DO SCIENCE STUDENTS GRADUATE KNOWING WHAT THEY KNOW AND DON’T KNOW? 
THE CASE OF QUANTITATIVE SKILLS

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The UQ Context

*Group of 8 and Universitas 21*

In top 3 for research income in Australia

~40,000 students with ~2,800 academic staff
The UQ Science Context

2006 Bachelor of Science Review

Structure and choice in curriculum (coherence)

2008: First year foundation in enabling sciences to lead into majors
2010: Capstone courses in final year of major

Our Degree Programs

~1000 students per year

Bachelor of Science (20 Majors), Science-based degrees, Science dual degrees
Bachelor of Biomedical Science

McManus et al, 2007; Strong et al, 2009
International agreement: science students need mathematical and statistical knowledge


**Australia**: Matthews et al. (2012). The state of quantitative skills in science. Report to Office for Learning and Teaching, Canberra.


Statement of Science Threshold Learning Outcomes

1. Guide whole of curriculum development
2. Underpinned by quantitative skills
Upon completion of a bachelor degree in science, graduates will:

<table>
<thead>
<tr>
<th>Understanding science</th>
<th>1. Demonstrate a coherent understanding of science by:</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1.1 articulating the methods of science and explaining why current scientific knowledge is both contestable and testable by further inquiry</td>
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<td>1.2 explaining the role and relevance of science in society.</td>
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<tr>
<td>Scientific knowledge</td>
<td>2. Exhibit depth and breadth of scientific knowledge by:</td>
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<tr>
<td></td>
<td>2.1 demonstrating well-developed knowledge in at least one disciplinary area</td>
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<td></td>
<td>2.2 demonstrating knowledge in at least one other disciplinary area.</td>
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<tr>
<td>Inquiry and problem solving</td>
<td>3. Critically analyse and solve scientific problems by:</td>
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<tr>
<td></td>
<td>3.1 gathering, synthesising and critically evaluating information from a range of sources</td>
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<td></td>
<td>3.2 designing and planning an investigation</td>
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<td></td>
<td>3.3 selecting and applying practical and/or theoretical techniques or tools in order to conduct an investigation</td>
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<td></td>
<td>3.4 collecting, accurately recording, interpreting and drawing conclusions from scientific data.</td>
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<td>Communication</td>
<td>4. Be effective communicators of science by:</td>
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<tr>
<td></td>
<td>4.1 communicating scientific results, information, or arguments, to a range of audiences, for a range of purposes, and using a variety of modes.</td>
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<tr>
<td>Personal and professional responsibility</td>
<td>5. Be accountable for their own learning and scientific work by:</td>
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<td></td>
<td>5.1 being independent and self-directed learners</td>
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<td>5.2 working effectively, responsibly and safely in an individual or team context</td>
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<tr>
<td></td>
<td>5.3 demonstrating knowledge of the regulatory frameworks relevant to their disciplinary area and personally practising ethical conduct.</td>
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</tbody>
</table>
Australian Forum on First Year Mathematics in STEM

February 2014
Unclear

1. What mathematical and statistical knowledge is needed for science students?
2. How will such knowledge be used in science?
3. How able are students to use such knowledge in science?
Plan with the future in mind

1. Focus on the discipline and communicate
2. Picture of desired QS graduate learning outcomes for students
3. Gather data and use it to inform curriculum development
Plan with the future in mind

1. Focus on the discipline and communicate
   - biomedical sciences
   - discussed QS for life sciences
   - students

2. Picture of desired QS graduate learning outcomes for students
   - develop a purpose-built assessment task
   - students in capstone units complete the task

3. Gather data and use it to inform curriculum development
Quantitative Skills Assessment of Science Students (QSASS)

ARTIST Project to assess statistical conceptions

Mathbench Project to build biology students’ QS

UQ engineering diagnostic question in mathematics
unpublished
Quantitative Skills Assessment of Science Students (QSASS)

Applied Mathematical Knowledge
1. Metric conversations (2 questions)
2. Reading a pipette (3 questions)
3. Logarithmic scales (3 questions)
4. Serial dilutions (2 questions)

Applied Statistical Knowledge
5. Graphical representation of data (8 questions)
6. Normal distributions (2 questions)
7. Test of significance (4 questions)
8. Correlation and causation (3 questions)
9. Sampling (5 questions)
10. Probability (3 questions)
QSASS

1. Administered to 211 students in the biomedical sciences capstone units
2. With 185 students answering the 35 questions
2. MATHEMATICS: 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.

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).

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

- .0011 micrometres
- .11 micrometres
- 1100 micrometres
- .011 micrometres
- 110 micrometres
- No clue

(QSASS: student view)
9. STATISTICS: Correlation and causation

29. Researchers surveyed 1,000 randomly selected adults in the U.S. 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.

- [✓] 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.
- [ ] 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.
- [ ] This result indicates that earning more money influences people to recycle more than people who earn less money.
- [ ] No clue
Results: Average Scores

- Overall QSASS: 34% to 89%
- Mathematical section: 20% to 100%
- Statistical section: 28% to 88%
applied mathematical knowledge

- Metric conversions: 60%
- Reading a pipette: 95%
- Logarithmic scales: 71%
- Serial dilutions: 63%
applied statistical knowledge

- Graphical representation: 66%
- Normal distribution: 49%
- Tests of significance: 63%
- Correlation and causation: 45%
- Sampling: 55%
- Probability: 49%
Overview of QSASS results

• Performance varies by students within the same graduating cohort
• Performance shows students better with application of mathematical knowledge than statistical knowledge
• Performance of students varies by sub-topic
Unclear

1. What mathematical and statistical knowledge is needed for science students?
2. How will such knowledge be used in science?
3. How able are students to use such knowledge in science?
Unclear although some guidance

1. What level of mathematical and statistical knowledge is actually needed for science students... Now (undergraduate degree)? In the future (for life and career)?

1. How will such knowledge be used in the science discipline? Is there a mathematical way of thinking that enables application in science (or any) discipline?

2. How can we enable students to use and apply mathematical knowledge in science discipline?
For you – today!

To be presented in Australian October 2014
Do graduating science students *know that they know*?

Quantitative Skills
Framework

• Bandura’s task-specific self-efficacy
• Boud’s sustainable assessment
• Sadler’s *evaluative expertise*
Categorise

• QSASS performance data were grouped into two categories:
  – ‘high’ representing performance in the top quartile or those scoring between 75-100%; and
  – ‘low’ representing those students who scored below 75%.

• Confidence scores were also divided into two categories:
  – ‘high’ group comprising *very confident* rating (numerical equivalent of 4); and
  – ‘low’ group comprising *moderately confident*, *a little confident* and *not at all confident* ratings (numerical equivalents of 1,2 and 3).
Categorise

under-confident

over-confident
67% as effective *evaluative experts*

More likely to be *under-confident*
<table>
<thead>
<tr>
<th>Table x</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematics sub-topics QSASS performance and confidence categorised into ‘high’ and ‘low’</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Metrics (%)</th>
<th>Pipette (%)</th>
<th>Logarithmic (%)</th>
<th>Serial Dilution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Performance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Low Confidence</td>
<td>43 (20.6%)</td>
<td>72 (34.4%)</td>
<td>92 (44.2%)</td>
<td>70 (33.7%)</td>
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<td></td>
<td><strong>36 (17.2%)</strong></td>
<td><strong>109 (52.2%)</strong></td>
<td><strong>10 (4.8%)</strong></td>
<td><strong>23 (11.1%)</strong></td>
</tr>
<tr>
<td><strong>High Performance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Confidence</td>
<td>93 (44.5%)</td>
<td>22 (10.5%)</td>
<td>102 (49.0%)</td>
<td>109 (52.4%)</td>
</tr>
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<td></td>
<td><strong>37 (17.7%)</strong></td>
<td><strong>6 (2.9%)</strong></td>
<td><strong>4 (1.9%)</strong></td>
<td><strong>6 (2.9%)</strong></td>
</tr>
</tbody>
</table>

**evaluative experts**  
62%  
63%  
54%  
64%

Not evaluative experts under-confident

Not
74% as effective *evaluative experts*

More likely to be *over-confident*
Table x
Statistics sub-topics QSASS performance and confidence categorised into ‘high’ and ‘low’

<table>
<thead>
<tr>
<th></th>
<th>Graphical Representation (%)</th>
<th>Normal Distribution (%)</th>
<th>Test of Significance (%)</th>
<th>Correlation and Causation (%)</th>
<th>Sampling (%)</th>
<th>Probability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Performance</td>
<td>77 (37.2%)</td>
<td>46 (22.0%)</td>
<td>88 (42.3%)</td>
<td>4 (1.9%)</td>
<td>51 (25.1%)</td>
<td>12 (6.1%)</td>
</tr>
<tr>
<td>Low Confidence</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>High Performance</td>
<td>17 (8.2%)</td>
<td>6 (2.9%)</td>
<td>21 (10.1%)</td>
<td>0 (0%)</td>
<td>6 (3.0%)</td>
<td>3 (1.5%)</td>
</tr>
<tr>
<td>High Confidence</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Low Performance</td>
<td>97 (46.9%)</td>
<td>142 (67.9%)</td>
<td>82 (39.4%)</td>
<td>171 (81.8%)</td>
<td>137 (67.5%)</td>
<td>163 (82.7%)</td>
</tr>
<tr>
<td>Low Confidence</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Low Performance</td>
<td>16 (7.7%)</td>
<td>15 (7.2%)</td>
<td>17 (8.2%)</td>
<td>34 (16.1%)</td>
<td>9 (4.4%)</td>
<td>19 (9.6%)</td>
</tr>
<tr>
<td>High Confidence</td>
<td></td>
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</table>

**evaluative experts**  55%  71%  50%  82%  71%  84%

Not **evaluative experts**  
under-confident with two exception: correlation & causation and probability
What could explain this?
interpret: curriculum

2010 graduates

2013 graduates
Assessment design
Thank you

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Overview

Research
Kelly Matthews' research involves practical applications into contemporary higher education.

http://researchers.uq.edu.au/researcher/1754