

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