A Practitioner's Guide to Implementing Cross-Disciplinary Links in a Mathematics Support Program

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Abstract

With widening participation in the university sector and the reduction in pre-requisites for entry into many university science courses, students are arriving at university with reduced competencies in mathematics. As quantitative skills are crucial for study in science, under-preparation has direct effects on multiple disciplines. The Maths Skills Program for first year science and statistics students at La Trobe University was developed in collaboration with science coordinators to provide students with mathematics support that highlights the relevance of mathematics to their disciplines. In a recent paper (Jackson & Johnson, 2013), the authors discuss this program and its effect on students' mathematics confidence, mathematical skills and subject learning outcomes. This current paper focuses on the challenges faced in developing such programs, how and why cross-disciplinary links were highlighted, and what responses were obtained from surveys of students and interviews with science coordinators. The model used for this support, from creation to implementation, is also detailed in this paper. Questionnaire results indicated the students saw the relevance of the program to their educational goals, believed the questions written in context helped them learn their subject, and the focus on relevance helped them understand how mathematics was related to their subject. This corresponded with the responses from the science coordinators who found the program to be relevant to their disciplines and assisted students in applying mathematics in context.

Introduction

Mathematical competence is increasingly recognized as crucial for study in a wide range of science disciplines. Significant study of mathematics is normally built into study of physics, engineering and statistics but has been less evident in bioscience curricula (Bialek & Botstein, 2004). National calls in Australia and elsewhere for integration of mathematics into undergraduate science curricula emphasize the importance of creating explicit links between mathematics and science (Australian Academy of Science, AAS, 2006; Brewer & Smith, 2011). However, embedding mathematics into science curricula is complex and depends on the mathematical skills of students on entry as well as the support available during tertiary study.

Although once taken for granted, core competency in mathematics is now less widespread amongst commencing students in science courses in Australia. Analysis of mathematics enrolments in the final year of secondary schooling in Australia shows the proportion of students studying advanced mathematics dropped below ten per cent for the first time in 2011 (Barrington, 2012). The number of students studying elementary mathematics in the final year of secondary education increased. At the same time, fewer Australian Universities require mathematics as a pre-requisite for study in science (AAS, 2006) despite calls for this trend to be reversed (Australian Mathematical Sciences Institute (AMSI), 2012). Students are selecting less demanding mathematics subjects and, unsurprisingly, are less able to use mathematics during university study. Rylands and Coady (2009) in a study of first year mathematics and physics found that "a student's secondary school mathematics background, not their tertiary score, has a dramatic effect on pass rates." (Rylands & Coady, 2009, p.741)

Under-prepared students need mathematics support programs to help develop the mathematical skills needed for study in science (MacGillivray & Croft, 2011). Universities have responded by developing a range of interventions including introductory mathematics subjects or programs (Varsavsky, 2010; Meenan, 2010), mathematics support centres (McGillivray, 2008; Lawson, Halpin & Croft, 2001; Gill, Mac an Bhaird & Ni Fhloinn, 2010) and mathematical skills modules for science subjects (Thompson, Nelson, Marbach-Ad, Keller & Fagan, 2010; Tariq & Jackson, 2008; Holmes, 2006). Compulsory mathematics subjects and mathematics support centres often tend to offer more generalized help with less emphasis on links to disciplinary context. In some, students may suffer from disengagement by students at risk and dominance by mathematics-competent students (Lawson, Croft, & Halpin, 2003). In others, a more nurturing and flexible environment results in tangible student benefits (Patel & Little, 2006; Gordon & Nicholas, 2012; Dowling & Nolan, 2007). Any strategy will be a compromise between complex and diverse needs.

Science faculties are faced with the twin problems of supporting under-prepared students and linking mathematics to science to maintain emphasis on quantitative literacy. In a recent paper (Jackson & Johnson, 2013), the authors describe a mathematics support program for first year science and statistics students implemented at their university. In that paper, the authors discuss the program's effect on students' mathematics confidence and mathematical skills. The current paper extends this discussion. The strategies used to embed disciplinary relevance into the support and to develop core competencies are described. We discuss the challenges faced in creating such a program and describe, in detail, the model used.

Connecting mathematics and science

Integration of mathematics into the science curriculum is emerging as a key theme for undergraduate science degrees (Marsteller, 2010). This approach aspires to reference the authentic use of mathematics in science. It assumes that students will be motivated to develop mathematical skills when they are aware of their relevance to a preferred science discipline. Integration assumes isolation of mathematical skill development from its application will either discourage student engagement with mathematics or obscure the links between mathematics and science. Two strategies described in the literature to achieve integration between mathematical skills and science are the construction of new interdisciplinary subjects/curricula (Matthews, Adams, & Goos, 2009; Usman & Singh, 2011) and embedding links and/or skills development modules within existing subjects (Holmes, 2006).

Analysis of a new subject at the University of Queensland highlighted both the strengths and limitations of introducing an interdisciplinary subject as a vehicle for developing mathematics skills. Matthews, Adams and Goos (2009) concluded such courses: "can be beneficial in introducing students to the interdisciplinary nature of science and mathematics through analysis of real-world issues, while improving students' mathematical skills" but added "students with weak mathematical skills derived little benefit from an interdisciplinary approach and are likely to disengage from learning, in comparison with students who enter university with a solid foundation in mathematics." (Matthews, Adams & Goos, 2009, p.891).

Modification of existing science subjects can simplify introduction of cross-disciplinary links. For example, White and Carpenter (2008) discuss an integrated science curriculum for mathematics and biology at Louisiana Tech University, which was achieved by increasing emphasis on mathematics and chemistry in the biology laboratory program. The revised program increased student awareness of the relationship between biology and mathematics, and also student engagement. The revision of the course materials occurred without changing curricular requirements, and they found that there was increased collaboration, communication and understanding amongst participating faculty members. Increased student engagement has been observed for other similar approaches (Blumberg, Mostrom, Bendl, Kimchuk & Wolbacjh, 2005).

Skills development in context extends the idea of creating explicit links to application of cross-disciplinary skills. Embedded mathematics skill development modules have been created in-house (Thompson, Nelson, Marbach-Ad, Keller & Fagan, 2010; Tariq & Jackson 2008; Holmes, 2006) and by commercial providers (eg MyMathTest, Pearson Education). Both types of products rely on local curriculum design to optimize the programs so they support the relevant scientific content and address the characteristics of local student cohort including the level of mathematics competence at entry. Tailored solutions for individual disciplines can become complex as students need assistance with multiple subject areas. Holmes (2006) addressed this problem by producing a library of interactive learning modules, which covered many areas of mathematics and its applications for undergraduate study. Students felt strongly that the modules facilitated learning and Holmes concluded: "the modules successfully bridge multiple disciplines and break down the disciplinary barriers commonly found in their math and non math courses" (Holmes, 2006, p. 255).

Embedded modules for mathematics skill development compete for space in a crowded curriculum. A middle path between the generalized support of a central mathematics centre and the specialized support of embedded program was the motivation for construction of the Maths Skills Program in the Faculty of Science, Technology and Engineering at La Trobe University. It uses a modular approach but has been moved outside the limits of an individual subject. The program has been designed to link to science disciplines and encourages students to apply mathematical skills in parallel to multiple science subjects.

Case study: co-curricular mathematics support with disciplinary relevance

The Maths Skills Program at La Trobe University was developed as a co-curricular program to allow extended support for under-prepared students (Jackson & Johnson, 2013). It is composed of three activities: face-to-face sessions with a mathematician, worksheets incorporating underpinning theory, relevance, worked examples and practice questions, and a commercial online skills development program (Table 1). Each activity area can be undertaken independently but all are cross-referenced to create an integrated program. The program is optional but recommended to students with low scores on an optional screening test delivered through participating science subjects. The program is characterized by a supporting and non-threatening environment in response to the low mathematics confidence reported by students. Students progress at their own pace, and they are encouraged to manage their participation in the program around other commitments. The program was designed, and is led by, an academic mathematician.

Table 1: Maths Skills Program activities

Worksheets	Online program *MyMathTest* (Pearson Education)	One-to-One Help
➢ Relevance ➢ Theory ➢ Worked examples ➢ Questions in context ➢ Exercises ➢ Answers	➢ Pre- & Post-Diagnostic Tests ➢ Study Plans for skill development ➢ Practice Exercises with guidance ➢ Video explanations ➢ Self-diagnostic tests to monitor progress	➢ Face-to-Face with mathematician ➢ Discussion and Guidance

The program covers a range of mathematics topics, with selected topics recommended for specific science disciplines as negotiated with science discipline coordinators (Table 2). The program focuses on mastery of basic mathematical skills to ensure students develop mastery over these fundamental capabilities. However, application of those skills to science or statistics is seen as equally important.

Table 2: Mathematics topics required by discipline subjects

Discipline Subject Mathematics Topics	Chemistry	Physics	Biology	Statistics
Algebra	✓	✓	✓	✓
Areas, Volumes & Surface Areas		✓	✓	
Differentiation and Integration	✓			
Fractions	✓	✓	✓	✓
Indices and Measurement	✓	✓	✓	
Logarithms	✓	✓	✓	
Percentages				✓
Straight Lines	✓	✓	✓	✓
Summation				✓
Trigonometry		✓	✓	
Vectors		✓		

Relevance to science disciplinary study is constructed through the Maths Skills Program worksheets. Each worksheet has theory and worked examples, but also includes a section explaining relevance to science entitled "Why you need to know this …" The worksheets ask students to practice application with questions written in the context of science as well as showing them how to master the skills needed to answer the questions correctly. The majority of students enrolled in the program will be studying in multiple participating disciplines and can access all worksheets.

Math Skills Program Model - cross-disciplinary collaboration and action research

Action research methodology (Stringer,1996; Carr & Kemmis,1986) was used to develop the program from its beginning. Team members observed, analysed and refined the program each semester over five successive semesters (Figure 1). Analysis of learning outcomes and students' self-ratings following participation, have been reported elsewhere (Jackson & Johnson, 2013). In summary, as reported in that paper, results showed the program built mathematics confidence, which has been correlated with improved learning outcomes (Parsons, Croft & Harrison, 2009; Tariq, Qualter, Roberts, Appleby & Barnes, 2013). Participating students also felt they had improved their mathematical skills. Analysis of grades from science subjects revealed a positive correlation between engagement in the Maths Skills Program and successful completion of each respective science disciplinary subject. This is not necessarily a causal relationship and requires further study to identify those factors in the program, which promote success.

The project team included the program leader, a mathematician, and subject coordinators for each of the participating science disciplines. Collaboration was built through personal interactions and open sharing of materials. Team members had input into the overall development through team meetings as well as control over materials recommended for their area through work on individual disciplines. As the program developed the collaboration also identified overlap in mathematical skills between disciplines.

An appreciation of the mathematics required for each discipline was developed between the program leader and the science coordinators. The program leader invested time in viewing lecture notes and laboratory manuals for each subject to ensure worksheets complemented the disciplinary material. Science subject material was used to identify examples of the use of mathematical topics and to construct questions for discipline screening tests and questions in context for the worksheets.

A major challenge faced when designing a multi-disciplinary program was ensuring relevance and requirements for the different disciplines. To overcome this, disciplinary relevance was built into the program using three strategies: close collaboration between the program leader and the science discipline coordinators, construction of sections describing the links between the mathematics topic and relevant science disciplines, and the construction of questions in context which requires students to practice mathematics skills using the science discipline language and context. Materials for the Maths Skills program are delivered to students through first year science subjects highlighting the links between the program and each discipline.

Another challenge was catering for diverse student needs. This required a flexible approach. Students were free to choose to engage in different learning modes or all modes and/or attend help sessions. Students were encouraged to be self-motivated and self-regulated.

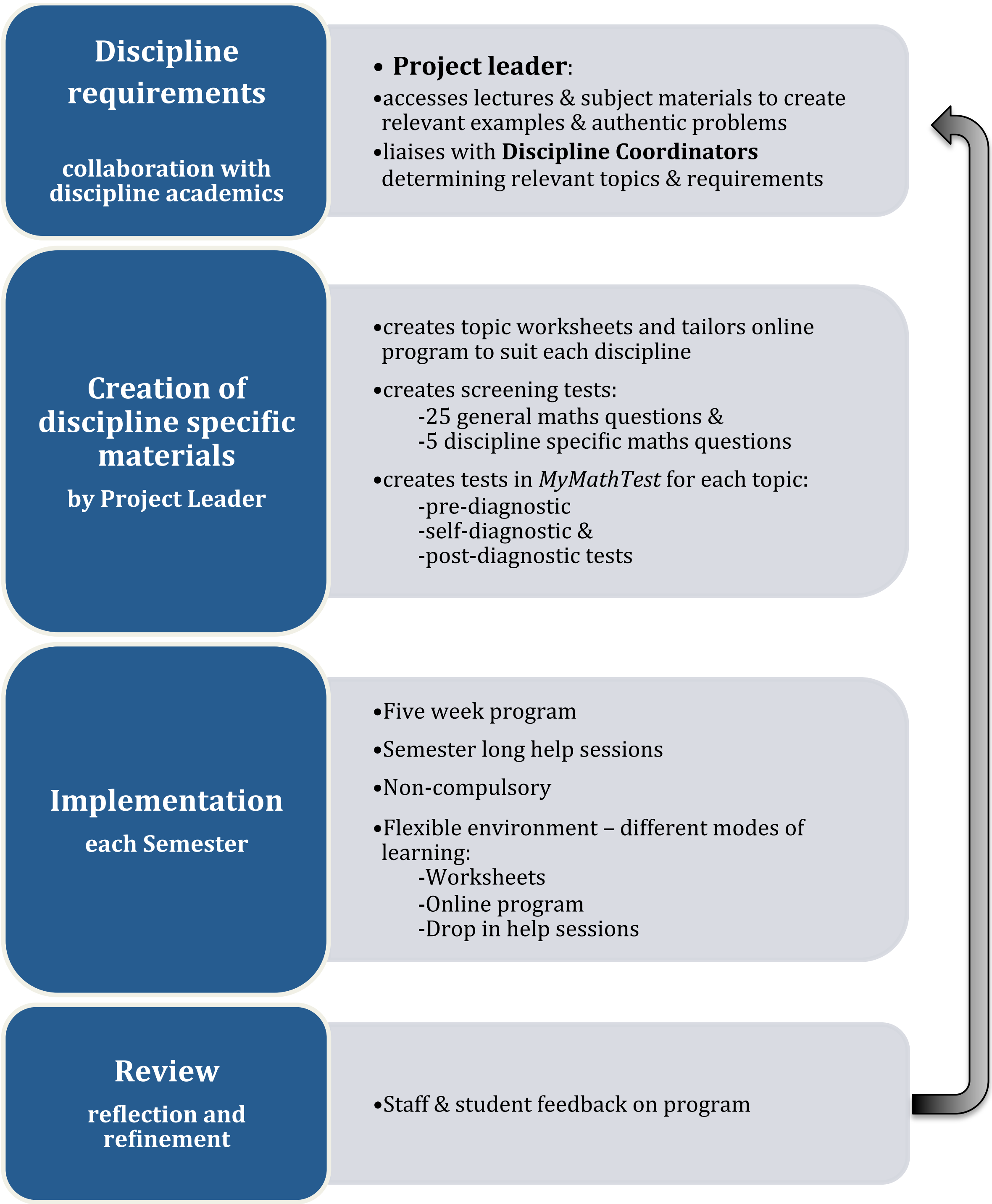

Figure 1: Model for Maths Skills Program

Relevance: using mathematics topics in science

Each Maths Skills worksheet includes a section entitled: "WHY you need to know this" (Figure 2). This section explains how the mathematics topic or relevant skills can be used in the respective disciplines. The section reinforces disciplinary material and shows transfer of the same mathematical skills/topic across scientific disciplines.

WHY you need to know this (INDICES & MEASUREMENT)

Scientists are constantly faced with multiplying or dividing very large or very small numbers, and it is here that the index laws are most helpful. They are also helpful in correctly manipulating formulae which include exponents, or powers of numbers.
Scientific notation is extensively used in science. It is a way of writing numbers in the form $a10^b$, where b is an integer and a is a real number greater than, and including, 1, and less than 10. Such notation makes complicated results simple to understand and work with. Index laws are used when scientists work with exponential growth or exponential decay.
Biologists use exponential growth functions to estimate growth such as the number of bacteria present in a culture over time.
Nuclear ***chemists*** use exponential decay functions when they work with problems involving radioactive decay. The half-life of a substance is the time it takes for that substance to lose half of its pharmacological, physiological or radiological activity and its formula is an exponential function. Hazardous materials often continue to be dangerous for many years after their disposal. Scientists and environmentalists use the half-life of radioactive substances and pesticides to predict when such substances become safe.

Figure 2: Example of a section explaining relevance from a Maths Skills worksheet. This section is extracted from the worksheet "Indices and Measurement".

Questions in context

Discipline-specific questions were constructed for the pre-program screening test and for worked examples and questions in context on the Maths Skills worksheets to add to the theory provided and skills development presented. In the initial screening tests, 25 mathematics questions and 5 questions in context relating to a student's subject were generated from specially written question banks. There were three different screening tests, one each for Chemistry, Physics and Biology. The mathematician wrote the question banks for the mathematics questions incorporating relevant skills in collaboration with the coordinators, and the coordinators/representatives provided suitable question banks for the 5 other questions written in context relating to their subject. Question order was randomly assigned.

Practice questions in the online self-paced tutorial program also focused on skills development and mastery. Questions in context on the worksheets applied those skills to problems that used scientific disciplinary language (Figure 3).

Practice questions written in science context (INDICES & MEASUREMENT)

1. A beaker contains 625 mL of a suspension of yeast cells. The yeast cells make up 18% of that volume.
How many yeast cells are in the beaker? The average volume of a yeast cell is 50 femtolitres (10^{-15}L).

2. Bacteria can multiply at an alarming rate when each bacteria splits into two new cells, thus doubling.
(a) Suppose we begin with just one bacterium which can double every hour. How many bacteria do we have at the end of 24 hours?
(b) Suppose we begin with two bacteria which can double every half hour. How many bacteria do we have at the end of 8 hours?

3. Polonium-210 has a half-life of 138.4 days. If we begin with 10 milligrams of Polonium-210, how much do we have after 100 days?

4. The amount of carbon-14 in a sample is halved over the course of 5730 years. Suppose a living tree trunk initially contained 200g of carbon-14 while it was alive. Suppose a log from that tree was excavated 10,000 years after it had died. Use the half-life formula to and how many grams of carbon-14 remained in it? Give your answer correct to 2 decimal places.

Figure 3: Example of questions in context from a Maths Skills worksheet. These questions are extracted from the worksheet "Indices and Measurement".

Student perceptions of disciplinary links

Student perceptions of the relevance and utility of the program give some indication of the value of cross-disciplinary links (Figure 4). Student surveys were collected at the completion of the program across 5 iterations of the program over 3 years using the online Survey Monkey site for 2011 and 2012, and a paper survey for the pilot program of 2010. Surveys were completely anonymous. About a quarter of engaged students responded. Most questions were the same each year, except for added questions in 2012 about the sections on relevance (which were introduced into the worksheets that year) and the usefulness of the questions written in context. Questions were asked about how much time and effort they put into the worksheets, the online modules, and the help sessions, as well as which aspects of the program they found most useful. They were also asked whether they had improved their confidence and skills, whether the program was relevant to their educational goals, whether it was relevant to their subjects, and whether they felt the program was useful to them and/or to future students.

From 2010 to 2012, students rated the relevance and utility of the Maths Skills program on a 5-point Likert scale of very low (1), low (2), medium (3), high (4) and very high (5).

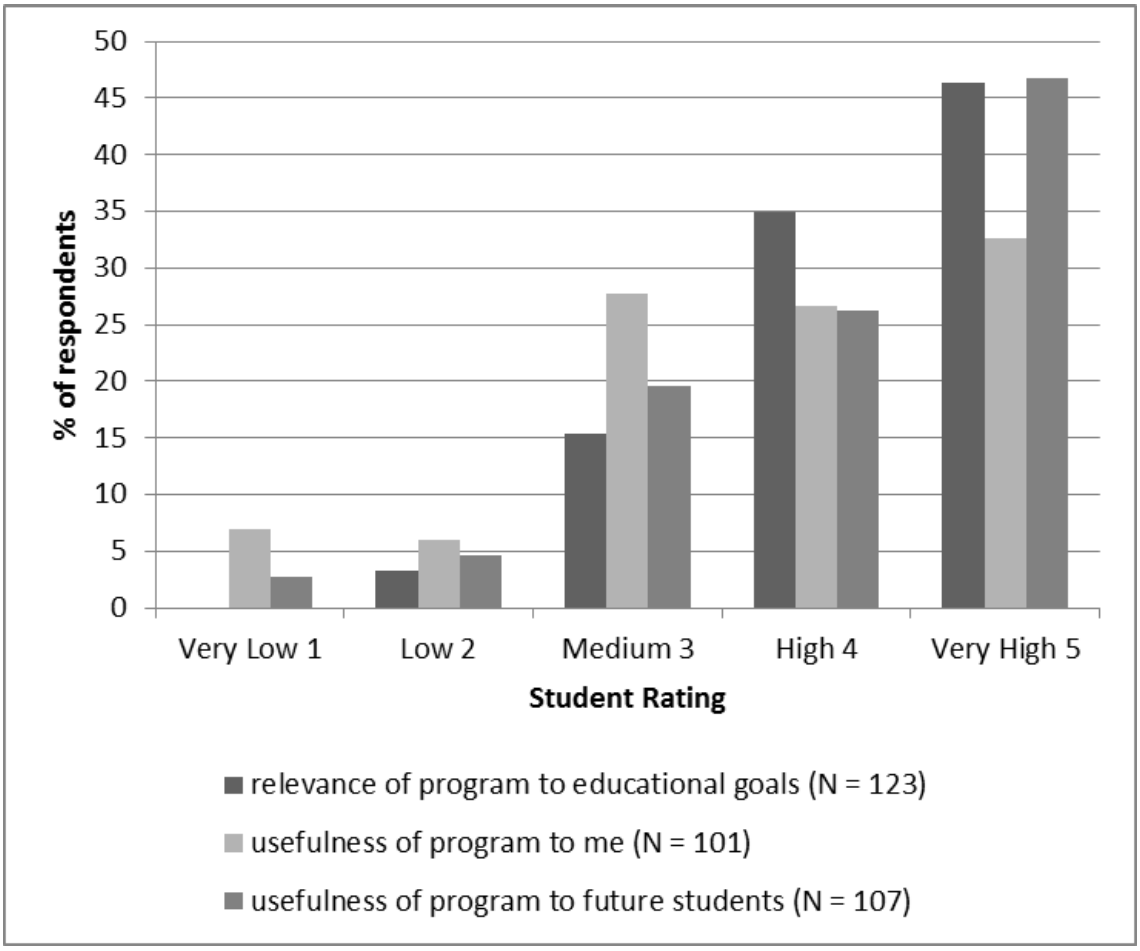

Figure 4: Student rating of the relevance and utility of Maths Skills Program

Students found the program relevant to their education goals (mean 4.2, s.d. 0.83). They rated relevance more highly than personal usefulness (mean 3.7, s.d. 1.2) but interestingly believed the program would be more useful to future students (mean 4.1 s.d. 1.1). Anecdotal comments suggest that at least some students felt they had limited the value of the program by not spending more time on it. This might explain the difference between ratings of person utility and rating to other students.

Students were also asked in 2012 about the contribution of worksheet elements explicitly written to emphasize cross-disciplinary links (Figure 5). In this case, students rated how often those sections assisted learning on a 5-point Likert scale of never (1), rarely (2), sometimes (3), usually (4) and always (5). Most students felt the questions in context usually or always helped them learn their related science subject (mean 3.9, s.d. 1.1). Similarly, most students believed sections on relevance usually or always helped them understand how mathematics was related to their subjects (mean 3.9, s.d. 1.0). Students are certainly aware that mathematics is important for study in science disciplinary subjects. The outcome is also likely to be a product of the collaborative design approach used which encouraged science subject coordinators to emphasize quantitative skills within normal subject curricula.

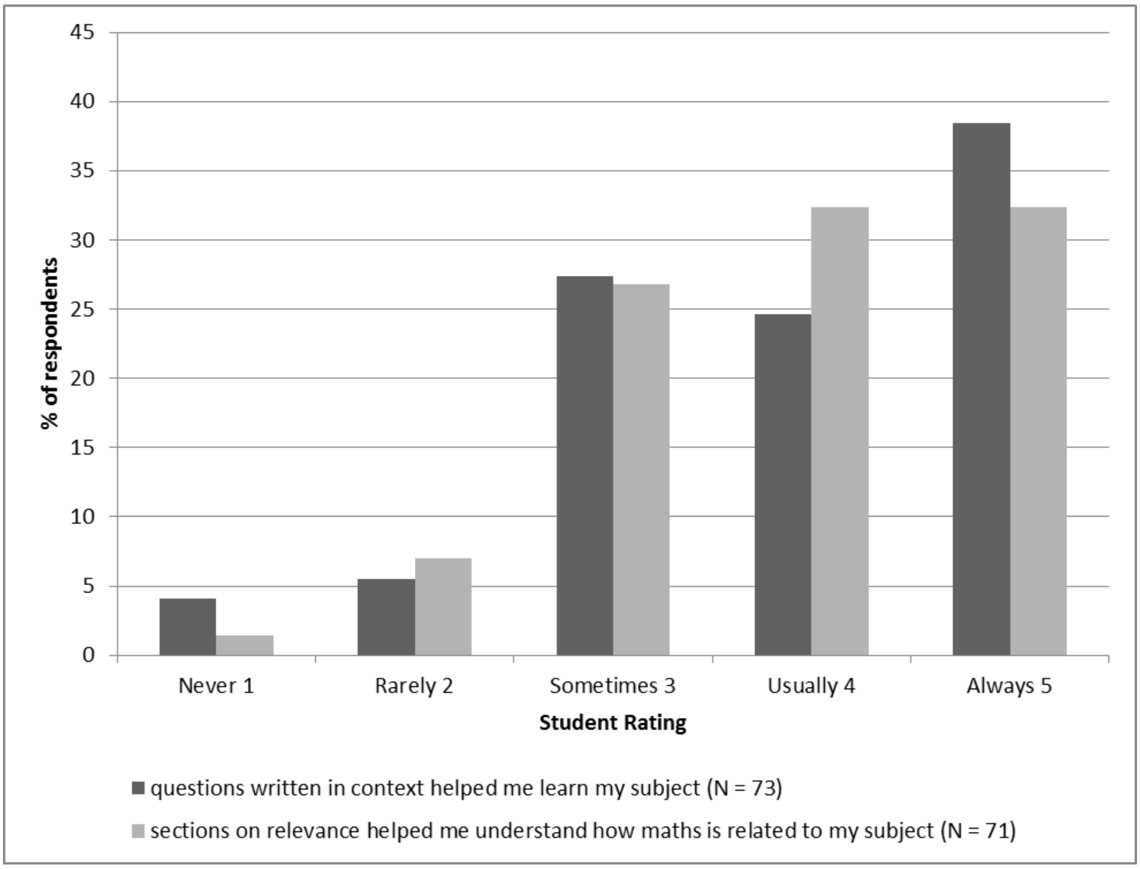

Figure 5: Student rating of the questions in context and sections on relevance from the Maths Skills worksheets

Science co-ordinators' perceptions of cross-disciplinary links

At the end of the fifth iteration of the Maths Skills Program, a focus group with collaborating academic staff was carried out to gather their perceptions of the relevance and efficacy of the program to their disciplinary teaching. A semi-structured approach was used in the focus group, and the responses were recorded and transcribed. The subject coordinators all agreed the availability of the program had reduced the time spent triaging and supporting the growing number of mathematically under-prepared students. The coordinators agreed that linking the program to the requirements of the discipline subjects meant students were able to develop their mathematics literacy in context of the discipline. The coordinators noted that transfer of mathematical skills and techniques into science disciplinary study is not straightforward for students.

> "*… even students who do well at maths are often unable to apply what they know in the subject …"* (Coordinator A)
>
> *"So many little iddy bitty things they just don't understand… and it separates them from learning…. Whereas they realise how easy it is they feel more confidence overall …"* (Coordinator B)

The coordinators felt that increased confidence with mathematical skills was an important outcome for participating students.

> *"… it has disciplinary relevance and raises their confidence … "* (Coordinator B)
> *"…The students are relieved about the support, it is an extra workload but saves them time in the long run…"* (Co-ordinator B)

Discipline coordinators noted that a consistent approach across the different discipline subjects highlighted the importance of mathematical literacy to the students. This was thought to be particularly important for those students who have limited time available for study.

> *"… it emphasises that maths is important across all these disciplines and is hard… students put aside more time for it in their studies …"* (Co-ordinator C)

Discussion

Calls for integration across science and mathematics curricula have stimulated a range of responses. The underlying assumption is that integration improves student engagement, improves transfer of basic skills between applications and prepares students better for the real-world problems, which rarely fit neatly within disciplinary boundaries. Integration can be achieved through inter-disciplinary or cross-disciplinary subjects, cross-referencing within existing curriculum or, as in this case study, by asking students to apply basic skills to multiple disciplines. This paper extends the discussion found in Jackson and Johnson (2013). It focuses on the model used for the support provided by Maths Skills Program and highlights the challenges faced and the role of relevance to science in mathematics support.

The goal for the Maths Skills Program at La Trobe University is to improve quantitative literacy to support study in science and statistics. Students practice basic mathematics skills to achieve mastery and, at the same time, work on problems in context to practice transfer of those skills into disciplinary study. Student feedback from the Maths Skills Program suggests that explicit links with disciplinary study are important to students, increase appreciation of the value of mathematics and produce immediate pay-off for participation. This is echoed by participating science subject coordinators who noted the effect of embedding links to the program across the different discipline subjects emphasized the importance of mathematical literacy across science and encouraged the students to increase time dedicated to improving their mathematical literacy. Although not yet measured for this study, it is likely that increased confidence with mathematics in context will improve future student engagement with science.

Transfer of mathematical skills between disciplines is not trivial. Anecdotal comments from participating students in the program indicate that differences in the language used for essentially the same skills in mathematics and science can create artificial barriers. Students may not recognize that they are using mathematical techniques in solving scientific problems and then have difficulty re-using the same technique elsewhere. The science subject coordinators reported the difficulty students had applying mathematics to solve problems in a disciplinary context. Difficulty with application of mathematical skills in a new context has been reported previously (Hoban, Finlayson, & Nolan, 2013; Britton, New, Sharma & Yardley, 2005) although further research is needed to understand this better.

An unplanned positive outcome from the project has been the collaboration between mathematics and science disciplinary academics. Collaboration between mathematics and science staff has overcome the challenges encountered when working across disciplines.

This has led to a better understanding of each other's discipline and increased consensus regarding core quantitative skills. White and Carpenter (2008) also found increased collaboration, communication and understanding amongst participating faculty members with development on an integrated curriculum between biology, chemistry and mathematics.

Understanding the "other" discipline is a significant step forward in creating tangible links for students. Kirkup (2009) in an investigation of service teaching suggested that those designing service teaching would benefit from sitting in on classes in the related discipline. Working directly with science discipline material had an immediate effect in the Maths Skills program through building sections on relevance in the worksheets and in capacity to work with students using shared language. The collaboration across first year science subjects has reinforced horizontal integration and consistent messages to students.

The Maths Skills Program at La Trobe University has brought the idea of cross-disciplinary links into a dedicated mathematics support program. This approach complements other integrative curriculum design while recognizing the value of individualized and personal support for under-prepared students. A program where learning is relevant to a student's education and future, which is flexible, self-assessing and self-motivating, with a supportive environment, can help students improve their mathematical skills and improve their chance to attain their goal of academic success.

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Appendix: Subjects participating in Maths Skills Program

	Subject code	Name of subject
Semester 2, 2010	CHE1APL	Applications in Chemistry
Semester 1, 2011 *ME = Melbourne* *AW = Albury-Wodonga* *BE = Bendigo*	CHE1BAS (ME, AW)	Basic Chemistry
	CHE1GEN (ME, AW)	General Principles of Chemistry
	BIO1OF (ME, AW)	Organisation and Function of Cells
	PYH1LSA (ME)	Physics for Life Sciences A
	BIO1CO (BE)	Cells and Organisms
	CHE1C1A (BE)	Chemistry 1A
Semester 2, 2011	CHE1APL (ME)	Basic Chemistry
	BIO1GEN (ME)	Genetics, Human Biology and Evolution
	BIO1PS (ME)	Plant Science
	PYH1LSB (ME)	Physics for Life Sciences B
	STA1LS/SS (ME)	Statistics for Life Sciences/Social Sciences
	STA1DCT (ME)	Data-based Critical Thinking
	MAT1PHM (BE)	Pharmacy Mathematics
Semester 1, 2012	CHE1BAS (ME, AW)	Basic Chemistry
	CHE1GEN (ME, AW)	General Principles of Chemistry
	BIO1OF (ME, AW)	Organisation and Function of Cells
	PYH1LSA (ME)	Physics for Life Sciences A
	BIO1CO (BE)	Cells and Organisms
	CHE1C1A (BE)	Chemistry 1A
	STA1DCT (ME)	Data-based Critical Thinking
Semester 2, 2012	CHE1APL (ME)	Basic Chemistry
	BIO1GEN (ME)	Genetics, Human Biology and Evolution
	BIO1PS (ME)	Plant Science
	PYH1LSB (ME)	Physics for Life Sciences B
	STA1LS/SS (ME)	Statistics for Life Sciences/Statistical Science
	MAT1PHM (BE)	Pharmacy Mathematics
	STA1PSY (ME)	Statistics for Psychology
Semester 1, 2013	CHE1CHF (ME, AW)	Chemistry Foundations
	CHE1GEN (ME, AW)	General Principles of Chemistry
	BIO1OF (ME, AW)	Organisation and Function of Cells
	PYH1LSA (ME)	Physics for Life Sciences A
	BIO1CO (BE)	Cells and Organisms
	CHE1C1A (BE)	Chemistry 1A
	STA1DCT (ME)	Data-based Critical Thinking