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The Influence of Undergraduate Science Curriculum Reform on Students' Perceptions of their Quantitative Skills

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In this study, the Science Student Skills Inventory was used to gain understanding of student perceptions about their quantitative skills and compare perceptions of cohorts graduating before and after the implementation of a new science curriculum intent on developing quantitative skills. The study involved 600 responses from final-year undergraduate science students across four cohorts in an Australian research-intensive institution. Students rated their perceptions on a four-point Likert scale of: the importance of developing quantitative skills within the programme, how much they improved their quantitative skills throughout their undergraduate science programme, how much they saw quantitative skills included in the programme, how confident they were about their quantitative skills, and how much they believe they will use quantitative skills in the future. Descriptive statistics indicated overall low levels of perceptions with student perception of the importance of quantitative skills being greater than perceptions of improvement, inclusion in the programme, confidence, and future use. Statistical analysis of responses provided by the cohorts graduating before and after the new quantitative skills-intended curriculum revealed few differences. The cohorts graduating after implementation indicated that quantitative skills were included more in the curriculum, although this did not translate into them reporting higher levels of confidence or anticipated future use compared to the cohorts that graduated before the new curriculum was implemented. Implications for curriculum development are discussed and lines for further research are given.

Keywords: *Quantitative skills; Learning gains; Undergraduate science; Student perceptions; Curriculum development*

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1. Introduction

There is international agreement that quantitative skills are essential for science and are an expected learning outcome from university science degree programmes. For example, in the USA, professional and academic organisations along with government associations are calling for better prepared science graduates, specifically graduates confident and competent in scientific applications of mathematics and statistics (AAAS, 2011; AAMC, 2009; Augustine, 2007; NRC, 2003, 2009). In the UK, the lack of quantitative skills is also being lamented with calls for urgent educational reform at the national level (Fazackerley & Richmond, 2009; Koenig, 2011). In Australia, the issues of declining mathematical preparedness of students entering university and the subsequent flow-on effects for quantitative disciplines, including the sciences, are of national concern (Brown, 2009; Chubb, 2012; Lyons & Quinn, 2010; Rubinstein, 2009).

As the calls for better prepared science graduates with improved quantitative skills continue, science and mathematics departments in universities are struggling to reform curriculum accordingly, particularly in the life sciences (AAAS, 2011; AAMC, 2009; Brakke, 2011; Koenig, 2011; Matthews, Belward, Coady, Rylands, & Simbag, 2012; Matthews, Adams, & Goos, 2009, 2010; NRC, 2003, 2009). Little research has explored students' beliefs about their quantitative skills at the level of the degree programme, despite numerous international calls to reform university science curriculum. Insight into how science students are experiencing their undergraduate studies is needed to inform these on-going reform efforts.

1.1. *Quantitative Skills in Science*

Quantitative skills refer to the application of mathematical and statistical thinking and reasoning within a given external context, and can be thought of in terms of quantitative reasoning (as defined by AAMC, 2009) or mathematical literacy (as defined by OECD, 2003), as both definitions include the notion of application with an eye to connecting mathematics to life beyond the classroom.

In Australia, attention has been drawn to the undergraduate science curriculum by reaching consensus on desired learning outcomes at the level of the science degree programme, referred to as the Science Threshold Learning Outcomes (Yates, Jones, & Kelder, 2011). These outcomes are underpinned by quantitative skills. The challenges of curriculum reform to build quantitative skills have been investigated in Australia from the perspective of academics and revealed a broad spectrum of curriculum design models across institutions, a lack of confidence of science curriculum leaders to integrate quantitative skills effectively from first- to final-year levels, and a dearth of evidence on students' quantitative skills being used to inform curriculum reform activities (Matthews et al., 2012). A study investigating how quantitative skills were included across 13 science degree programmes with a focus on specialisations in life sciences revealed how little quantitative skills were taught or assessed (Matthews, Belward, Coady, Rylands, & Simbag, in press). The study drew on interviews with multiple academics at each institution, including 11 Australian universities. Comparative analysis across the degree programmes found a general pattern of quantitative skills being more included in first-year units with a decline in second-year units and a further decline in third-year units (Matthews et al., in press).

Studies from the perspective of university science students are now emerging. For example, a recent study outlining teaching and learning efforts to build quantitative skills in the life sciences at a university in the USA found graduating students' beliefs about the importance of quantitative skills steadily increased over a six-year period (Thompson et al., 2013). An in-depth qualitative study at the same university concluded that students' epistemological beliefs about quantitative skills are context-dependent and dynamic (Watkins & Elby, 2013). However, instructional strategies to build positive perceptions of quantitative skills are not clear. The use of research case studies was found to be an ineffective instructional strategy for instilling the importance of quantitative skills in a first-year statistics unit (Familari, Elliott, Watson, & Matthews, 2012). The pre-post survey revealed a decline in students' perceptions of the relevance of quantitative skills in science from the beginning to the end of the unit. However, efforts to design interdisciplinary first-year units in which mathematics is applied in science have demonstrated positive outcomes in raising science students' perceptions of the role of quantitative skills (Gyuris, Everingham, & Sexton, 2012; Matthews et al., 2009). One study demonstrated how real-world case studies of quantitative skills in science improved biology students' perceptions of the importance of quantitative skills (Matthews et al., 2010).

The literature reveals a range of recently emerging empirical investigations, mainly at the level of individual units of study. Until recently, studies in which quantitative skills have been investigated at the level of the science degree programme have only been conducted in the USA. An empirical investigation of final-year Australian university science students' perceptions of their learning gains revealed that quantitative skills were not as visible to students as other science learning outcomes such as scientific content knowledge, writing skills, oral communication, or team-work skills (Varsavsky, Matthews, & Hodgson, 2014). More importantly, this study suggested, 'these perceptions seem to be a reflection of the curriculum' (Varsavsky et al., 2014, p. 946). The authors indicated that quantitative skills as an expected learning outcome for university science students 'stood out' from other outcomes and warranted further investigation.

2. Purpose of Study

The purpose of this study is to address the scarcity of research on quantitative skills developed in the context of a whole science undergraduate programme, and to begin to understand how curriculum reform efforts to build quantitative skills influence students' perceptions. We gathered data from four graduating cohorts of final-year science students over a four-year period from the same university, using the Science Students Skills Inventory (SSSI) with a focus on student perceptions of quantitative skills.

The specific research questions addressed in this study are

(1) What perceptions do graduating science students have of the importance of having developed their quantitative skills during their degree programme? What is their perceived confidence and improvement in quantitative skills, and to what extent do they believe quantitative skills were included in their degree programme and will be used in the future?
(2) How do these student perceptions of quantitative skills change with the implementation of a new science curriculum intent on developing quantitative skills?

3. Methodology

3.1. *The Study Context*

The study was situated within an Australian research-intensive university ranked in the top 100 universities worldwide (e.g. Times Higher Education World University Rankings, Quacquarelli Symonds World University Rankings). The Bachelor of Science (BSc) degree programme underwent an extensive curriculum review followed by the implementation of a new degree programme intent on enhancing students' quantitative skills. The 'new BSc' degree programme was more structured than the 'old BSc' by requiring students to complete a statistics unit in first-year and a final-year unit (referred to as a capstone unit) designed to bring together knowledge and skills in each major. In addition, a new first-year unit applying mathematics in science was developed and highly recommended to all science students with approximately half of BSc students enrolling in the unit. While many Australian universities have removed the requirement for high school mathematics for entry into science degree programmes (Belward et al., 2011), the BSc review process maintained the institutional requirement for students to have previously completed high school level, calculus-based mathematics.

3.2. *The Survey*

The SSSI instrument is specific to science and explores how the whole science degree programme contributes to the development of several science skills, including quantitative skills. The SSSI has been published previously, including information on its validity and reliability (Matthews & Hodgson, 2012) and used in published research (Matthews, Hodgson, & Varsavsky, 2013; Varsavsky et al., 2014). This study drew on a subset of the full instrument with respect to quantitative skills. Cronbach's Alpha was calculated for data from this part of the survey (0.81) and demonstrated robust internally consistent reliable variance.

The survey elicited students' perceptions of their own quantitative skills and the role of quantitative skills in the science programme, on a four-point Likert scale, across five indicators.

- How *important* is it to have activities that develop quantitative skills in the science programme (from 1 = not at all important, to 4 = very important).
- The level of *improvement* they made regarding quantitative skills as a result of the overall science programme (from 1 = no improvement, to 4 = a great deal of improvement).
- To what extent activities to develop the quantitative skills were *included* in their science programme (from 1 = not included at all, to 4 = included a lot).
- To what extent they felt *confident* with their quantitative skills as a result of the science programme (from 1 = not at all confident, to 4 = very confident).
- Five years after they graduate from the science programme, how much do they believe they will *use* the quantitative skills (from 1 = not at all, to 4 = a lot).

The SSSI also asked students to self-rate their own quantitative skills, in addition to self-ratings of mathematical, statistical, and programming skills, as a result of the science programme on a 7-point Likert scale (from 1 = very poor, to 7 = very good) that mirrors the 7-point grading scale of the university in the study. Students were then prompted to identify units at each year level that required them to use their quantitative skills. The SSSI also collected demographic information from students: gender, age, and intentions after graduation (employment, postgraduate studies (research or other), or no plans yet).

3.3. *Data Collection and Participants*

The survey was administered online to four cohorts of students undertaking their final semester of the BSc over a four-year period at the same institution. The selection strategy aimed to reduce influences from outside the institution's science curriculum. The following criteria were applied:

- Only single degree BSc students (no dual or double degree enrolled students).
- No more than one semester of transfer credit from another university.
- Full-time enrolment graduating within five years of entering the programme.

In total, 600 useable surveys ($n = 107$ in Cohort 1; $n = 163$ in Cohort 2; $n = 176$ in Cohort 3; $n = 154$ in Cohort 4) were included in the study after removing partially completed surveys or those surveys from students who did not meet the above criteria, which represents 52% of all surveyed students. Cohort 1 students were not presented with the *Future Use* question as it was added to the SSSI in the following year. Of the 600 respondents, 81.5% reported a life sciences field of study, which was consistent across the four cohorts (Cohort 1 = 80.0%; Cohort 2 = 81.0%; Cohort 3 = 80.1%; Cohort 4 = 84.4%). The data set included 56% female students, 93% in the 19–22 age bracket, and 81% intending to pursue post-graduate studies following graduation. Descriptive statistics are presented for gender (Table 1), age group (Table 2), and post-graduate plans (Table 3) by cohort.

Table 1. Percentage of gender by cohorts

	Male (%)	Female (%)
Cohort 1	37.4	62.6
Cohort 2	41.7	58.3
Cohort 3	42.6	57.4
Cohort 4	51.9	48.1

3.4. *Data Analysis*

Descriptive statistics of the five indicators of importance, improvement, confidence, inclusion, and future use were examined for each cohort. The SSSI captures both ordinal and continuous data. For categorical (ordinal) data, the percentages of responses were added to create two categories for 4-point Likert scales following the procedure of Wyer (2003). These were low (two lower points of agreement [*not at all; not very*] on a four-point scale) and high (two higher points of agreement [*moderate; a great deal*] on a four-point scale) categories. Previous research employing the SSSI has used this analytic method (Matthews et al., 2013; Varsavky et al., 2014).

The ages (χ^2 (12) = 17.230, p = .14), gender (χ^2 (3) = 6.330, p = .10), and post-graduate plans (χ^2 (12) = 14.905, p = .25) of the four cohorts were not found to be statistically significantly different, which was anticipated given the similar entry requirements into the BSc over the duration of the study and the homogeneous nature of the student cohorts enrolling in science degrees at the institution being studied. The homogeneity of the cohorts was seen to reduce the confounding factors when comparing across cohorts. Thus, the two cohorts graduating from the BSc prior to the implementation of the curriculum review (Cohorts 1 and 2) were grouped together into a single new variable, 'old BSc'. The two cohorts graduating from the BSc post the implementation of the new curriculum (Cohorts 3 and 4) were grouped together into a single new variable, 'new BSc'. This grouping facilitates comparison of students' perceptions based on their experiences of the BSc before and after implementation of the review recommendations.

However, grade point average (GPA) between cohorts (χ^2 (2) = 12.987, p = .002) was found to be statistically significantly different with students in the 'old BSc' cohorts reporting higher GPAs than students in the 'new BSc' cohorts. Thus, the

Table 2. Percentage of age bracket by cohorts

	Cohort 1 (%)	Cohort 2 (%)	Cohort 3 (%)	Cohort 4 (%)
Age 19	8.7	14.7	14.2	11.0
Age 20	57.7	58.3	64.2	56.5
Age 21	24.0	16.0	9.7	16.2
Age 22	1.9	5.5	4.5	7.1
23 and older	7.7	5.5	7.4	9.1

Table 3. Percentage of post-graduate plans by cohorts

	Cohort 1 (%)	Cohort 2 (%)	Cohort 3 (%)	Cohort 4 (%)
Job not in science	1.9	0.6	4.0	1.9
Postgraduate or further study	80.4	86.5	77.3	77.9
Job in science	11.2	4.9	7.4	6.5
Other	2.8	5.5	6.8	7.1
Not sure	3.7	2.5	4.5	6.5

variable of 'GPA' is taken into consideration when interpreting any differences in students' perceptions across the old BSc and the new BSc.

To investigate how students' perceptions changed with the implementation of a new science degree programme, Pearson's chi-square tests for independence was used (following the procedure of Muehlenkamp, Williams, Gutierrez, & Claes, 2009). This is an appropriate analysis technique for ordinal data, used to explore changes in students' perceptions for each of the five indicators across the 'old BSc' and the 'new BSc'. For continuous data (self-ratings, number of units), mean and standard deviations were calculated. Independent *t*-tests were used to compare means between students in the 'old BSc' and 'new BSc'. Analysis employed the commonly established threshold of $p < .05$ for statistical significance. All statistical analysis was completed using SPSS version 20 (Professional).

4. Findings

4.1. *Perceptions of Importance of Quantitative Skills as a Result of Science Curriculum*

Overall, 88.3% of students across the four years indicated a high level of perceived importance for quantitative skills activities in the science curriculum (see Table 4). These results changed very little from the old BSc cohorts (87.1%) to the new BSc cohorts (88.8%). Pearson's chi-square analysis, χ^2 (1) = 0.147, $p = .70$, revealed no statistically significant difference between the old and new BSc cohorts by perception of importance.

Table 4. Cross tabulation of old and new BSc cohorts by perceptions of importance of quantitative skills

		Importance		
Curriculum		Low	High	Total
Old BSc	Count	33	237	270
	% within cohort	12.2%	87.8%	100.0%
New BSc	Count	37	293	330
	% within cohort	11.2%	88.8%	100.0%
Total	Count	70	530	600
	% within cohort	11.7%	88.3%	100.0%

4.2. *Perceptions of Improvement of Quantitative Skills as a Result of Science Curriculum*

Overall, 67% of students across the four years indicated a high level of perceived improvement in their quantitative skills as a result of the science curriculum (see Table 5). These results increased from the old BSc cohorts (62.6%) to the new BSc cohorts (70.6%). Pearson's chi-square analysis, χ^2 (1) = 4.313, p = .04, revealed a statistically significant difference between old and new BSc cohorts by perception of improvement in quantitative skills.

4.3. *Perceptions of Inclusion of Quantitative Skills in the Science Curriculum*

Overall, 61.6% of students across the four years indicated a high level of perceived inclusion of learning activities involving quantitative skills in the science curriculum (see Table 6). These results increased from the old BSc cohorts (53%) to the new BSc cohorts (68.7%). Pearson's chi-square analysis, χ^2 (3) = 15.513, p = .001, revealed a statistically significant difference between old and new BSc cohorts by perception of inclusion of quantitative skills.

4.4. *Perceptions of Confidence in Quantitative Skills as a Result of Science Curriculum*

Overall, 59.4% of students across the four years indicated a high level of perceived confidence in their quantitative skills as a result of the science curriculum (see Table 7). These results changed little from the old BSc cohorts (56.7%) to the new BSc cohorts (61.7%). Pearson's chi-square analysis, χ^2 (3) = 1.560, p = .21, revealed no statistically significant difference between old and new BSc cohorts by perception of confidence in quantitative skills.

4.5. *Perceptions of Future use of Quantitative Skills*

Overall, 51.3% of students across the three years indicated a high level of perceived future use of quantitative skills (see Table 8). Recall, participants in Cohort 1 were

Table 5. Cross-tabulation of old and new BSc cohorts by perceptions of improvement of quantitative skills in the science curriculum

		Improvement		
Curriculum		Low	High	Total
Old BSc	Count	101	169	270
	% within cohort	37.4%	62.6%	100.0%
New BSc	Count	97	233	330
	% within cohort	29.4%	70.6%	100.0%
Total	Count	198	402	600
	% within cohort	33.0%	67.0%	100.0%

Table 6. Cross-tabulation of old and new BSc cohorts by perceptions of inclusion of quantitative skills in the science curriculum

		Inclusion		
Curriculum		Low	High	Total
Old BSc	Count	127	143	270
	% within cohort	47.0%	53.0%	100.0%
New BSc	Count	103	226	329
	% within cohort	31.3%	68.7%	100.0%
Total	Count	230	369	599
	% within cohort	38.4%	61.6%	100.0%

not asked this question. These results changed very little from the old BSc cohorts (49.1%) to the new BSc cohorts (52.4%). Pearson's chi-square analysis, χ^2 (1) = 0.489, $p = .49$, revealed no statistically significant difference between old and new BSc cohorts by perception of using quantitative skills in the future.

4.6. *Self-Rating of Quantitative Skills*

The mean value of self-rated quantitative skills was 4.63 on a 7-point scale for respondents across the cohorts. This was higher than their mean self-rating of mathematical skills (4.53), statistical skills (4.15), and programming skills (3.52). Respondents from the new BSc reported slightly higher mean self-ratings for programming skills (3.55 compared to 3.48 in the old BSc), while reporting lower means for quantitative skills (4.57 compared to 4.69 in the old BSc), mathematical skills (4.43 compared to 4.66 in the old BSc), and statistical skills (4.03 compared to 4.30 in the old BSc) (see Table 9). Independent *t*-test analysis between the old and new BSc cohorts for each self-rating revealed statistical skills to have the only statistically significant difference, with the new BSc cohorts reporting a lower perception of their statistical skills, which is surprising given the requirement to complete a compulsory statistics unit in the new curriculum.

Table 7. Cross-tabulation of old and new BSc cohorts by perceptions of quantitative skills confidence

		Confidence		
Curriculum		Low	High	Total
Old BSc	Count	117	153	270
	% within cohort	43.3%	56.7%	100.0%
New BSc	Count	126	203	329
	% within cohort	38.3%	61.7%	100.0%
Total	Count	243	356	599
	% within cohort	40.6%	59.4%	100.0%

Table 8. Cross-tabulation of old and new BSc cohorts by perceptions of the use of quantitative skills in the future

		Future use		
Curriculum		Low	High	Total
Old BSc	Count	83	80	163
	% within cohort	50.9%	49.1%	100.0%
New BSc	Count	157	173	330
	% within cohort	47.6%	52.4%	100.0%
Total	Count	240	253	493
	% within cohort	48.7%	51.3%	100.0%

4.7. *Units of Study Requiring Quantitative Skills at Each Year Level*

The total number of units listed at year level was calculated for each respondent. Across all cohorts, respondents cited the most quantitative skills units at first-year level (mean of 2.42), then a decrease at second-year level (mean 2.05), and a further decrease at third-year level (mean of 1.81). Both the old and new cohorts reported more quantitative skills units at first-year level compared to second- and third-year levels (see Table 10). The new BSc cohorts indicate a sharper decline in quantitative skills units at second-year level (2.53 units at first year reducing to 1.97 second-year level units, compared to 2.29 reducing to 2.16 from first to second year in the old BSc). However, the new BSc cohorts reported more quantitative skills units at third-year level than the old BSc cohorts. Independent *t*-test analysis revealed a statistically significant difference between the old and new cohorts in terms of the number of quantitative skills units identified at third-year level.

5. Discussion

Although mere possession of a qualification contributes to finding employment, employers are increasingly interested in the skills gained from a degree programme (Yorke & Knight, 2006). Quantitative skills are essential for participation in the

Table 9. Comparison of old and new BSc cohorts by self-ratings of quantitative skills

	Old BSc		New BSc		
Self-rating	Mean	SD	Mean	SD	*t*-Statistic
Quantitative skills	4.69	1.34	4.57	1.35	1.053
Mathematical skills	4.66	1.41	4.43	1.55	1.846
Statistical skills	4.30	1.41	4.03	1.49	**2.209**
Programming skills	3.48	1.74	3.55	1.63	−0.509

Note: Bold indicates a statistically significant difference ($p < .05$).

Table 10. Comparison of old and new BSc cohorts by number of quantitative skills units at each year level

	First-year units			Second-year units			Third-year units		
Curriculum	Mean	SD	*t*-Statistic	Mean	SD	*t*-Statistic	Mean	SD	*t*-Statistic
Old BSc	2.29	1.63	−1.592	2.16	1.56	1.310	1.62	1.51	**−2.691**
New BSc	2.53	1.92		1.97	1.79		1.96	1.55	

Note: Bold indicates a statistically significant difference ($p < .05$).

scientific and science-dependent workforce (e.g. allied health or medical-related professions). This study gives an insight into how students perceive the development of quantitative skills in the context of science studies across their whole degree programme, as they approach graduation, and how these perceptions change with the implementation of new curriculum explicitly designed with quantitative skills as a graduate learning outcome.

5.1. *Perceptions of Quantitative Skills of Final-Year Students*

Of those 600 students participating in the study, the results of this study suggest that the vast majority of graduating science students appreciate the important role of quantitative skills in science. These findings are similar to a recent study comparing SSSI results from two universities (Varsavsky et al., 2014). Given the role of mathematics (including statistics) in science, one would expect science graduates to report high perceptions of its importance. Beliefs about importance have been associated with students' motivation and effort towards learning within a curriculum (Lattuca & Stark, 2011), making it a common variable in studies of perception. However, students have been found to repeat the rhetoric espoused by teachers (Schoenfeld, 1989) and care should be taken when interpreting students' perceptions of importance. Thus, the high perceptions of importance indicated by students are informative but insufficient, which is why multiple perceptual indicators were explored in this study.

One could argue that, for quantitative skills to be developed, opportunities to learn quantitative skills must be included in the curriculum. However, it appears that opportunities to learn quantitative skills were not sufficiently integrated or visible in the curriculum from the perspective of many students as indicated by 38% of respondents reporting quantitative skills were not included at a high level in the BSc. This finding is similar to the Varsavsky et al. (2014) study. To further explore the inclusion of quantitative skills in the science curriculum in this study, students identified units that required them to utilise their quantitative skills across each year level. The findings of the SSSI reveal a perception that the number of units requiring quantitative skills declined from the first to the third year. On average, students indicated 2.42 of their first-year units emphasised quantitative skills (out of eight units). By second year, they reported that 2.05 units required them to use quantitative skills, which dropped down to just 1.81 units in the third year (with a total of eight units required for each year level).

The study design does not provide an explanation for why some students indicated inclusion of quantitative skills in the undergraduate curriculum more than others. One potential explanation is that quantitative skills were genuinely lacking in the degree programme. More than half of students enrolled in the BSc graduated with a life sciences major, a feature repeated across the four cohorts involved in this study. This is also a common trend across Australian science degree programmes (Chubb, 2012). Life sciences have gained the reputation for being non-quantitative compared to other science disciplines (Matthews et al., 2009), suggesting quantitative skills may have been lacking inclusion in the curriculum for students in life science majors. Another potential explanation is the flexible nature of the science curriculum, which offers students a plethora of unit choices and hence the potential to avoid, or select more, quantitative units according to their preference. Mathematics anxiety has been documented in science students, suggesting that some students do actively avoid quantitative subject matter (LeBard, Thompson, Micolich, & Quinnell, 2009). Finally, perhaps the students who perceived low inclusion of quantitative skills were not as able to recognise when and where quantitative skills were being taught and assessed in the science curriculum, particularly when embedded within science units. Research investigating science students' conceptions of quantitative skills would enrich the literature in this area.

Given that 38% of respondents reported low inclusion of quantitative skills in the BSc curriculum, it is perhaps unsurprising that 33% indicated low levels of improvement in their quantitative skills, and 40% cited low levels of confidence in their ability to use quantitative skills as a result of the BSc. Students' beliefs about their future use of quantitative skills have been identified as a predictive factor for higher perceptions of quantitative skills (Matthews et al., 2013). In this study, approximately half of the students (51%) perceived a low level of quantitative skills use in their near future (five years' time). The relationship between believing quantitative skills would serve some future value and students then seeking out more quantitative skills learning opportunities is unclear from the SSSI results of this study but warrants further study.

5.2. *Changing Science Students' Perceptions of Quantitative Skills across the Old and New BSc*

This study captured SSSI data from two cohorts that graduated from the old BSc prior to a curriculum review, and two cohorts that graduated following the implementation of a new BSc curriculum intent on developing quantitative skills. The comparison of the characteristics of the old and new BSc cohorts revealed only one statistically significant difference: GPA. Otherwise the cohorts were similar with respect to age, gender, and postgraduate plans. The difference indicates that students from the new BSc had generally lower GPAs. GPA has been identified as a factor predicting higher self-ratings of quantitative skills (Matthews et al., 2013), which suggests that differences in perception of quantitative skills in this study might be associated with the declining GPA of students in the new BSc.

The interpretation of the GPA difference should be done in light of broader changes to assessment policies. The institution being studied was focused on assessment standards, particularly around the perceived possibility of 'grade inflation'. Thus, assessment approaches were introduced in the new BSc. For example, science unit coordinators were encouraged to set a 'pass threshold' on the final exam, requiring that students must earn (at least) a particular grade on the final exam to pass the unit. This was to address an issue that arises from the common practice of simply adding scores from individual assessment tasks to determine the final grade for a unit. This additive practice had made it possible for students to pass units based primarily on performance in non-exam assessments, usually comprising 50–60% of the total weighting for the unit assessment, without having to achieve a passing score in the final examination. A decline in unit grades was observed following the implementation of this new assessment policy, which was widely adopted across the degree programme. This provides another potential explanation for the GPA decline from the old BSc to the new BSc cohorts.

Students in the new BSc cohorts reported higher levels of perceptions of inclusion of quantitative skills in the curriculum and improvement in quantitative skills as a result of the curriculum. However, no differences were evident for perceptions of importance of quantitative skills, confidence in using quantitative skills, and perceived future use of quantitative skills. Considering these findings in the context of the intended new BSc curriculum offers some potential explanation for the differences, and lack thereof, between the old BSc and new BSc cohorts.

As the new BSc structured curriculum model required students to complete particular units, including dedicated quantitative units, the increased perception of inclusion of quantitative skills by the new BSc cohorts was expected. The flow-on effect of more quantitative skills units could reasonably result in the increased sense of improvement in quantitative skills identified by the new BSc curriculum cohorts. However, that sense of improvement did not translate into an increase in confidence between the old and new BSc cohorts. Confidence has been found to play a significant role in students' perceptions of quantitative skills (Matthews et al., 2013) and their mathematical and statistical achievement (Breen, Cleary, & O'Shea, 2009; Carmichael & Taylor, 2005; Hackett & Betz, 1989; Tariq & Durrani, 2012; Wilson & MacGillivray, 2007). This phenomenon has been demonstrated in school level studies within the domain of mathematics education (Schoenfeld, 1988). Confidence in one's ability to successfully complete tasks (mastery) has been most associated with increased self-efficacy in educational contexts (Bandura, 1986). Mastery results in students understanding how they can use their skills and knowledge. Thus, learning activities and assessment tasks must be designed to promote conceptual understanding and demonstrate relevance of the skills being mastered. However, the SSSI did not provide insight into students' perceptions of how quantitative skills were taught or assessed, which limits conclusions about the quality of pedagogical practices in relation to quantitative skills. Regardless, the findings do raise questions about the teaching of quantitative skills to build mastery, with approximately 50% of science students failing to see how they would be using quantitative skills in their futures and 40% reporting low confidence in their use of quantitative skills.

Inclusion of the third-year compulsory capstone unit within each major provided a new opportunity for inclusion of quantitative skills in the new BSc curriculum. Several capstone units, particularly in the life sciences majors that captured the majority of BSc students, included statistical applications in assessment tasks. Perhaps the focus on applying statistics in the life sciences context in the semester prior to graduation (when students completed the SSSI) resulted in students in the new BSc realising their deficiencies in statistics, providing a potential explanation for the reduced self-rating for statistical skills between the old BSc and new BSc cohorts.

The dearth of literature on curriculum, and curriculum change, in higher education generally, and in the domain of science and mathematics specifically, complicates interpretation of these results. However, drawing on the small body of curriculum research at the level of the degree programme offers some insights.

Australian universities increasingly are attempting to design degree programme curricula around stated graduate attributes or learning outcomes, which has resulted from external drivers for increased accountability in the higher education sector (Barrie, 2006). A structural approach to curriculum, such as the approach adopted in the BSc review, is typical in higher education (Lattuca & Stark, 2011). Curriculum goal setting (naming attributes or outcomes) to drive curricular reform efforts has been found to result in an additive approach in Australian universities (Barrie, Hughes, & Smith, 2009). That is, in an attempt to achieve the stated graduate learning outcomes, such as quantitative skills, units are typically added to the existing curriculum as the means to build the desired outcome in students. This approach can fragment a curriculum by disconnecting the learning outcome, usually a skill, from the disciplinary context and content knowledge of existing units (Barrie, 2006). This approach also limits responsibility for implementing curriculum reform to a handful of academics (Barrie et al., 2009) which reduces the involvement and thus likelihood of pedagogical change across the numerous units within a degree programme curriculum.

Although the SSSI does not offer insights into students' perceptions of fragmentation of quantitative skills or how quantitative skills were integrated into disciplinary contexts or with disciplinary content knowledge, the implementation of the new BSc suggested an emphasis on structural changes with an additive curricular approach to build quantitative skills that may have overshadowed pedagogical reform efforts. Educational change, while multifaceted, is reliant on teachers changing their practices (Fullan, 1993, 2013). The comparative analysis between students graduating from the old and new BSc revealed few changes in perceptions of quantitative skills, suggesting curriculum design in science higher education that focused on structure of units in the degree programme can raise the visibility of quantitative skills but is insufficient to raise the confidence of students in using their quantitative skills.

6. Conclusion and Further Research

Overall, this study painted a picture of a degree programme that, from the perspective of students, lacked in learning activities to develop quantitative skills. The findings of the study should be interpreted with consideration of several limitations. Results should be interpreted in the context of the chosen statistical procedure that involved summing ordinal data from four responses categories into two (high and low). While a common practice, the disadvantage is that it reduces quantitative variation. The research was conducted at a single institution with a specific institutional environment and student population. The research drew on a single source of data, namely the students. Thus, findings should be interpreted as the view of students who have a particular experience of education that differs from that of academics, administrators, and researchers.

The study suggests several implications for enhancing the design of science curriculum at the whole of degree programme level to improve students' quantitative skills. First, quantitative skills should be more visible across the whole of the science degree programme. Second, quantitative skills learning activities should be more included in upper level units, which are typically more specialised in the students' fields of study. Third, the quality of quantitative skills teaching, learning, and assessment activities should be examined with an emphasis on introducing approaches that build confidence.

The present study has several implications for further research and curriculum reform. First, investigations into the qualitative student experience to illuminate the quantitative findings would benefit the sector, particularly with a focus on fragmentation of opportunities for learning quantitative skills across units and year levels. Second, how learning experiences of quantitative skills influence students' beliefs about the role of quantitative skills as a graduate learning outcome in science is a question worthy of further research. Third, replication of this study with final-year science students in different universities would provide insight into the possibility of generalising these findings. Fourth, there is a need for studies that delve into potential variation of students' perceptions of quantitative skills through the lens of gender, discipline specialisation within science, and post-graduation plans. Finally, case study analysis of how data from students can inform curriculum development in science higher education would address a major challenge as the higher education sector attempts to assure graduate learning outcomes within an evidence-based framework of curriculum reform (Oliver, 2013).

Drawing on students to inform curriculum development seems wise given the time, resources, and effort dedicated to curriculum reform to enhance students' learning experiences. The focus of higher education research has been on individual units of study, usually highlighting the tremendous efforts of a single educator. However, students experience an array of units in their degree programmes and are influenced by a plethora of teachers. The recent emphasis on graduate learning outcomes in higher education recognises the degree programme curriculum and learning that should build across many units of study over a number of years. This study, while limited and situated at a single university, clearly demonstrates how students can offer insight into the effectiveness of curriculum designed to build graduate learning outcome. This pivotal insight can inform future curriculum development and further higher education research.

Disclosure statement

No potential conflict of interest was reported by the authors.

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