BUILDING QUANTITATIVE SKILLS OF UNDERGRADUATE SCIENCE STUDENTS: EXPLORING THE EDUCATIONAL RESOURCES

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KEYWORDS: quantitative skills, science, resources, higher education, evaluation

ABSTRACT

Science and mathematics are inherently interwoven, although they are often considered as separate entities for educational purposes. Consequently, teaching and learning in these fields is dominated by discipline perspectives without explicit mention of the need for knowledge of the symbiotic relationship between them. Not only do students entering science programs in higher education need a base level of mathematical knowledge, they are expected to apply this knowledge in scientific contexts, utilising their quantitative skills (QS). Many higher education science curricula reform efforts are responding to the increasing mathematical diversity of students, although they struggle to build QS of all students to an appropriate threshold prior to graduation. This paper aims to discuss educational resources that attempt to build the QS of science graduates. Data from interviews across nine Australian universities reveals a range of resources developed and delivered by mathematics departments and science departments usually in isolation from each other, but with some instances of cross-disciplinary resource development. Implications for the ongoing divide between mathematics departments and science departments, and the tension between teaching mathematical knowledge and the need for that knowledge to be applied in science, are discussed along with areas where further research could benefit the sector.

Proceedings of the Australian Conference on Science and Mathematics Education, University of Melbourne, Sept 28th to Sept 30th, 2011, pages 145-150, ISBN Number 978-0-9871834-0-8.

INTRODUCTION

It is widely accepted that mathematics and statistics are crucial for the sciences, and the importance of these is increasing. Probability in genetics, manipulation of formulae such as $PV = nRT$ and simple exponential growth models have been used for many years in science. The increasing capacity for the recording and analysis of large amounts of data and the increasing use of more sophisticated models has made mathematics and statistics more important than ever in many areas of science.

The need for mathematics in science goes beyond simply performing calculations divorced from any context. There is a need for students to be able to apply mathematical and statistical thinking and reasoning in the context of science, which here is referred to as quantitative skills or QS (Matthews, 2010). Science has always had a quantitative basis; however, there has been a shift towards teaching certain disciplines in a non-quantitative approach, particularly in the life sciences (Jourdan, Cretchley & Passmore, 2007). In recent years, there has been a myriad of reports highlighting the role of QS in science and the need for all sciences to be underpinned by QS, for example, Rubenstein (2009) neatly summarises Sadler and Tai (2007) ‘Mathematics is the only science subject whose study consistently enhances performance across all fields of science’.

It is accepted that many science undergraduate students do not have the desired level of QS (Jourdan et al., 2007; Quinnell & Wong, 2007) and these skills are worsening as students choose less and lower levels of mathematics at secondary school (Barrington, 2007). Brown (2009) writes

> Australia has gone backwards over the last 20 years in terms of the quality and quantity of students completing Year 12 mathematics. This is despite considerable effort put into improving the situation, including Government funding. This deterioration hasn’t been the case in every country. (p. 3)

The problem of poor QS in science is not purely an Australian problem, as is noted in Feig (2004; p.17).

The Australian government's plans to increase the number of people aged 25 – 34 with a bachelors degree from 32 percent to 40 percent (Gillard, 2009) will only exacerbate the problem. Some of these students will study science; more will need assistance with QS.

Universities do not seem to be effectively communicating to prospective students that QS are needed and are important for the study of science at university (Belward, Matthews, Rylands, Coady, Adams, & Simbag 2011). Also, universities have been accepting students into their degrees, including science, with inadequate mathematical backgrounds (Rylands & Coady, 2009; Rubinstein, 2009; Broadbridge, & Henderson, 2008; King, 2008).

Universities are now under considerable pressure to provide catch-up courses according to Brown (2009)

> The universities cannot ignore the downward change in mathematics preparedness affecting entering students. In the short term there appear to be only two conceivable responses: the provision of enabling (i.e. remedial) programs and the lowering of standards. (p. 7)

The inclusion of QS into science units is another strategy for improving QS (Matthews, Adams, & Goos 2009; Matthews, Adams & Goos 2010), and it might increase disciplinary learning (Madlung, Bremer, Himmelblau, & Tullis 2011).

Our study explored some Australian universities that were actively working to build the QS of their science students. This paper presents some of the resources used or being developed in these institutions aimed at addressing the QS in science issue.

THE QUESTIONS

As part of a larger study into how QS are being incorporated into undergraduate science curricula, this paper is presenting initial findings on educational resources being used to build QS. The Australian Learning and Teaching Council (ALTC) funded the larger study, QS in Science, in 2010, and further information on the overall aims and outcomes are available at www.qsinscience.com.au. The purpose of this paper is to:

- discuss a selection of identified QS resources from nine Australian universities;
- discover whether it is mathematicians, scientists or staff working across disciplines who are developing these QS resources; and
- suggest implications of our findings.

METHODOLOGY

A case study approach within a qualitative research design was employed for this study. The case study unit of analysis was the university and the science degree program. Within the larger study, our project aims to enhance science and mathematics teaching and learning by exploring effective curricular approaches for building QS in science. As such, universities that are actively working to build QS were identified through insider knowledge of the project team. The methodology was not intended to gather representative, comprehensive data on what is happening to build QS across all Australian science degree programs, nor to 'inventory' where QS were being built across the sector. The goal was to learn from instances where QS were identified as an issue and steps were being taken to build QS as a key learning outcome of an undergraduate science education.

DATA COLLECTION

Associate Deans Learning and Teaching (ADLT), or equivalents, in science were emailed an invitation, to participate in the study, along with an information sheet. All invited ADLTs accepted the invitation and were then asked to identify between two and four academics who were working to build QS, with a focus on the life sciences, although some academics from chemistry and mathematics were suggested. Interviews were semi-formal, face to face and conducted by team members. All interviewees were asked to discuss educational resources currently being used to foster and build the QS of their students, including purpose-built, subject-specific resources, textbooks, online resources, educational materials adapted from other institutions, numeracy centres and the like. Whilst the interviews covered a range of topics, the resource question is the focus of this paper.

The data in this paper is from interviews with nine universities, four of which are Group of Eight universities. On average, the Group of Eight universities each enrol far more science students than the other universities.

DATA ANALYSIS
The interviews were audio recorded and transcribed, with transcripts sent to interview participants for review and editing.

Deductive coding was used based on eight broad categories or themes including 'resources', which is the main interest of this paper. Each of the five project members present during a working meeting took up a case study (university) and were given all of the associated transcripts to code. Before actual coding began, members undertook several practice codings and differences in coding were discussed until variations were resolved. All were encouraged to discuss with other members when not completely confident in their coding. In addition, a document consisting of questions and trigger words for each code was developed to facilitate, standardise and reduce variation.

BASIC MATHEMATICAL SKILLS

While QS refers to application of mathematical and statistical thinking and reasoning in context, there is an appreciation that students need a solid knowledge base from which to apply their skills. As such, all but two of the nine universities have a compulsory mathematics subject taught by mathematicians in first year, though fewer than half have a mathematics prerequisite for students entering a science degree. Where there is a compulsory mathematics subject in the science degree, some science academics indicate that students sometimes deliberately delay enrolling in this subject in first year, which has implications for those science based subjects that aim to build on and apply mathematics.

The Australian Network in Learning Support in Mathematics and Statistics (ANiLSiMS) website http://sky.scitech.qut.edu.au/~macgilli/carrick/sites.html lists 30 mathematics support centres in Australian universities. It is therefore not surprising that eight of the nine universities reported that they provided such a service to their students. Many universities run mathematics bridging courses also for incoming students with an inadequate mathematics background. One university is trialling a program where incoming students are tested, and if their mathematics is below a certain level (which depends on which area of science they intend to study) they are directed to a (non compulsory) mathematical skills program.

These prerequisites, subjects and support measures attempt to build basic mathematical skills, but do not integrate these with science contexts. Science students must be able use the mathematics they have developed in context.

RESOURCES FOR BUILDING QS IN SCIENCE

The nine universities considered in this study report a wide variety of strategies for increasing students' QS. However, there was little evidence of formalised, sustainable structures in place to facilitate ongoing cross mathematics-science disciplinary communication around QS in the science curriculum. The majority of academics discussing QS across disciplines were occurring based on prior collegial relationships or individual academics seeking out information to inform their own subject design that involved QS.

In six universities there is evidence that staff are talking across discipline boundaries about the skills that are desired and how they might be achieved. Sometimes academics have an awareness of resources to build QS in science produced by other schools, a necessary condition for the sharing of these resources. In five universities mathematics staff are talking to science academics, finding out what they do with mathematics and statistics and/or seeking examples from science academics so that some of the mathematics can be set in a science context. At one university mathematics academics are reading science papers to learn about how mathematics is used in science. An indication that communication across boundaries could be improved is the message from one scientist that mathematicians wanted to teach too much mathematics, not concentrate on the skills that science students actually need.

A common theme, perhaps unsurprising given the many reports on the poor skills of new students, is that the resources were often targeted at low level mathematics. Indeed, sometimes at a level covered in early secondary school.

The resources mentioned in the interviews have been classified under the headings:
- QS as an integral part of a subject, used in context;
- Mathematics modules, including online and video resources;

- Human resources;
- Textbooks that integrate mathematics and science.

1. QS AS AN INTEGRAL PART OF A SCIENCE SUBJECT
Two universities are taking an innovative approach to QS in science by working across discipline boundaries to combine QS and science in one subject. One university has been running such a subject at first year level for several years, recommended for all science students. The subject was developed by staff from both science and mathematics.

A second university is currently developing such a subject, again with development and teaching to be undertaken by both science and mathematics staff. This subject is to be at second year level, targeted at students in a life sciences major and will be a prerequisite for some third year subjects.

Another university offers a third year subject on research methods in biology which is taught by biologists.

2. MATHEMATICS MODULES INCLUDING ONLINE AND VIDEO RESOURCES
Three universities reported that they use resources that target particular aspects of QS and science. These resources are a part of many strategies, built by staff working in isolation, by mathematics support centres or as part of large projects. The resources are mostly optional supplementary material. They have the potential to be used by different groups of students as each can target one skill or topic that could be of relevance in several disciplines. It should be possible to share these across institutions and maybe across schools within an institution.

Two universities have put substantial effort into producing QS resources for science. In the first, a biologist has developed interactive, online modules to supplement a second year biology based subject. The other university has developed a range of materials for a host of science based subjects including short videos, self teaching online tutorials and online quizzes. Topics covered include graphing skills for calibration curves, simple calculations, scientific notation and chi squared tests. Some show the mathematics in context, and some are developed specifically for first and second year biology. These have been developed by staff from several schools and over many years. The resources to produce these are also varied and include grants and the assistance of a unit which specialises in producing quality presentations.

Another university has purchased licences to an online system for use by students from a book publisher. This targets just mathematics, not QS in science, though it is a part of a larger project that aims to improve QS in science students.

3. HUMAN RESOURCES
A mathematics support centre is a big commitment to building mathematical knowledge, but these generally do not target QS in science. Some universities have shown a real commitment to improving the QS of their science students by employing staff or giving staff time for this purpose through strategic funding associated with science curriculum review or via academics applying for teaching and learning funding at the faculty or institutional level.

At one university in a science school an academic has a grant to develop resources which target QS in science, and it was reported that at another a science school appointed a mathematician.

The ADLT at another university appointed a mathematician to develop both add-on and embedded QS resources for science, and to put in place a support program which aims to raise the level of QS of science students to the base level required for their discipline.

In one instance, the head of a life sciences-based school hired a postdoctoral researcher to analyse first year statistics and conduct a mapping exercise to identify where QS were included in the science curriculum.

4. TEXTBOOKS THAT INTEGRATE MATHEMATICS AND SCIENCE
Textbooks that integrate mathematics and science were mentioned by two universities. Neither has yet adopted such books, but both are giving it serious consideration.

DISCUSSION AND CONCLUSION

By design, all the universities studied had recognised QS as an issue that needed to be addressed in the science curriculum. Although access to financial resources varied, as did curricular design for building QS, all the institutions were taking steps to address the QS problem. Within each university there was some discussion across schools and disciplines, with both mathematicians and scientists wanting to improve students' QS in science. However, evidence of formalised structures to facilitate ongoing communication across mathematics and science disciplines around QS of science students was lacking.

Whilst all the institutions were working to address QS in the science curriculum, each was working largely in isolation. No one reported using resources developed by other universities with the exception of one where an academic moved from one university to another, bringing with him the resources for building QS. There was only one instance of the use of external resources: the purchase of licences for a commercial product from a publisher, though this was for mathematics, but not in a science context. This suggests that gains and efficiencies could be made from cross-institutional collaboration and the sharing and adapting of existing resources. For this to occur, communication across science and mathematics needs to be improved, and the availability of resources needs to be publicised across universities. The *QS in Science* project will make some of these Australian QS resources available soon via the project website (www.qsinscience.com.au).

Bridging courses in mathematics and mathematics support centres have existed at most universities for many years. Where they were mentioned, their role was to support mathematics subjects that aim to build mathematical knowledge. It is unclear whether science staff are aware of mathematics support centres where they exist, and whether science students are directed to these centres if they have problems with QS in their science subjects.

Some academics discussed the use of additional learning resources. However, such modules, tutorials and supplementary materials are of no use unless students actually use them. This was a particular concern in one case where the university paid a commercial provider for licences. Many students indicated that they wanted access to these resources, so licences were bought. Actual use was lower than predicted and so financial resources were wasted. The same concerns apply to support centres and bridging courses: are they being accessed by all who need them? Some interviewees expressed doubt that good use was made of these 'add-on', supplementary resources, and it is interesting to note that no one claimed that good use was made of such resources.

An obvious question about the identified resources is: 'How effective are they?'. There was almost no mention of previous evaluation of any resources except in one university where an introductory subject that aims to integrate mathematics and science as a means to build QS (Matthews et al., 2009; Matthews et al., 2010) was evaluated. Yet this is of utmost importance if academics are to make the best choices for the future.

Finally, it is noteworthy that only two institutions made mention of the literature, or looking to research and reports to guide decisions on how QS might be built into the curriculum. No institutions mentioned central teaching and learning units, which house curriculum designers, academic developers and/or researchers in higher education, as a resource that could be utilised to inform how this problem could be addressed. Indeed, as (almost) no mention was made of evaluation of these resources, it seems that looking to the literature and to teaching and learning units would be beneficial.

This paper has explored some educational resources to build QS in undergraduate science programs. The increasing number of students entering science with poor mathematical skills has implications for how and when this knowledge could be applied in the science curriculum. Largely, it appears that fairly elementary levels of mathematics are sparking the development of QS resources. However, there are still many students who enter university with a strong mathematics background and who have enormous QS potential. How is a typical science curriculum engaging these students?

The case studies so far have suggested the following points for improvement and further research:

- There is an urgent need to evaluate the effectiveness of the QS resources. This can then be used as evidence to identify which approaches should be adopted and adapted more widely.
- There should be substantial scope for publicising and sharing existing resources.

- Institutions need to communicate clearly to staff and students the role of mathematics support centres, expanding the briefs to support QS in science subjects as needed.
- Institutions need to introduce more formalised structures to facilitate ongoing communications across mathematics and science disciplines around QS of science students.
- Stronger efforts need to be taken to encourage students to make appropriate use of resources.

In conclusion, this initial exploration into what resources are being developed, adapted and utilised to build the QS of science students suggests that academics are working in isolation, struggling to resolve the QS problem at a subject level. Whilst every university appreciates individual teaching and learning champions, the QS issues appear to be more widespread and complicated, requiring a more strategic approach to the development of educational resources to build QS, and to the integration of QS across the entire science curriculum. We would suggest this approach should involve ongoing discussions across mathematics and science, with strong leadership at the program level taking responsibility for how QS are built and evaluated so that evidence-based decisions are in place to ensure continuing improvement in this area. The QS in science problem has been a long time in the making, will be intensified with changing government policies to increase student diversity, so will take time to resolve. Short term strategies with long term planning and vision are required of science curricular leaders at the program level so that the work of teaching and learning champions in the classroom can be sustained.

ACKNOWLEDGEMENTS

We wish to thank the committed and enthusiastic academics who took the time to be interviewed by our team.
Support for this study has been provided by the Australian Learning and Teaching Council, an initiative of the Australian Government Department of Education, Employment and Workplace Relations. The views expressed in this article do not necessarily reflect the views of the Australian Learning and Teaching Council.

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