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# Quantitative skills as a graduate learning outcome of university science degree programmes: student performance explored through the *planned–enacted–experienced* curriculum model

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**ABSTRACT**

Application of mathematical and statistical thinking and reasoning, typically referred to as quantitative skills, is essential for university bioscience students. First, this study developed an assessment task intended to gauge graduating students' quantitative skills. The Quantitative Skills Assessment of Science Students (QSASS) was the result, which examined 10 mathematical and statistical sub-topics. Second, the study established an evidential baseline of students' quantitative skills performance and confidence levels by piloting the QSASS with 187 final-year biosciences students at a research-intensive university. The study is framed within the planned–enacted–experienced curriculum model and contributes to science reform efforts focused on enhancing the quantitative skills of university graduates, particularly in the biosciences. The results found, on average, weak performance and low confidence on the QSASS, suggesting divergence between academics' intentions and students' experiences of learning quantitative skills. Implications for curriculum design and future studies are discussed.

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Quantitative skills; student performance; bioscience education; higher education; mathematics in science

## 1. Introduction

In the sciences, the ability to apply mathematical and statistical thinking and reasoning, typically referred to as quantitative skills, is an international expectation for university graduates, particularly in the biosciences (AAAS, 2011; Brown, 2009; Koenig, 2011; Matthews, Belward, Coady, Rylands, & Simbag, 2012; NRC, 2003) and underpins agreed-upon Australian outcome statements for science graduates (Yates, Jones, & Kelder, 2011). Students in science degree programmes favour biosciences majors in Australia, which comprise over half of enrolments (Chubb, 2012). While reform activities have been underway across Australian university science departments, embedding quantitative skills across biosciences curricula has proven challenging (Matthews et al., 2012). The interdisciplinary nature of quantitative skills complicates efforts with the applied nature of mathematics in science adding another layer of complexity onto the already complex topic of learning

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mathematics (Matthews, Adams, & Goos, 2009; Sriraman & English, 2010). Research is beginning to emerge specifically focused on quantitative skills in undergraduate science education.

The purpose of this study is to investigate the quantitative skills of final-year bioscience students using a purpose-built quantitative assessment task that captures both performance and confidence levels. Specifically, the study contributes (1) a quantitative skills assessment task purposely built for final-year bioscience students relevant to national statements on science graduate learning outcomes in Australia (Yates et al., 2011), and (2) an evidential baseline of the performance and confidence levels of final-year bioscience students. An understanding of what quantitative skills are expected of bioscience students and how students meet those expectations is lacking in both research and practice. Students are the intended beneficiaries of curriculum reform efforts. As a consequence, knowledge of their abilities and learning outcomes is vital. At present, such information is not informing science curriculum development. This study attempts to address this issue and argues for more coherent curriculum development in undergraduate science education to ensure students have sufficient and effective opportunities to develop their quantitative skills.

### *1.1. Quantitative skills performance and perceptions of science students*

Some studies have explored the quantitative skills performance of science students. For example, an empirical study at an American university revealed that the performance of 214 graduating biology students largely exceeded academics' expectations of what students could do (Hurney et al., 2011). In a study of 346 first-year biosciences students across seven universities in the United Kingdom (U.K.), completion of a performance task revealed students achieved higher marks on purely mathematical calculation problems compared to science contextualised problems (Tariq, 2008). However, the Australian body of research on science students' performance on quantitative tasks or mathematical performance at the level of the degree programme is sparse. What is emerging instead is a body of literature exploring science students' *perceptions* of their quantitative skills at the level of the degree programme. Such studies have found final-year science students report low perceptions of quantitative skills being included in the curricula (Matthews, Adams, & Goos, 2015; Varsavsky, Matthews, & Hodgson, 2014).

As highlighted in an Australian review, research on mathematics teaching and learning in science is limited with no recent research on the mathematical performance of university science students (Barton, Goos, Wood, & Miskovich, 2012). One factor inhibiting studies on the quantitative skills of Australian biosciences students is an understanding of what mathematical and statistical skills are needed (Matthews et al., 2012). Thus, whilst there is general consensus that quantitative skills are essential for university science students (Matthews et al., 2012; Yates et al., 2011), *what* quantitative skills should be expected of graduates have yet to be articulated.

### *1.2. Quantitative skills needed in biosciences degree programmes*

A nationally funded project in Australia interviewed 46 academics in science and mathematics departments across 13 university science degree programmes engaged in reform efforts to build quantitative skills, particularly in the biosciences (Matthews et al., 2012). The results of the study suggested the following:

> Statistics was seen as necessary in the life sciences and much effort was expended to build students' statistical skills. Other mathematics (not statistics) was discussed … much of it was at a very low level, often early secondary school. Over a third of the mathematics topics were about material taught in early or middle secondary school in Australia.
> (Rylands, Simbag, Matthews, Coady, & Belward, 2013, p. 839)

The state of quantitative skills taught in bioscience undergraduate education in the U.K., as described by Koenig (2011), reported similar mathematical topics to the Australian study.

> Statistics is the most commonly taught mathematical topic along with algebra, calculating concentrations and dilutions, and exponential equations and logarithms … Only approximately one third of degree programmes included topics such as calculus, differential equations and mathematical modelling. (p. 7)

In the U.S.A., collaborations amongst biologists and mathematicians resulted in the production of online modules designed to enhance quantitative skills, called MathBench Biology Modules, developed at the University of Maryland (Nelson et al., 2009; Thompson, Nelson, Marbach-Ad, Keller, & Fagan, 2010). The numerous modules were designed to complement introductory biology units and have been adopted by (approximately) 25 universities in the U.S.A. They are currently being adapted for use in Australian universities. MathBench comprises 26 modules that draw exclusively from precalculus mathematics, which offers an indication of the quantitative topics needed for biology students, including rates of change, probability, inferential and descriptive statistics, graphical representation, logarithms and scientific notation, and translating biological descriptions into mathematical equations or models (Nelson et al., 2009).

There have been strong arguments for the inclusion of calculus and more advanced mathematical topics in biology (NRC, 2003). While Hastings et al. (2005) acknowledge that mathematical biology majors are important for some bioscience students, they argue the need to link mathematics and life sciences authentically for the benefit of all bioscience students. In Australia, the national science graduate learning outcomes are underpinned by quantitative skills with the explicit expectation that all science students gain such a skillset (Matthews & Hodgson, 2012; Yates et al., 2011). However, as suggested above, what quantitative topics are needed has not been articulated.

### 1.3. Curricular framework

This study is framed within the broad, established model in primary and secondary school education of the *planned–enacted–experienced* curriculum. The Erickson and Shultz (1992) model has been utilised in various higher education studies (Aulls, 2004; Cook-Sather, 2006; Dvorakova & Matthews, 2016; Lerch, 2004; Matthews, 2014b; Matthews & Mercer-Mapstone, 2016; Zidon, 1996). The hallmark of the model is the relational emphasis of educators and students, which is considered across three levels. The first refers to what is *planned* or the intentions of the curriculum; that is, curricular goals or learning objectives. Next, the plan is put into action or *enacted* by educators who make decisions on content, pedagogy, and assessment. Students are the beneficiaries of teachers' actions and activities as they *experience* the curriculum and ideally achieve the intended learning outcomes.

For the purposes of this study, the model has been represented visually as a nested diagram (refer to Figure 1) and adapted to incorporate the educational context and the disciplinary nature of higher education that strongly influence the unfolding of curriculum and student learning experiences (Becher & Trowler, 1989; Trowler, Saunders, & Bamber, 2012). We apply this model at the meta-level of quantitative skills as a graduate learning outcome. Thus, quantitative skills are a goal of the science degree programme (the *planned* curriculum), intended to guide academics' teaching practices (*enacted* curriculum) that foster students' learning of quantitative skills (*experienced* curriculum).

## 2. Purpose of study

This study investigated the *experienced* curriculum of final-year bioscience students in regard to their quantitative skills. To do this, the broad *planned* curriculum of quantitative skills as a science graduate learning outcome had to be translated into a task whereby students could demonstrate their quantitative skills. The study is guided by the following research questions:

(1) What quantitative skills are expected of graduating biosciences students?
(2) How do graduating students perform on the expected quantitative skills?
(3) What are the confidence levels of students on the expected quantitative skills?

The study design allows for the examination of variation in performance and confidence across mathematical and statistical topics, and sub-topics.

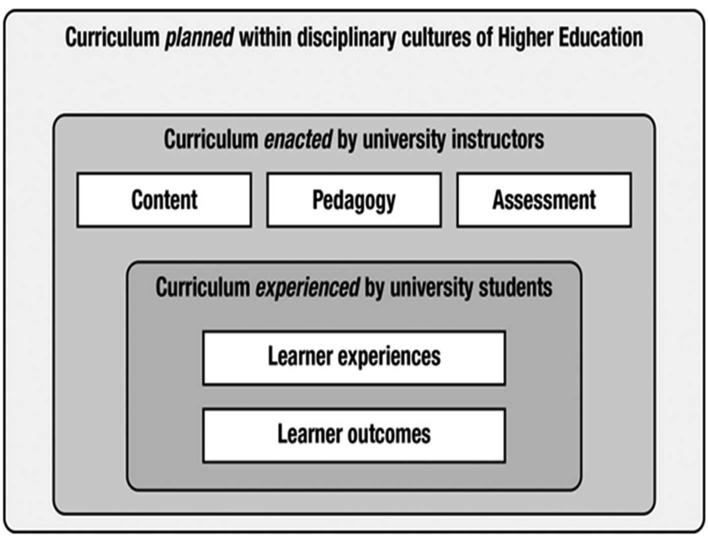


**Figure 1.** Curriculum framework guiding the research (Matthews et al., 2013).

## 3. Methods

### 3.1. Institutional and curricular context of study

The setting for this study was a research-intensive university in Australia. Entry into the science degree programme included a mathematics pre-requisite of passing a high school calculus-based mid-level mathematics subject. Quantitative skills were an explicitly stated graduate learning outcome for all science students. To realise this science-specific graduate learning outcome, several curriculum reform activities were implemented (McManus & Matthews, 2015). First, an introductory statistical unit was made compulsory for all science students. Second, a new, interdisciplinary first-year mathematics–science unit was developed and made highly recommended for all science students (Matthews, Adams, & Goos, 2010). Third, a final-year unit specific to each major was made compulsory for the purpose of integrating knowledge and skills from across the degree programme, including quantitative skills. Reform efforts focused on building a pathway of quantitative skills learning activities across the year levels in biosciences majors, extending from first-year quantitative skills units to upper-level biosciences units in second and third years.

### 3.2. Developing and validating a quantitative skills assessment task

To explore the broad science graduate learning outcome statements (*planned* curriculum), an assessment task that allowed students to demonstrate their quantitative skills (*experienced* curriculum) as a result of the *enacted* curriculum was needed. First, the literature was searched for existing quantitative skills performance tasks with none fitting the specific purposes of this study or the context of quantitative skills in the science curriculum being studied. However, existing statistical and mathematical tasks and modules offered potentially relevant questions that had been tested in previous studies (Delmas, Garfield, Ooms, & Chance, 2007; Nelson et al., 2009). Next, these potential questions were collected into a database. Then, four biologists, a statistician and a mathematician, all with experience teaching students in the science curriculum being studied, were consulted. Through an iterative process of development, consultation, and re-development with these academics, a quantitative assessment task was created. This involved multiple meetings to determine which questions addressed an important aspect of quantitative skills. If a question was judged to be important, then the question was discussed in regard to being appropriate in terms of the academics' expectations that final-year bioscience students should be able to answer. If so, then the question was considered with respect to what was actually being taught in the degree programme. Through this multiple-staged process, many questions were eliminated. Thus, the depth and scope of the questions were selected to align with the intended (*planned*) and *enacted* curriculum as articulated by academics who taught into the degree programme. Finally, the task was then piloted with approximately a dozen final-year students, followed by two focus groups to validate the clarity of the questions.

The Quantitative Skills Assessment of Science Students (QSASS) resulted from this process. Drawing on the *planned–enacted–experienced* curriculum, the general expectation would be that graduating bioscience students should be able to answer the questions.

### 3.3. The quantitative skills assessment task

The QSASS consists of 35 multiple-choice questions to be completed in one hour. The questions are grouped into two topics, displayed in Table 1 and presented in full (Matthews, 2014a).

The QSASS was not designed to test procedural knowledge or memory of rote-learned information. Instead, the intention was to explore students' application of mathematical and statistical reasoning. Thus, the QSASS did not test memorisation of concepts or attempt to 'trick' students. To align with the *intended curriculum*, the depth and scope of the questions were selected in consultation with academics familiar with the curriculum. Furthermore, the QSASS was not much more than school-level mathematics, which aligns with recent evidence suggesting the expected level of mathematical knowledge required for biosciences is typically low (Matthews et al., 2012). For example, a metric conversion question adopted from Nelson et al. (2009) asked students:

> The diameter of ribosomes start at about 11 nanometres. How many micrometres is this?

(A) .0011 micrometres
(B) .011 micrometres
(C) .11 micrometres
(D) 110 micrometres
(E) 1100 micrometres
(F) No clue

Given the emphasis on thinking and reasoning as opposed to rote-learned knowledge, information from MathBench (Nelson et al., 2009) was provided on the metric system to assist students in answering questions on metric conversions:

> The metric system is the numerical system of choice for scientists. It is based on powers of ten, which makes calculations and conversions simple and easy. The decimal measuring system uses the metre, litre, and gram (or kilogram) as units of length, volume and mass.

**Table 1.** Overview of QSASS including topic and sub-topic areas with corresponding number of questions.

| Topic | Sub-topic | Number of questions |
|---|---|---|
| Mathematical | Metric conversations | 2 |
| | Reading a pipette | 3 |
| | Logarithmic scales | 3 |
| | Serial dilutions | 2 |
| | *Total mathematical questions* | *10* |
| Statistical | Graphical representation of data | 8 |
| | Normal distributions | 2 |
| | Test of significance | 4 |
| | Correlation and causation | 3 |
| | Sampling | 5 |
| | Probability | 3 |
| | *Total statistical questions* | *25* |

> The metric vocabulary includes TERA (trillions), GIGA (billions), MEGA (millions), KILO (thousands), MILLI (thousandths), MICRO (millionths), NANO (billionths) and PICO (trillionths).
>
> The easiest way to convert metric measurements is to move the decimal place. Every time you move to the right on this list, the unit gets smaller (by 3 decimal places), so you need more of them to compensate (move the decimal place 3 to the right).

The statistical questions explored conceptual understanding of data and interpretation of statistical results. For example, students were asked the following question sourced from the Delmas et al. (2007) project:

> Researchers surveyed 1,000 randomly selected adults in the United States of America. A statistically significant, strong positive correlation was found between income level and the number of containers of recycling they typically collect in a week. Please select the best interpretation of this result.

(a) We can not conclude whether earning more money causes more recycling among U.S. adults because this type of design does not allow us to infer causation.
(b) This sample is too small to draw any conclusions about the relationship between income level and amount of recycling for adults in the U.S.
(c) This result indicates that earning more money influences people to recycle more than people who earn less money.

Following completion of the questions for each sub-topic, students were asked to indicate their level of confidence on a four-point alpha scale (*not at all confident*, *a little confident*, *moderately confident*, *very confident*).

### 3.4. Participants and data collection

In total, 211 final-year students participated in the study with 76% enrolled in a Bachelor of Science, 21% in a Bachelor of Biomedical Science, and 3% in either science dual degrees or named science degrees (e.g. Bachelor of Biotechnology). Male respondents (47%) were slightly less represented than females. Due to incomplete data, 187 responses were included in this study with 24 students (12.3%) excluded from analysis. Results were analysed in SPSS.

Students completed the QSASS in a supervised lecture theatre. As a low-stakes assessment task with no impact on students' academic outcomes, concerns about students' effort on the QSASS were considered. At the end of the assessment task, students completed questions that comprised a motivation scale, via subscales of importance and effort, used for low-stakes assessment tasks (Thelk, Sundre, Horst, & Finney, 2009). These results found the students' percentile rank for motivation was above average based on mid-Atlantic university norms. This indicates that students expended effort to complete the task.

### 3.5. Analysis

The number of correct answers for each student was calculated along with the percentages correct at the sub-topic, section and overall levels. Confidence was evaluated via the four-point alpha scale (1 = not at all confident; 2 = a little confident; 3 = moderately confident;

**Table 2.** Performance on the mathematical and statistical sections of the QSASS along with overall score, confidence indicators, and average scores and confidence.

| Overall mathematical score (10 questions) | | Overall statistical score (25 questions) | | Overall QSASS score (35 questions) | |
|---|---|---|---|---|---|
| # Correct (%) | Confidence | # Correct (%) | Confidence | # Correct (%) | Confidence |
| 7.4 (74.1) | 2.81 | 14.1 (56.2) | 2.74 | 21.5 (61.3) | 2.77 |

Note: Confidence scores were indicated on a four-point alpha Likert scale (1 = not at all confident; 2 = a little confident; 3 = moderately confident; 4 = very confident).

4 = very confident). The data were treated as continuous as per common practice in studies using scale items on surveys (Weng, 2004). The average confidence level was calculated from the responses of 187 participants for each sub-topic. Confidence at topic level was calculated for each student by summing sub-topic confidence indicators and dividing by four to give a confidence level for each topic, typical of subscale approaches in survey research. The overall confidence level was calculated for each student by summing all sub-topic confidence indicators and dividing by four. Average confidence for each topic and overall were then calculated.

Differences in confidence and performance were explored by comparing means using simple *t*-tests or ANOVAs. Statistically significant differences were determined using the commonly accepted threshold of 0.05.

## 4. Results

Table 2 displays an overall QSASS average score of 61.3% for 187 participants with a range of 34–89%. The average score for the mathematical section was 74.1% with a range of 20–100%. The average score for the statistical section was 56.2% with a range of 28–88%. Overall, participants performed significantly better on the mathematics questions when compared to the statistics questions on the QSASS by a difference of 6.7 points, $t(184) = 13.00$, $p < .001$. On average, students indicated a slightly higher level of confidence in mathematics than statistics, although this difference was not statistically significant, $t(201) = 1.53$, $p = .13$.

Performance on the four mathematical sub-topics presented in Table 3 highlights substantial variation in performance and confidence. Students demonstrated their ability to read a pipette with an average score of 94.8%, which represents the highest score for any sub-topic examined by the QSASS (all $p < .001$). On average, students expressed the highest level of confidence in this area (3.40 on a 4.0 scale) relative to all QSASS sub-topics (all $p < .001$). Although student performance was poorest on metric conversions with an average score of 60%, their confidence in this sub-topic

**Table 3.** Performance on mathematical sub-topics of the QSASS, topic-specific confidence indicators, and average scores and confidence.

| | Metric conversions (2 questions) | | Reading a pipette (3 questions) | | Logarithmic scales (3 questions) | | Serial dilutions (2 questions) | |
|---|---|---|---|---|---|---|---|---|
| | # Correct (%) | Confidence scale | # Correct (%) | Confidence scale | # Correct (%) | Confidence scale | # Correct (%) | Confidence scale |
| Average | 1.2 (60) | 3.12 | 2.84 (94.8) | 3.40 | 2.13 (71) | 2.25 | 1.25 (62.7) | 2.46 |

**Table 4.** Performance on statistics sub-topics of the QSASS, topic-specific confidence indicators, and average scores and confidence.

| | Graphical representation (8 questions) | | Normal distribution (2 questions) | | Tests of significance (4 questions) | | Correlation and causation (3 questions) | | Sampling (5 questions) | | Probability (3 questions) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | # Correct (%) | Confidence scale | # Correct (%) | Confidence scale | # Correct (%) | Confidence scale | # Correct (%) | Confidence scale | # Correct (%) | Confidence scale | # Correct (%) | Confidence scale |
| Average | 5.25 (65.7) | 2.87 | 0.99 (49.3) | 2.55 | 2.51 (62.9) | 2.96 | 1.36 (45.4) | 2.82 | 2.73 (55.0) | 2.59 | 1.35 (44.8) | 2.64 |

was significantly higher than their confidence in logarithmic scales and serial dilutions ($p < .001$).

The six statistical sub-topics, as shown in Table 4, proved more challenging with students performing significantly better in graphical representation (65.7%) and test of significance (62.9%) relative to other statistical sub-topics (all $p < .001$). The students indicated, on average, highest confidence levels for test of significance when compared to the other statistical sub-topics (all $p < .03$). Students performed worst in the areas of normal distribution (49.3%), correlation and causation (45.4%), and probability (44.8%) with little difference in scores on these sub-topics. Overall, students expressed moderate levels of confidence across all statistical areas.

## 5. Discussion

Interpreting the findings of these results is difficult given the dearth of existing empirical research in the context of bioscience students at the whole of degree programme level. The discussion is framed around interpreting the results through the *planned–enacted–experienced* curriculum model, and draws on broader mathematics and science education research, primarily at the tertiary levels.

The QSASS questions were selected to align with the *enacted* curriculum through consultation with academics teaching into the science degree programme. As a graduate learning outcome it would be expected that most final-year students would perform in the 75% or above quartile on a quantitative skills assessment task purpose-built to align with the biosciences curriculum. This was because the QSASS questions were not designed to test memorisation of concepts and did not include any ‘tricks’. Furthermore, the QSASS was not designed to categorise students into different grades based on their individual performance. As a consequence, it was the considered belief of the academic question writers that most or all graduating students would be able to answer most or all questions correctly. This belief was also based on the pre-requisite level of mathematical knowledge required for entry into the BSc. Thus, it is reasonable to expect that the average scores would be high. Overall, the results revealed weak quantitative skills amongst students in this study in the context of the QSASS. Average scores in the top quartile (75–100%) were observed in only one sub-topic (reading a pipette) with average scores below 50% found for three sub-topics (normal distribution; correlation and causation; probability). Drawing on the *planned–enacted–experienced* model, these results suggest a divergence, or misalignment, between academics’ intentions for, and students’ experience of learning, quantitative skills in the degree programme. Thus, the low QSASS results indicate that students’ *experienced curriculum* was not aligned with the *planned curriculum* of academics in this study. The intersection of academic goals for learning and students’ opportunities to learn is the *enacted curriculum*. The discussion explores potential explanations between the apparent misalignment in regard to the quantitative skills presented in the QSASS and the performance of students within the *enacted curriculum*.

One potential explanation is that the academics consulted were a small subset of those teaching into the biosciences units, and they were not representing the broader curriculum. Thus, the selected QSASS questions were possibly not aligned to the *enacted* curriculum. Recall, the QSASS questions drew on precalculus mathematical knowledge typically included in upper middle and lower secondary school years in Australia. This suggests, that whilst the selected questions might not have been aligned to the *enacted* curriculum, the questions were not introducing new mathematical knowledge. Furthermore, the structure of the curriculum required students in this study to complete a first-year statistics unit and offered a first-year mathematics applied in science unit. Although a final-year unit within each of the biosciences major was also a requirement to graduate, it is not clear the extent to which quantitative skills were included in these units. The biomedical sciences major capstone unit included a substantial quantitative skills assessment task requiring statistical design and analysis. Students struggled with the task. After discussions with discipline-based colleagues, the unit coordinators realised students had few opportunities to practise statistical design and analysis in their upper-level biomedical sciences units. This indicated a lack of progressive development of quantitative skills from first to second to third-year units. This latter point highlights how the *enacted* curriculum could have been misaligned with the *planned* curriculum as represented by the QSASS.

While first-year units were dedicated to quantitative skills in the curriculum, the extent to which upper-level bioscience units taught and assessed quantitative skills comes into question. An Australian study that produced 13 case studies that mapped quantitative skills across science degree programmes, mostly within biosciences majors and including the university where the present study was conducted, found academics were more likely to identify explicit inclusion of quantitative skills in first-year units compared to upper-level units (Matthews, Belward, Coady, Rylands & Simbag, 2016). The students in this study completed a required first-year statistics unit, suggesting that students had opportunities to gain quantitative skills. The possible misalignment in the *enacted* curriculum could potentially be explained by a lack of progressive, coherent development of those quantitative skills from first to final year. Thus, the skills established in first year were not utilised in upper-level units. The case study of quantitative skills across the curriculum (Matthews, Belward, et al., 2016) specific to the university in this study would confirm that quantitative skills were more included in first-year units than upper-level biosciences units.

Another potential explanation for the misalignment between the *planned* and *experienced* curriculum is the applied nature of the QSASS questions, which assumed students could transfer mathematical knowledge to bioscience contexts. Implicit in the science degree programme structure for students in this study was the notion that students would transfer mathematical knowledge gained from secondary school, and the first-year quantitative units, to other biosciences units. Although the QSASS drew on school level, precalculus mathematical knowledge, most of the questions were applied. A small scale study of Australian university science students' abilities to apply mathematics found that they struggled to transfer known mathematical knowledge to science contexts in first year (Britton, New, Sharma, & Yardley, 2005). The Tariq (2008) study with U.K. first-year bioscience students also found students struggled to transfer mathematics to the bioscience, although the reason differed (students lacked mathematical knowledge). Thus, the low results of the QSASS suggest that transfer could be an issue for the final-year students in this study.

The QSASS also explored confidence by sub-topic. Studies of confidence are emerging in the context of the biosciences in Australia (Matthews, Hodgson, & Varsavsky, 2013). An Australian study found 39.5% of 400 science students reported low levels of confidence in their quantitative skills prior to graduation (Varsavsky et al., 2014). The study also explored other science graduate learning outcomes (e.g. content knowledge, ethical thinking, and communication skills) and found the graduate outcome with the lowest levels of confidence was quantitative skills. Given this study and the overall low performance on the QSASS, it is unsurprising that students reported low-confidence levels with 8 of the 10 sub-topics receiving an average confidence below 3.0 on a 4.0 scale.

The patterns of confidence and performance levels found in this study are worthy of attention. Analysis shows the highest performed sub-topic (reading a pipette) also had the highest confidence level amongst the 10 sub-topics. However, this pattern of high performance and high confidence does not continue, with the second highest performing sub-topic (logarithmic scales) receiving the lowest confidence score amongst all the sub-topics. The results show only a few instances of general alignment between levels of confidence and performance. This suggests that the *enacted* curriculum was not allowing students to gain insight into their own quantitative skills performance, such that they could not judge accurately their confidence on quantitative topics.

Given the intention of this study (to established an evidential baseline of performance and confidence in quantitative skills), correlating confidence with performance has been the focus of another study (Matthews, Adams, & Goos, 2016).

## 6. Limitations

The findings of the study should be interpreted with consideration of two limitations. First, the research was conducted at a single institution with a specific institutional environment and student population. Thus, generalisation of findings should be done only with careful consideration of the educational context. Second, the QSASS, a purpose-built data collection instrument, should not be interpreted as a general measure of quantitative skills. The questions were selected and developed for the specific context being studied with the intent of aligning questions to the curriculum under investigation.

## 7. Implications and conclusion

This study was conducted in a university with an explicit goal to build students' quantitative skills in science degree programmes. Drawing on the *planned–enacted–experienced* curriculum model, the results have implications for curriculum development. Recent research suggests that quantitative skills are not highly visible to students across the degree programme (Varsavsky et al., 2014) with science academics reporting limited inclusion of quantitative skills across the curriculum (Matthews, Adams, et al., 2015). Reform efforts to build quantitative skills across science degree programmes can take years to impact on students (Matthews, Adams, et al., 2015; Thompson et al., 2013). As a complex outcome of learning, opportunities to practise and gain mastery of quantitative skills will require a coherent, progressive development approach across units of study and year levels (Knight, 2001; Mercer-Mapstone & Matthews, 2015). Assessment regimes should focus on building mastery to enhance confidence (Bandura, 1982) while also allowing students to make evaluative judgements about, and take responsibility for, their own learning (Boud, 2000; Sadler, 1989).

The study makes two important contributions to an under-researched, yet vital and relevant, area of inquiry within the tertiary science education field. First, it shows examples of quantitative skills expected in the biosciences at one research-intensive university through the QSASS, which was developed in consultation with academics and is relevant to the broader Australian statements of science graduate learning outcomes (Yates et al., 2011). Second, the results established an evidential baseline of final-year students' performance and confidence in their quantitative skills. Replicating this study at the same institution, and in other contexts, is a worthwhile direction for future research. Examining results by demographic variables (e.g. gender, age) would be beneficial. Moreover, qualitative studies focused at the intersection of the bioscience learner and science curriculum in regard to specific quantitative topics at the tertiary level would advance the field with a particular focus on the transfer of mathematical knowledge to bioscience contexts.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

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