



Fellowship Report

Embedding quantitative principles in life science education

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Cover image

Philip Poronnik 2008 *Wanderweg VII*



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Executive Summary

There is a well-documented “flight from science” highlighted by a significant reduction in the numbers of students taking the “enabling sciences”, particularly mathematics. One of the more alarming (but less well-documented) consequences of this “fright of numbers” is that the basic mathematical and quantitative skills of many students in the life sciences is below the level required for the quantitative data acquisition and analysis that underpins fundamental scientific activity, education and research.

The purpose of this Fellowship program was to quantify the extent of the mathematical deficiency in first year life science students and to develop contextualised interventions to address these deficiencies. The key research questions which guided the Fellowship were:

- What are the real levels of mathematical skills possessed by, and required by, first-year life science students at The University of Queensland (UQ) and elsewhere?
- What are the most appropriate methods of assessing the levels of life science students’ engagement with mathematical concepts?
- How can essential mathematical principles be embedded in first-year life sciences?

Around the time of commencing this Fellowship, UQ undertook a comprehensive review of the BSc, a flagship degree with around 1000 students enrolling each year. The review identified an urgent need to improve students’ quantitative skills, via the best possible learning aids and assistance. This Fellowship was a key driver in developing a new course¹ which combined mathematical content with scientific applications.

The primary activities undertaken in the Fellowship program were:

- identifying the level of mathematical knowledge required in a typical introductory life science course, and any deficiencies in knowledge and skills of commencing students;
- designing and implementing effective teaching and learning approaches that present core quantitative material in a manner that is relevant, accessible and timely;
- embedding the developed materials and approaches in an introductory course designed to increase the quantitative skills and knowledge of students entering the life sciences and integrating with some qualitative skills in another first-year biology course;
- conducting a comprehensive evaluation of the outcomes of this embedding; and
- disseminating outcomes and findings of the project activities.

The primary tangible outcomes of the Fellowship are:

- a comprehensive set of teaching materials for an interdisciplinary, introductory quantitative science course, with a genuine blend of mathematical, philosophical, computational and scientific knowledge and principles;
- extensive evaluation information obtained from students over two years, collected from large surveys and focus group discussions;
- several publications and presentations; and
- a substantial increase in the profile and responsibilities of the Fellows in the institutional and national contexts.

¹ At UQ, a course is a subject.



Findings

Developing genuinely interdisciplinary learning experiences which are effective and (reasonably) accepted by large groups of students is very difficult, but it can be done. There were components of the course which did not work well, and there were groups of students who did not appear to benefit from the experience. However, overall the response from students was fairly positive.

The level of mathematical knowledge required in Life science courses is unclear. However, practical experience suggests that the level is not particularly high, and certainly should not be beyond the capabilities of students entering tertiary study having completed intermediate level mathematics to the final year of secondary school.

Students appear to enter science study at university with a belief that mathematics is important in the life sciences. It is important that this belief be converted to a functional truth immediately upon commencing a science degree.

Developing the direct teaching materials (such as lecture notes and assessment items) is particularly challenging. Many months of skilled effort were required to produce the materials linked to this report, with numerous revisions already completed, and more to be done. Getting a reasonable balance between mathematical and scientific content is very difficult (and is probably an area for infinite discussion).

It is possible to establish courses at the introductory level which require students to understand, analyse, apply, synthesise and evaluate.

We wish to highlight that this is one of the few **shared** Fellowships that has been awarded by the ALTC. Given the fundamentally interdisciplinary nature of this work, we do not believe that the program could have been undertaken successfully by a single individual based in just one of the discipline areas.



1.0 Intended outcomes

The original nomination stated that “the key outcome of this project will be to lay the foundation to provide tools and strategies to improve students’ quantitative skills, broaden their scientific outlook, help overcome the fear of mathematics that many such students feel, and better equip them to move into an increasingly technology-focused workforce”. This key outcome was broken into two key aims, which were further refined into several core activities, finally leading to identified deliverables.

Aim 1: To research and develop context-sensitive instruments to determine the level of mathematical and quantitative competency achieved and required in first-year life science students and their engagement in quantitative aspects of the life sciences.

Activity 1.1 *Identifying exactly what quantitative skills and level of mathematical sophistication are important in order for modern life science students to succeed in both their education and their subsequent employment, and to measure their current general mathematical skill level.*

Activity 1.2 *Highlighting those essential quantitative skills which often cause a problem for life science students, including identifying specific reasons why the problems arise.*

Aim 2: To initiate the development and implementation of transferable and scaleable teaching tools that enable the embedding of relevant mathematical principles within life science courses.

Activity 2.1 *Designing and implementing effective teaching and learning approaches that present core quantitative material in a manner that is relevant, accessible and timely.*

Activity 2.2 *Using the developed materials and techniques in one or more introductory, large-enrolment life science courses, measuring effectiveness of project outcomes, and using feedback to make further improvements.*

The following specific deliverables were identified:

- A clearly defined list of core mathematical skills required by all first-year science students, to be released as a formal report;
- A framework to guide the development and reinforcement of quantitative principles in years 2 and 3 of tertiary life science courses;
- Validated surveys and interviews for investigating quantitative skills of first-year science students, their engagement in these activities, and their performance;
- At least three publications in peer-reviewed, relevant journals, reporting the survey data, implementation and student engagement/performance; and
- Validated, documented and transferable modules that embed contextualised mathematical principles and skill sets in a first-year human biology course.



2.0 Approach and methodology

2.1 Driving principles

The interdisciplinarity of mathematics and science is the core principle underpinning this Fellowship. In the past, boundaries between disciplines such as biology, mathematics, physics and chemistry have changed relatively slowly. However, the pace of modern science is accelerating and these boundaries are starting to collapse. There is a growing consensus that the greatest scientific and technological discoveries of the 21st century will be made by researchers working at the interface between disciplines. Graduates who are narrow and insular often do not have the intellectual richness and diverse technical skills required to engage successfully in interdisciplinary work. As a result the tertiary education environment must be able to adapt and respond quickly and flexibly to a changing landscape, and to foster collaboration with “non-traditional” partners, both at the teaching and research levels.

In particular, there is an urgent need to overcome the common perception of both educators and students that the life, physical, quantitative and information sciences are completely separate disciplines that can be studied in isolation from each other. Rather than encouraging breadth and enabling interdisciplinary research, current education often treats the life sciences and mathematics as distinct, isolated activities. The result of this disconnect is that students fail to realise the relevance of these sciences in their chosen disciplines, which in turn places them in their career paths with serious deficits.

These problems are increasingly recognised at the international level, as highlighted in several landmark studies released around the time of the original nomination. Findings and recommendations from these studies motivated and informed the goals and activities of this Fellowship.

In contrast to biological research, undergraduate biology education has changed relatively little during the past two decades. The ways in which most future research biologists are educated are geared to the biology of the past, rather than to the biology of the present or future. Like research in the Life Sciences, undergraduate education must be transformed to prepare students effectively for the biology that lies ahead. Life science majors must acquire a much stronger foundation in the physical sciences (chemistry and physics) and mathematics than they now get..... Incorporating mathematics, physical science and emerging fields such as the information sciences into a biology curriculum is not easy, especially for faculty who do not consider themselves well versed in those topics.

(BIO2010: Transforming Undergraduate Science Education, National Academies Press, Washington, 2003.)

Concepts, examples and techniques from mathematics and the physical and information sciences should be included in biology courses ... Faculty in biology, mathematics and physical sciences must work collaboratively to find ways of integrating mathematics and physical sciences into Life Science courses...

(BIO2010: Transforming Undergraduate Science Education)

Scientists will need to be completely computationally and mathematically literate, and by 2020, it will simply not be possible to do science without such literacy. This therefore has important implications for education policy right now.

(Towards 2020 Science, Microsoft Corporation, 2005)

Thus, the need to recognise and build upon the interdisciplinary nature of this program also drove the approach and methodology. The program was undertaken as a shared Fellowship precisely for this reason.



2.2 Approach and activities

The approach is presented according to the four activities identified in the “Intended Outcomes” stated above.

Activity 1.1 *Identifying exactly what quantitative skills and level of mathematical sophistication are important in order for modern life science students to succeed in both their education and their subsequent employment, and to measure their current general mathematical skill level.*

The depth and sophistication of mathematical knowledge required for students to undertake successfully introductory courses in the life sciences was analysed in three ways.

1. The approach and rationale was heavily influenced by the landmark BIO2010 report. For example, it stated that:

Biological concepts and models are becoming more quantitative, and biological research has become critically dependent on concepts and methods drawn from other scientific disciplines. The connections between the biological sciences and the physical sciences, mathematics and computer science are rapidly becoming deeper and more extensive.

(BIO2010: Transforming Undergraduate Science Education)

The report goes on to identify specifically a range of mathematical skills and concepts which it regards as “essential” for life science students. These concepts include: complex numbers, limits, continuity, derivatives and integrals, Fourier series, multidimensional calculus, integration over multiple variables, eigenvalues and eigenvectors, phase plane analysis, sensitivity to initial conditions and chaos, algorithms and computability.

2. An advisory group was formed, comprising around 20 UQ academic staff from areas such as biomedical science, biology, zoology, molecular biology, mathematics, physics, computer science, geological sciences, geographical sciences, psychology and chemistry. Six working meetings were held in May and June 2007, during which people identified and debated the areas of mathematical knowledge which were important for their area of science, and then jointly proposed a unified list. Topics identified included functions (including exponentials, logarithms and periodic functions), graphs, equations (linear, quadratic, simultaneous), matrices, recurrence relations, simple differential equations, numerical techniques for root finding, and for solving simple differential equations.
3. A ‘quantitative analysis’ was conducted of the textbook *Biology*, Campbell et al (2006, 7th edition (Australian version), Pearson). This is the text used in introductory life science courses at (UQ). Quantitative concepts covered in the textbook were classified into a number of categories, including: topic, frequency, style, intensity and purpose.

All science students at UQ have completed intermediate level secondary school mathematics to Year 12 level, so this provided an indication of their mathematical skill level (in theory, at least). In order to gauge the extent to which this knowledge is typically transferred into tertiary study, 530 students entering science programs in 2008 were administered a short mathematical quiz. Questions covered skills such as: solving simple equations, interpreting word-based questions, functions, derivatives, simple optimisation and integrals. Student performance on this test appeared consistent with expectations: students had clearly covered the core concepts, but had forgotten some of the techniques. Hence there was no further investigation of current levels of mathematical knowledge.

Activity 1.2 *Highlighting those essential quantitative skills which often cause a problem for life science students, including identifying specific reasons why the problems arise.*

To a substantial extent, this activity was subsumed by Activity 1.1, in particular the advice given by the advisory group. Members of that group had extensive experience in observing the educational performance of life science students over a number of years, and hence incorporated into their recommendations precisely those areas which students typically find difficult. That is, the text book demonstrated that little new mathematical material needed to



be covered, and it was more a matter of strengthening and broadening students' understanding of concepts and techniques which they had already seen. Any areas which students often find easy were not incorporated into the proposed list of topics.

Activity 2.1 *Designing and implementing effective teaching and learning approaches that present core quantitative material in a manner that is relevant, accessible and timely.*

By far the most difficult and time-consuming aspect of this program was producing the materials to use in the scheduled lectures. These materials provided the framework for how and what would be covered, and also were the primary resource used by students in their regular study.

There are several core messages that this course (and hence the materials) were intended to promote:

1. Science and mathematics are intimately linked, rather than being distinct.
2. There are many common approaches between areas of science that at first appear quite distinct, and there are logical reasons behind these similarities. For example, the exponential function arises in population modelling, radioactive decay, electrical discharge from a capacitor, rate of change of temperature, and rate of elimination of drugs from the bloodstream. A deep understanding of the nature of the exponential function makes it clear why this **has** to be the case.
3. Much science is based on *models*, which attempt to approximately represent phenomena in a manner with sufficient accuracy to allow useful deductions to be made, whilst being sufficiently simple to be practical.
4. Computational techniques are important in modelling.
5. It is possible to develop some very effective models of phenomena using mathematical techniques to which students have already been exposed.
6. A range of additional skills and knowledge is fundamental to doing science, including: communication (written and verbal, formal and informal), quantitative reasoning, and a sound basis of scientific thought and reasoning.

Key principles which were used to inform development of the materials include:

1. This is not a course in mathematics, and most students taking the course are not particularly interested in mathematics for its own sake, so presenting concepts in a formal, traditional fashion was inappropriate.
2. Learning should be motivated by a number of interesting, authentic, but accessible, contexts. Thus, most material is presented around a number of authentic case studies.
3. Students cannot be passive observers, but in addition must be required to participate in solving problems. As a result, there are many gaps in the notes, which are completed in class.
4. The content covered should be directly relevant and of interest to students in a wide range of science disciplines, not only the life sciences.
5. Mathematical content often needs to be covered in a certain sequential order, because more advanced concepts typically require knowledge of earlier concepts.
6. Probability and statistics are covered elsewhere in the curriculum, so should not be addressed in this course.
7. Students will all enter with at least intermediate level high school mathematics (which includes some experience with calculus).

Activity 2.2 *Using the developed materials and techniques in one or more introductory large-enrolment life science courses, measuring effectiveness of project outcomes, and using feedback to make further improvements.*

Rather than embedding these approaches in a life science course, this fellowship was able to take advantage of the opportunities presented by the introduction in semester 1 2008 of a



new quantitative science course, highly recommended for all science students at UQ. Design, development, introduction and operation of the new course became tightly coupled with the Fellowship activities, and the approaches and materials were used in an initial cohort of around 500 students.

Once semester was completed, a range of evaluation and feedback activities was conducted. Standard UQ course evaluation surveys were obtained. In addition, all class members were requested to complete an online survey, asking some course-specific questions. Finally, four focus groups were interviewed, with students classified according to their level of academic performance and their enrolled program. This feedback identified some necessary changes, which have been made. The course operated again in 2009, followed by more focus groups and electronic surveys.

In addition, related activities were undertaken in a life science course that provided a programmatic link to ensure that the embedded course elements are meaningful within the whole degree structure. This is of particular importance in terms of the first-year transition phase and recognition of students' prior knowledge. Thus we took a more systematic approach in addressing one of the key objectives of the program: that is, to develop in the students the capacity to integrate the quantitative principles of the new first-year course into the context of their chosen programs. The notes for the new course already contained many intentional links to other disciplinary knowledge.

In this context, the Fellowship developed two additional approaches: (1) a theoretical investigation of the role that creativity could play in the reinvigoration of the life sciences; and (2) embedding a written task in another first year course that would help foster students' communication skills around science.

The creativity aspect arose as a direct collaboration with Professor Erica McWilliam and her ALTC Fellowship, "Developing pedagogical models for building creative workforce capacities in undergraduate students". We investigated current creativity theory to produce some guiding principles to reinvigorate the science curriculum and inform aspects of curriculum innovation and design.

The written aspect was done in collaboration with Dr Roger Moni (ALTC Fellow) and ABC Radio National's *Science Show* (with Robyn Williams). This activity aligns with the aims of the quantitative course in enhancing general scientific literacy and engagement by allowing students to explore their interests in various topics in science, many of which relate to and make explicit links with the subject matter in each course.



3.0 Actual outcomes: advances in knowledge

3.1 Specific outcomes

The advances in knowledge are presented according to the activities discussed above.

Activity 1.1 *Identifying exactly what quantitative skills and level of mathematical sophistication are important in order for modern life science students to succeed in both their education and their subsequent employment, and to measure their current general mathematical skill level.*

A copy of the informal report (as yet unpublished) of the analysis of the introductory life science textbook *Biology*, Campbell *et al* (2006, 7th edition, Australian version) is given at [Appendix A: Investigation](#). We would like to acknowledge Professor Daniel Kaplan from Macalester University (Minnesota, USA) for his valuable assistance in the design of this part of the project as well as Joshua Bartlett, research assistant at UQ, who did the bulk of this work.

The clearest message arising from this activity is the substantial variation in the level of mathematical sophistication suggested by BIO2010, the advisory group of science academics, and the analysis of the introductory textbook.

Some of the mathematical concepts identified as “essential” in BIO2010 are fairly sophisticated, and are typically not covered in any detail until second-level mathematics courses. They are certainly well beyond the scope of the skills identified as necessary in the analysis of the introductory life science textbook, and also exceed the level of content proposed by the advisory group. When the list of topics in BIO2010 was shown to mainstream mathematics academics, a common response was surprise to the point of disbelief. When the topics were shown to science academics, the most common response was disbelief to the point of derision. This is not to say that the recommendations in BIO2010 are incorrect; we instead deduce that in the context of a Go8 Australian university, the level of mathematical knowledge proposed in BIO2010 is unrealistic. Certainly, there was unanimous agreement that most students would not have the time, room in their study program, interest or base level of mathematical knowledge to allow them to assimilate the proposed topics.

Conversely, the introductory textbook incorporated only a very low level of mathematical and quantitative material. Essentially, familiarity with fractions, arithmetic, simple algebra, graphs and simple equations would be sufficient for students to comprehend the material contained in the textbook. In most cases, students who have completed mathematics courses only to middle secondary years should be prepared sufficiently to access that material. This level of knowledge is substantially lower than that proposed by the advisory group. There are several possible explanations for this. One is that the advisory group was “out of touch” with the reality of what is required. Another is that the particular textbook chosen for introductory life science courses at UQ may have a particularly low-level quantitative content (if so, this may have been a conscious or subconscious criterion when selecting the text). A third possible explanation is that introductory life science study has only a low quantitative requirement, but that students will require more quantitative skills as they advance through their studies. In this case, if quantitative skills are not directly developed in subsequent courses, then it would be necessary to expose students at the introductory level to more sophisticated quantitative material than they immediately require. On reflection, it appears that all three of these factors are true to varying extents.

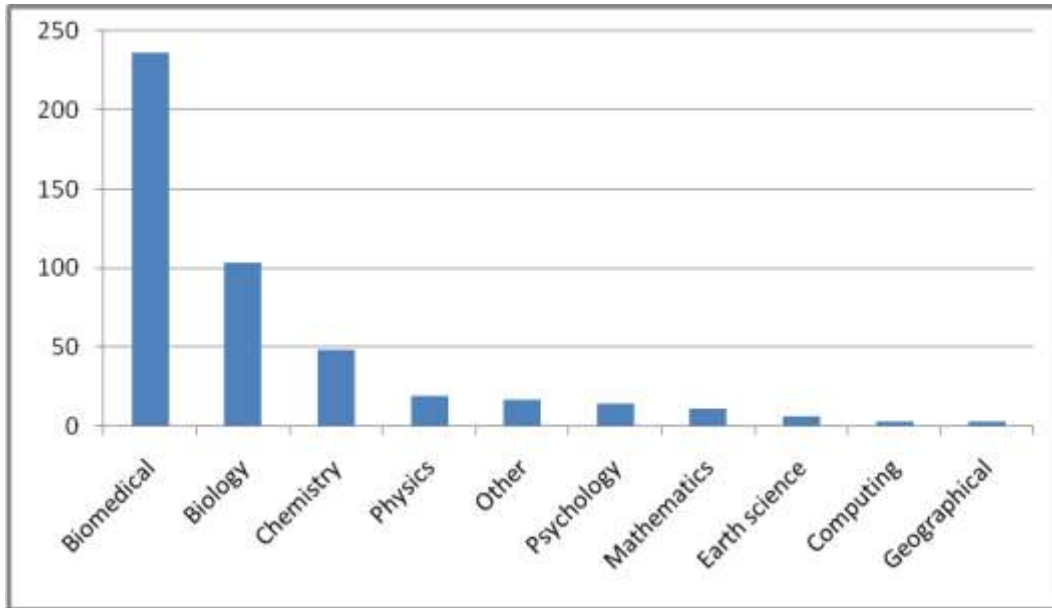
After extensive consultation and discussion, it was decided to follow, largely, the recommendations of the advisory committee. This group was guided by BIO2010, their intimate knowledge of introductory and advanced life science courses, their experience with the quantitative requirements of careers in research and industry, and familiarity with the quantitative knowledge students (should) have on entry.

In addition to identifying the level of mathematical knowledge required by students of introductory life science courses, we also surveyed their attitudes towards the importance of mathematics in such disciplines. We were particularly interested in measuring to what extent

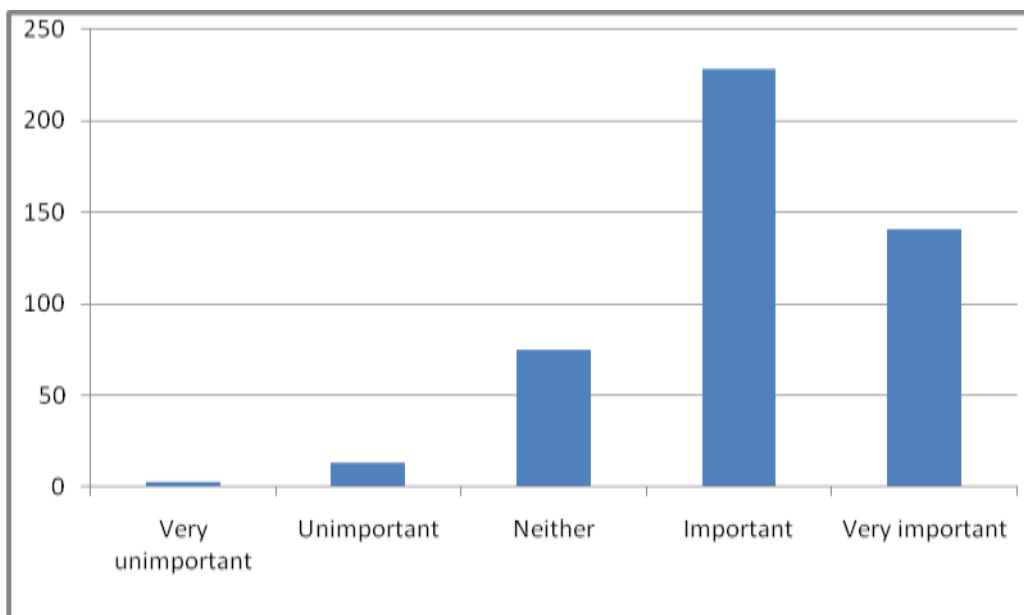


they believed that mathematics was relevant to their chosen scientific discipline. The response to this question is important in designing the most appropriate teaching approaches and materials. If students believe that mathematics is unimportant or irrelevant to what they will do, then more care must be taken to motivate *why* it matters. Conversely, if they are receptive to its relevance, then more time can be devoted to covering content and techniques.

Graph 1 shows student responses to the question “Which area of science interests you most?”. Students were drawn from a range of areas of science, but a substantial majority identified a life science as their primary area of interest. Graph 2 shows student responses to the question “How important is mathematics in science?”. The results in this graph were unexpected, but very encouraging. Around 80% of the class believed that mathematics was important or very important in science.



Graph 1: Student responses to the question “Which area of science interests you most?”.



Graph 2: Student responses to the question “How important is mathematics in science?”.



Activity 1.2 *Highlighting those essential quantitative skills which often cause a problem for life science students, including identifying specific reasons why the problems arise.*

As described above, this activity was subsumed by Activity 1.1.

Activity 2.1 *Designing and implementing effective teaching and learning approaches that present core quantitative material in a manner that is relevant, accessible and timely.*

Designing effective approaches to learning and assessment is always challenging. This is even more pronounced in the context of a course which tightly links concepts and materials from areas that would commonly be treated as distinct disciplines. Students' quantitative and scientific learning must be supported and assessed in a manner which requires them to appreciate and demonstrate an understanding of the links, rather than having experiences which are solely mathematical, and others which are solely scientific. However, we were assisted by the perception of most students that mathematics is important in their area of science.

The materials produced and used during this project represent one of the core advances in knowledge. Copies of some of these materials (in particular, lecture notes and assessment items) are available on The University of Queensland's website, <http://www.maths.uq.edu.au/~pa/ALTCfellowship/>.

[Lecture notes \(Attachment 1\)](#)

These are the materials used in the delivery of the course in 2010; these represent a substantial revision of material used in the first delivery, following feedback from students and colleagues. Further refinement of these materials is continuing, informed by student and staff surveys, focus groups, and informal discussions.

[Final examination \(Attachment A1\)](#)

This is the final examination used in 2009. Very few of these questions would appear on a typical mathematics examination script or a science examination script: there is substantially more discussion, evaluation and interpretation than in a typical mathematics examination, and substantially more mathematical content than in a typical science examination. The range of question types includes those which are:

- quite mathematical (such as Qns 1(a) and 13);
- based on interpreting word-based questions and doing some calculations (such as Qns 1(b), 2, 10, 11, 12);
- predominantly interpretative/discussion based (such as Qns 3, 4, 5);
- interpretative in a computational context (Qn 6); and
- philosophical in nature (Qns 7, 8, 9).

The level of mathematical knowledge required to complete this examination was mostly covered in upper-secondary studies. However, the mathematical content is certainly more sophisticated than that encountered in the analysis of the introductory life science text.

[Common assignment \(Attachment A2\)](#)

This is the question sheet for an assignment completed by all students. Chemical equations were not otherwise covered, so students were required to read and understand the concepts from chemistry, and then perform calculations and interpret (in words) a number of topics which probed fundamental understanding of the associations between the quantitative and scientific principles.

[Projects \(Attachments A3 and A4\)](#)

Students were presented with four choices of project topic; these are two examples. Each option focused on a different area of science, allowing students to select a topic related to their general area of interest. Every option covered a combination of science, quantitative skills, computation and written communication.



Interestingly, only about 10% of the class identified that their primary area of interest was mathematics, yet around 20% of the class chose the project topic which was most mathematical in nature.

Activity 2.2 *Using the developed materials and techniques in one or more introductory large-enrolment life science courses, measuring effectiveness of project outcomes, and using feedback to make further improvements.*

Student performance on the final examination given above was disappointing: fewer than 2% of the class received a score of more than 90%; around 50% of the class received a score of more than 50%; with many students scoring between 40% and 50%. Anecdotal evidence suggests that while most students did not find the exam to be difficult intellectually, they found it to be too long. Future examinations will be shorter.

Despite comparatively poor exam performance, overall course results were pleasing when all assessment scores were combined to give final grades; see the following table. The mean grade in this course was slightly higher than that in introductory chemistry and biology courses.

Grade	% of students
7 (highest)	10%
6	22%
5	27%
4 (lowest pass)	27%
3	8%
2	5%
1	1%

Table 1: Final grade distribution, 2009.

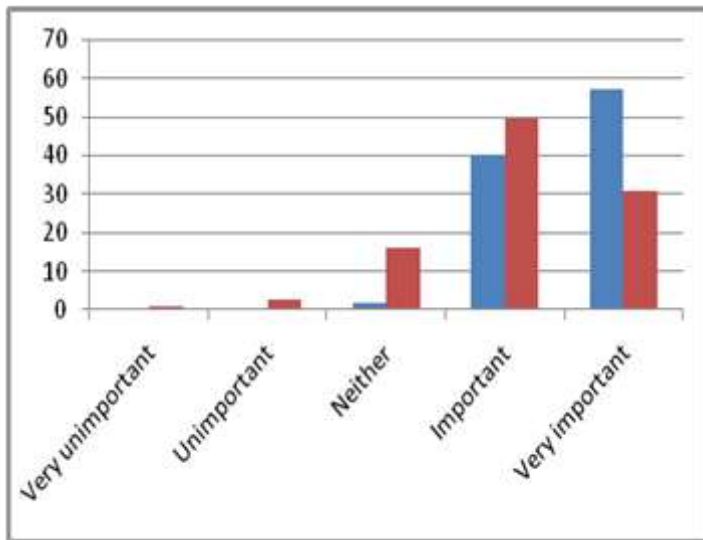
The formal evaluation results from the online course survey administered in 2009 are given at [Appendix B: Evaluation](#). A total of 439 students completed the course and hence were eligible to participate in the evaluation; hence the response rate was around 97%. Some of the more interesting factors highlighted in the student feedback include the following.

1. As shown by the responses to Question 5, overall the course was reasonably well-received. Around 72% of students rated the course as “good” or “outstanding”, whilst only around 8.2% rated it as “very poor” or “not so good”. On a 5 point scale, the overall mean score for the course was 3.81.

For comparison, students in a total of 11 introductory science courses completed course evaluations, each of which included Question 5. There were four biology courses, two chemistry, two physics and two statistics, in addition to this course. The overall mean responses to Question 5, in decreasing numerical order, were 4.05, 3.98, 3.91, 3.81, 3.79, 3.64, 3.55, 3.45, 3.43, 3.22 and 3.18. Clearly, student evaluations of courses are not a competition. However, it is interesting to note that this course received the fourth highest evaluation. The other quantitative courses (statistics, physics and a quantitative chemistry course) were much more poorly received.

2. Most students attended most or all of the scheduled classes.
3. Only around 14% of students were interested primarily in heavily quantitative disciplines (mathematics and physics).
4. When they entered the course, students had a strong view that mathematics was important in science (see Graph 2). As shown in Graph 3, by the time they completed the course, this view was substantially strengthened. Around 97.5% of the cohort identified that mathematics was important or very important in science.

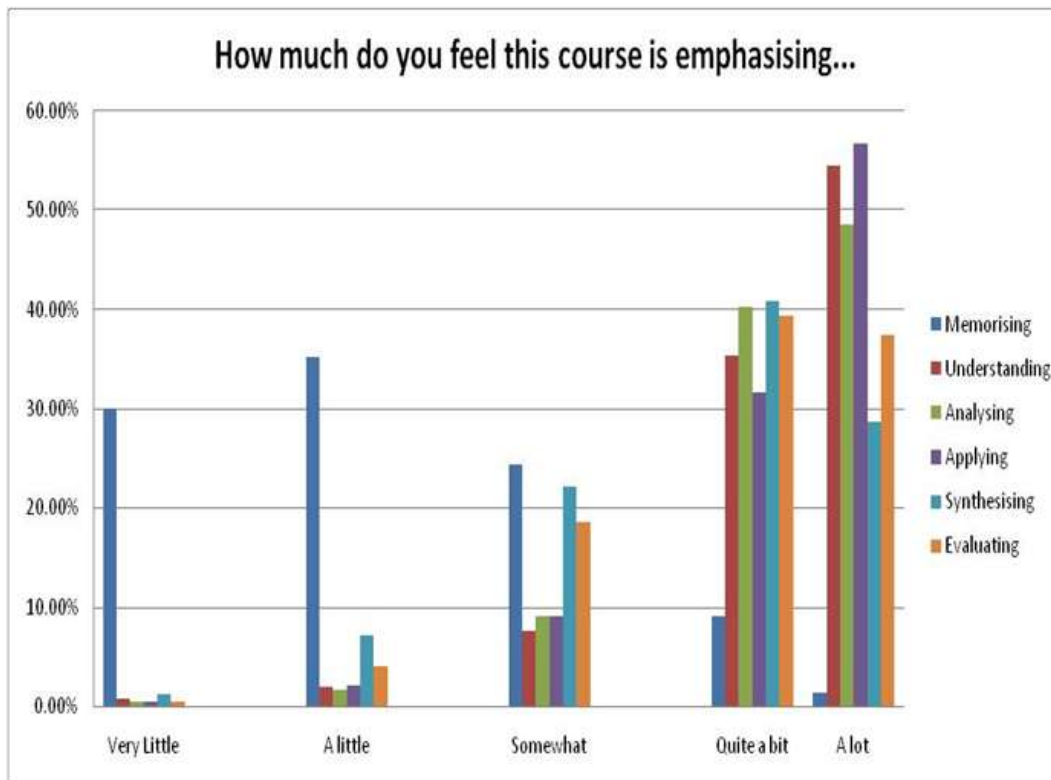




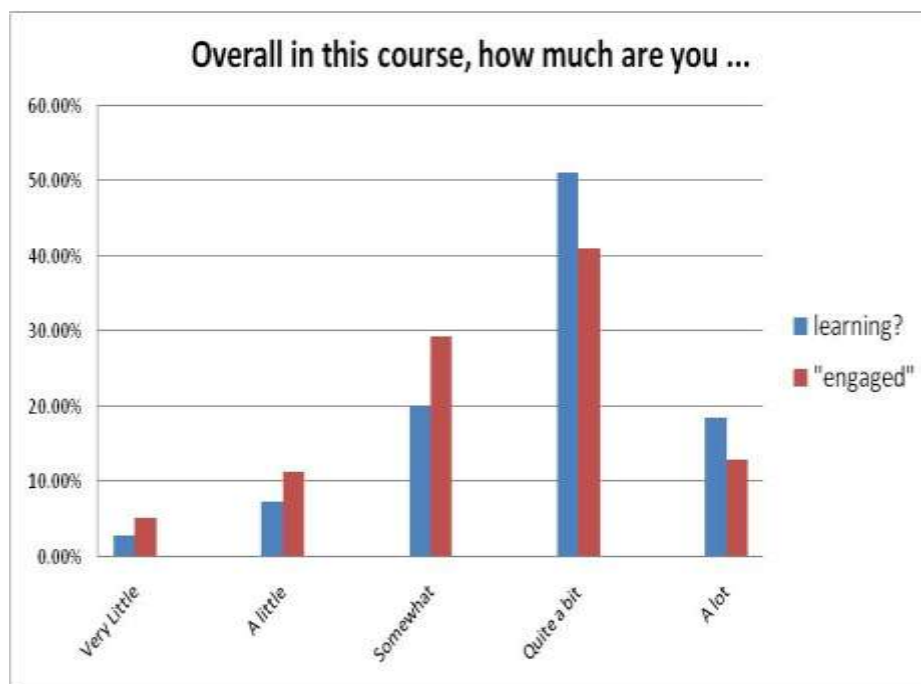
Graph 3: Student responses to the question “How important is mathematics in science?”. Results are shown post-course (left bar in each pair), and pre-course (right bar in each pair; this data is also shown in Graph 2.) The y-axis contains the % of respondents.

5. Overall, students found the range of learning resources and activities to be helpful towards their learning.
6. Responses to assessment were more mixed, with some items poorly perceived (the quantitative reasoning assignment and the programming assignment).
7. Students overwhelmingly agreed that they were supported within the course.
8. Students identified high levels of enthusiasm for mathematics and science as a result of taking this course, although they were substantially more negative about some other aspects, and programming in particular.
9. Responses to Question 23 are particularly illuminating, and arguably demonstrate a high level of success to the broad educational goals of the course. Students were asked to identify to what level the course emphasised thinking and analytical skills at various levels; student responses are summarised in Graph 4. Students identified strongly that the course does not emphasise memorising, but instead focuses much more on developing higher-order thinking skills.
10. Responses to Question 25 are also very encouraging. Students were asked to identify the level to which they were learning in the course, and engaged in the course. The responses are summarised in Graph 5. Overall, students feel that they are learning quite a bit or a lot, and feel a reasonable level of engagement.





Graph 4: Student responses to the question: "How much do you feel this course is emphasising memorising, understanding, analysing, applying, synthesising and evaluating?"



Graph 5: Student responses to the question: "Overall in this course, how much are you learning and engaged?"

In addition to formal evaluations, interesting informal feedback was received from colleagues in mathematics and in science who were given access to materials prior to delivery.

Mathematicians commented that "we thought this course was meant to be highly mathematical, but when we examine the materials, there is very little mathematics there. It is not a mathematics course". This comment is consistent with the comparatively low level of mathematical content in the introductory life science text.



Conversely, scientists commented that “This is not a science course... there is so much mathematics in it”. This comment is consistent with the self-acknowledged low level of mathematical knowledge of many of those staff.

Finally, some students also commented that “This is not a science course.... we don’t have to memorise facts.”

However, it should be noted that all of the above comments were **not** meant in a positive way. Mathematicians thought there should be more mathematics, scientists thought there should be less mathematics, and (some) students just wanted to memorise facts, and indeed used fact memorisation as a key defining attribute of science!

Developing other materials to engage students in the first year learning experience in the life sciences

An additional outcome was publishing a paper, ‘Re-Designing Science Pedagogy: Reversing the Flight from Science’ (McWilliam E, Poronnik P and Taylor PG (2008) *Journal of Science Education and Technology* 17:226-235) that has gained attention both nationally and internationally. This paper has been widely distributed and has been used in a number of ongoing collaborations to help frame new approaches to curriculum innovation and design including the courses described in this report. This work is being continued in ongoing projects between RMIT University and the Centre for Educational Innovation and Technology at UQ.

The Personal Response activity has been embedded within a first-year biology course at UQ and has been through numerous iterations. It was evaluated and published by Moni and Poronnik: ‘The Personal Response: A Novel Writing Assignment to Engage First Year Students in Large Human Biology Classes’ (Moni RW, Moni KB, Lluca LJ and Poronnik P (2007), *Biochemistry and Molecular Biology Education* Vol 35:89–96). This activity has been adopted by other institutions, including Flinders University, University of Technology, Sydney, RMIT University, Victoria University. It was also highlighted in a recent report by Mick Healey and Alan Jenkins “Linking discipline-based research and teaching through mainstreaming undergraduate research and inquiry” (see www2.warwick.ac.uk/fac/soc/).

Overall, these activities emphasise and reinforce the need for students to be presented with multiple and diverse opportunities to engage in their learning experience in the science curriculum. Communication around science together with quantitative literacy are key to a deeper learning experience and creativity is an important component in challenging students to think critically in diverse ways about science.

3.2 Overall conclusions

We believe that a number of overall conclusions can be drawn from this Fellowship:

1. Many groups, nationally and internationally, are struggling to come up with a model for increasing and reinforcing the quantitative and mathematical skills of students in a range of areas, including science.
2. Developing genuinely interdisciplinary learning experiences which are effective and (reasonably) accepted by large groups of students is very difficult, but it can be done. There were components of the course which did not work well, and there were groups of students who did not appear to benefit from the experience. However, overall the response from students was fairly positive.
3. The level of mathematical knowledge required in life science courses is unclear. However, practical experience suggests that the level is not particularly high, and certainly should not be beyond the capabilities of students entering tertiary study having completed intermediate level mathematics to the final year of secondary school.
4. Students appear to enter science study at university with a belief that mathematics is important in the life sciences. It is important that this belief be converted to a functional truth immediately upon commencing a science degree.
5. Developing the direct teaching materials (such as lecture notes and assessment items) is particularly challenging. Many months of skilled effort were required to produce the materials linked to this report, with numerous revisions already completed, and more to



be done. Getting a reasonable balance between mathematical and scientific content is very difficult (and is probably an area for infinite discussion).

6. It is possible to establish courses at the introductory level which require students to understand, analyse, apply, synthesise and evaluate.
7. By its nature, this Fellowship program is inherently interdisciplinary. The close collaboration of two successful research-active tertiary educators, one based in biomedical science and the other in mathematics, allowed us to audit, explore and develop innovative, contextually-relevant and accessible educational interventions, suitable for large and diverse cohorts of students. We do not believe that the Fellowship program could have been undertaken successfully by a single individual based in just one of the discipline areas. Hence we applaud the ALTC for awarding this shared Fellowship, and we hope that similar shared fellowships will continue to be awarded, as appropriate.



4.0 Factors impacting on the Fellowship

4.1 Factors supporting success

The successful outcome of this program arose from a number of critical factors. Some were expected, including:

- The effectiveness of the strong collaboration between a life scientist and a mathematician, thus covering the fundamental interdisciplinarity of the Fellowship;
- The importance of the program area, and the increasing body of relevant literature; and
- Administratively, having a motivated and participatory Fellowship team, and a budget that was reasonable for the nominated activities.

However, there were some unexpected factors that proved to be important to the success of the program, and enabled it to move beyond the initially anticipated scope. In particular, there were two external developments which each opened interesting and valuable opportunities.

First, around the time of the commencement of this project, UQ undertook a comprehensive review of the BSc, a flagship degree with around 1000 students enrolling each year. As a result of this review, for the first time, students in the UQ BSc are required to complete introductory courses with a heavy quantitative content, contextualised into a variety of scientific discipline areas such as biology, chemistry, psychology, physics and earth sciences. There was considerable nervousness amongst teaching staff about how students would “cope” with quantitative content, and how UQ could provide the best possible learning aids and assistance. This Fellowship was a key driver in developing the new course which combined mathematical content, scientific applications and computer programming. Thus, the timing of the Fellowship was ideal in terms of having the opportunity for an immediate and substantial impact.

Second, and at least partially as a result of receiving this Fellowship, both participants benefited from substantial increases to their roles and status after becoming Fellows. For example, Poronnik was promoted to professor, and has since been appointed as Discipline Head of Pharmaceutical Sciences at RMIT University and Research Professorial Fellow at the Centre for Educational Innovation and Technology at UQ (ceit.uq.edu.au). He is also National Secretary of the Australian and New Zealand Association for the Advancement of Science. Poronnik and Adams were appointed co-Chairs of the UQ Revised BSc Joint Management Committee. Adams has been appointed Associate Dean (Academic) in the Faculty of Science, and is now Secretary of the Federation of Australian Scientific and Technological Societies.

We believe that the key lesson for other projects and fellowships is the importance of timing, and the ability to take advantage of unexpected opportunities. This Fellowship was greatly enhanced by being able to align closely with the UQ curriculum review, and being able to take advantage of the increased roles and status of the Fellows.

4.2 Factors inhibitory to success

As noted, this Fellowship received substantial benefit by aligning (and in parts driving) the UQ BSc curriculum review. However, there was also a cost associated with this. Inevitably, this led to a substantial increase in the workload associated with the Fellowship, and in the institution's expectations of the Fellows. At times, managing this proved to be particularly testing. Minor challenges were also faced following the relocation of Poronnik to RMIT University in January 2009.

Hence, while fellowships must always be poised to take advantage as unanticipated opportunities arise, it is crucial for fellows to be wary of allowing their fellowship to take on responsibility for outcomes which are difficult to achieve.



5.0 Applicability to other institutions/locations

Numerous reports have identified that there is a widespread problem with increasing the level of mathematical confidence and competence of students in science, and that the scale and severity of this problem is predicted to increase over time. (Indeed, this problem arises in many areas other than science, including business, engineering and computing.)

There are many approaches which attempt to address this issue. These range from requiring students to take theoretical mathematics courses, to deliberately minimising the depth and breadth of quantitative science which students encounter in their studies.

In this Fellowship, we investigated an approach built around an interdisciplinary teaching program, in which both mathematics and science play important roles. Learning was based on authentic contexts, which demonstrated real science and real mathematics being used by real researchers and practitioners. By doing this, students did not view mathematics as a collection of curious but essentially esoteric techniques, and they did not view science as a set of detailed facts without any quantitative aspects. Evaluation of student responses suggested that the project had a reasonably effective educational outcome.

We believe that there are three areas in which the knowledge and experiences arising from this program can be applied usefully in other institutions. These are:

1. Other individuals and institutions which are seeking to address the issue of quantitative knowledge in science students may wish to examine the *processes* by which introduction of the interdisciplinary course garnered support, the course content was identified, and materials and approaches were developed.
2. The specific *teaching materials* (including lecture notes and assessment items) are likely to be of interest and use as similar courses are developed. Indeed the Personal Response has already been taken up at Flinders University by Karen Burke da Silva, at UTS by Les Kirkup and at Victoria University by Deanne Hryciw, as well as being in its second iteration at RMIT University (Semester 1, 2010).
3. The *evaluation results* are of substantial interest, as they demonstrate clearly that it is possible to introduce this type of learning experience in a successful manner. (At UQ, there was great nervousness before this course was introduced: a senior executive remarked “If this doesn’t work, we could drive many students away from the BSc.”).



6.0 Dissemination

The following dissemination activities have been undertaken:

1. A number of talks and presentations have been held discussing Fellowship activities and outcomes. These include:

- Kelly Matthews, Peter Adams and Merrilyn Goos, 'Putting it into perspective: mathematics in the undergraduate science curriculum', Delta Conference, South Africa, 2009.
- Kelly Matthews, Peter Adams and Merrilyn Goos, 'Translating the principles of BIO2010 into practice', Joint Mathematics Meetings, Washington, 2009.
- Kelly Matthews, Peter Adams and Merrilyn Goos, 'Building the mathematical and computational skills of science students', Joint Mathematics Meetings, Washington, 2009.
- Philip Poronnik and Peter Adams, 'Embedding Quantitative Principles in the Life Sciences', HERDSA, 2007.
- Philip Poronnik and Phillip Long, Uniserve Roundtable on Pedagogies of Uncertainty, 2009.
- Philip Poronnik, 'Teaching science – from the bench to the coalface', *Raising the Profile of Teaching and Learning: Scientists Leading Scientists' Conference*, Adelaide, 2007.
- Philip Poronnik, *Australasian Higher Education Evaluation Forum (AHEEF) 2009* (Byron Bay, keynote address).
- Philip Poronnik and Roger Moni, 'Innovative ways to address pedagogical issues in Science and Engineering Education', Newcastle, 2007.
- Philip Poronnik, 'Engaging students in Large Classes', RMIT Teaching Expo, RMIT, 2008.
- Philip Poronnik, National Creativity Showcase, QUT, 2007, Panel member.
- Philip Poronnik and Matthew Linden, 'Assessing understanding with the personal response', ATN Assessment Conference, Melbourne, 2009.

2. Publications which have arisen from Fellowship activities include:

- Kelly Matthews, Peter Adams and Merrilyn Goos, 'Putting it into perspective: mathematics in the undergraduate science curriculum', *International Journal of Mathematical Education in Science and Technology*, volume 40, issue 7, (2009), 891-902.
- Erica McWilliam, Philip Poronnik and Peter Taylor, 'Re-Designing Science Pedagogy: Reversing the Flight from Science', *Journal of Science Education and Technology*, volume 17, no.3, (2008), 226-235.
- Roger Moni, Karen Moni and Philip Poronnik, 'The Personal Response: A Novel writing assignment to engage first year students in large human biology classes', *Biochemistry and Molecular Biology Education*, volume 35, issue 2, (2007), 89-96.
<http://www3.interscience.wiley.com/cgi-bin/fulltext/114174628/PDFSTART>
- Roger Moni, Deanne Hryciw, Philip Poronnik and Karen Moni, 'Using explicit teaching to improve how bioscience students write to the lay public', *Advances in Physiology Education*, volume 31 issue 2, (2007), 167-175.
<http://advan.physiology.org/cgi/reprint/31/2/167?maxtoshow=&hits=10&RESULTFOR=MAT=&author1=poronnik&searchid=1&FIRSTINDEX=0&sortspec=relevance&resource=HWCIT>



3. Materials developed in this course have been made broadly available (for example, copies of some materials are included with this report). Individuals with whom materials have been shared include:
 - Debra L. Hydorn, Professor, Department of Mathematics, University of Maryland, Washington
 - Milo Schield, Professor, Augsburg College, Director, W. M. Keck Statistical Literacy Project, Vice President, National Numeracy Network, Web Manager, www.StatLit.org
 - Jeff Reitz, Professor of Mathematics, Garrett College, USA
 - Dr. Jeff Knisley, Interim Chair, Department of Mathematics, East Tennessee State University
 - Andy Long, Northern Kentucky University
4. Participation in the Quantitative Reasoning PKAL workshop at Carleton College in USA (2008).
5. Participation in PKAL Learning Spaces Workshop at George Washington University in USA (2008).
6. Visits to St. Olaf's College, University of Minnesota and Macalester University.
7. Visit to University of Maryland (2009) for discussions with the creators of Mathbench.
8. Visit to Carl Weiman Science Education Initiative UBC Vancouver (2007), which resulted in enrolment of a PhD student who is researching quantitative skills in undergraduate science education (2008 – 2012)
9. Following an ALTC workshop in Brisbane in October 2009, the ALTC issued a press release describing some of the fellowship goals and activities (although it is doubtful whether the story appeared anywhere in the press).



7.0 Links with other ALTC Fellows and projects

During the life of this fellowship, we had the benefits of interactions with other ALTC fellows.

1. ALTC Senior Fellow Professor Helen MacGillivray (2006) has substantial expertise in learning and teaching statistics, specialising in approaches which are suitable for students not intending to major in statistics. Professor MacGillivray was very generous with her time and knowledge, and particularly helpful in discussions around the appropriateness of the use of contextualisation, and risks associated with using this approach. (We also provided some advice to Professor MacGillivray on her Fellowship activities, but her contribution to ours was considerably more substantial!) We believe that the outcomes of Professor MacGillivray's Fellowship and our Fellowship are mutually supportive, given the related (but distinct) focuses of the programs.
2. ALTC Senior Fellow Professor Sally Kift (2006) is an expert in the first year experience and she provided valuable insights and advice as to pitfalls and other aspects in the design of our first year courses.
3. ALTC Fellow Professor Erica McWilliam has particular expertise in issues around creativity in an educational context. She provided advice and inspiration as our fellowship proceeded.
4. ALTC Fellow Professor Marilyn Goos is an acknowledged national expert authority on mathematics education, particularly at the secondary level. She was always particularly interested in, and encouraging of, our activities in this area. Indeed, subsequent to completion of the Fellowship, Goos and Adams have taken on joint supervision of two PhD students working on aspects of embedding quantitative and mathematical principles in entry-level tertiary courses.
5. ALTC Fellow Dr Michael Bulmer has great experience in teaching quantitative material to students in a range of discipline areas. Indeed, he taught statistics to the same group of students who took the course developed in this Fellowship. His advice and encouragement were important to the success of this program.
6. ALTC Fellow Dr Roger Moni played a major role in the communication aspects of this program. His expertise and collaboration were essential to the success of the program in this area.
7. Other ALTC projects in which we were involved included the "Scientists leading scientists" project with Dr Karen Burke da Silva and the "Biology Concept Inventory" (Charlotte Taylor, Pauline Ross).
8. Part of our work continues in other ALTC projects. Poronnik is a team member of a 2009 ALTC project, led by Dr Shane Dawson at the University of Wollongong, on social network analysis. Adams is a co-investigator on a 2008 ALTC project, led by Professor Lawrie Gahan and Dr Gwen Lawrie at UQ, on group inquiry and assessment in introductory chemistry courses.
9. Perhaps more important than these individual links, we would like to highlight the value of being part of a network of distinguished, talented, sensible and generous fellows. The ALTC has nurtured a very effective group of outstanding participants in the Australian higher education sector. We know that in the event of questions, doubts or difficulties, we will receive a high level of expertise and support from our colleagues.

Finally, perhaps the most significant aspect of the Fellowship is that it provided the foundation for two academics with strong discipline-based research profiles and expertise in teaching to realise the importance of an evidence-base to underpin curriculum innovation. This Fellowship has provided the foundation and networks for future projects and collaborations to improve the undergraduate science curriculum.



8.0 Appendices

Appendix A: Investigation



Investigation into mathematics in tertiary biology

J. D. Bartlett

December 2008

Motivation

Numerous academics have lamented the lack of quantitative skills and mathematical understanding of many tertiary biology students. It is generally agreed that a tertiary-level biology programme should teach the mathematical techniques and methods which are required for a full understanding of biology. The obvious question which arises is “What techniques and methods are required for a full understanding of biology?”.

In this study we investigate quantitatively what mathematical techniques are used and taught as part of an introductory tertiary-level biology programme. We believe that no previous study has done this. The data from this study shows only what is taught to tertiary biology students; it does not show what should be taught.

Approach

We selected the textbook *Biology* by Campbell et al (2006, 7th edition, Australian version) as a focus for this study. This is the textbook used at the University of Queensland for many of the first-year biology subjects. It was selected for this study because it covers many facets of life sciences including genetics, plant and animal biology and ecology.

The basic unit of analysis for this study was a page of the textbook. For a given page, a researcher identified any elements on the page which were deemed to either present or require some quantitative or mathematical understanding or technique (within certain constraints discussed below). For example, a graph with logarithmic scales would count as such an element, as would a mathematical formula. The researcher then classified each of these elements based on its topic, intensity, style, purpose and number of variables. This scoring schema was designed in the hope that the same scoring system will be useful in future for investigating the mathematics in life science journal articles. These different axes of classification are explained in more detail below.

Axes of classification

Topic

For each page we recorded the topics, or areas of mathematics, that were used on the page. These topics were selected from a list of topics which we had compiled. The list was compiled with an aim to cover much of mathematics. We aimed for it to be adequate to cover what one would expect to find in both introductory and advanced biology, but not limited to only what one would expect. The list of topics which we used was quite detailed and is presented here:

Statistics, design and sampling:	multiple groups	Orthogonality (experimental design)	sampling
Descriptive statistics	Precision vs. accuracy	Informal sampling	Sophisticated sampling
Statistical comparison of 2 groups	Randomising (experimental design)	Simple random sampling	method (any method not covered by informal, simple random, stratified, matched sampling)
Statistical comparison of	Block design	Stratified sampling	
	Named experimental design	Matched (case-control)	

Basic rates and fractions:	Affine solution ($ax+b = c$)	Sequences and series	(big O notation etc.)
Fractions, ratios, percentages	Translation	Limits, asymptotes	Information (includes
(anything which denotes a numerical measure of proportion)	Magnification	Integration techniques	encoding, storage, amount of information)
Rate as difference quotient (calculating a rate or average rate using a quotient)	Rotation	Line integrals	Electronic data organisation (structure of databases)
Finite differences	General linear transformation	Area integrals	Use of databases
Unit operations, conversions, comparisons.	Non-linear transformation (e.g. Conformal mapping)	Volume integrals	
Optimisation by trial and error	Logarithms	Differentiation techniques	
	Exponentials	Partial differentiation	
	Trigonometric functions	Optimisation concept (the idea of there being an optimum)	Geometry:
	Periodicity (discussion of periodic phenomena; calculation of period, amplitude, etc.)	Analytical optimisation	Geometric description (e.g. ellipse, archimedian spiral)
	Quadratics	Numerical optimisation	Lengths/distances
	Any other mathematical functions (e.g. erf())	Numerical integration	Angles
Probabilities:	Conceptual relationship (conceptual understanding/description of a relationship without mathematical description)	Linear approximation	Geometric relationships (e.g. interior angles of triangle sum to 180 degrees)
Probabilities (basic probabilities, multiplication and addition rules)	Partial fractions	ODEs	
Probability distribution (whether discrete or continuous)	Matrix inverses	PDEs	
Marginal/conditional probability	Eigenvalues/vectors		
Bayes law	Matrix determinants	Discrete mathematics:	Equilibria:
Named distribution (e.g. normal, binomial etc.)	Subspaces	Graphs and trees	Equilibrium existence (talking about or showing that an equilibrium exists)
	Complex numbers	Algorithms/statistics of graphs and trees (e.g. path lengths, traversals)	Equilibrium stability
Algebra and functions:		Combinatorics	Equilibrium bifurcations and parameter dependence
Linear solution ($ax = b$)	Calculus:	Information and programming:	Oscillations
	Differentiation/integration	Programming for a specialised purpose (e.g. programming a computational model)	Other:
	Second derivative	Computability / complexity	Chaos
			Negative feedback
			Positive feedback
			Symmetry and pattern

Style

For each item on each page, one of the following four styles was recorded.

<i>Style</i>	<i>Description</i>
Graphical	The item is presented graphically.
Numerical/Tabular	The item is presented numerically or in a table.
Simple analytic	The item is presented as a simple formula or analytic description.
Complicated analytic	The item is a complicated formula, derivation or analytic description.

By “analytic description” we mean something which may not technically be a formula, but may use words or symbols to explain the relationship or concept presented.

The first two possible styles should be fairly self-explanatory. The difference between the last two is supposed to represent the difference between, for instance, a simple proportionality equation, and the Nernst Equation. Because there is no clear definition of what is meant by “simple” and “complicated”, we can expect that which of these two categories that some of the results fall into will be subjective and therefore not completely consistent.

Purpose

For each item on each page, the apparent purpose of the item was recorded to be one of the following options:

<i>Purpose</i>	<i>Description</i>
Data presentation	The purpose of the item is to present data.
Concept/principle presentation	The purpose of this item is to present a known concept or principle.
Apply known principles	The purpose of this item is to explain data based on known models or relationships.
Derivation/proof	The purpose of this item is to derive a model or explanation starting with assumptions and known principles.
Model presentation	This purpose of the item is to present a mathematical model (without its derivation).

Note that the purpose of concept/principle presentation does not necessarily mean that a mathematical concept or principle is being presented. More often this may be a biological concept or principle which involves use of a mathematical topic. For instance, presenting the fact that $pH = -\log_{10}[H^+]$ would be recorded as presentation of a concept or principle, under the topic of logarithms.

The researcher cannot know for certain the purpose of the author in including a item, but can make a reasonable estimation of the purpose based on the context.

There are some situations, especially within the context of ecology, where it is difficult to know whether a particular result should be recorded as a model presentation or as a concept/principle presentation. For instance, the logistic equation is clearly a mathematical population model, but it is such a well-known model and it is presented not for the purpose of students seeing how the model is derived from the data, but simply so that the students know what the logistic model is and when it is used. These situations have most often been recorded as concept/principle presentation, and have only been recorded as model presentation when in the opinion of the researcher, the main purpose of the equation is to present a mathematical model.

Number of Variables

The number of variables of each item was recorded as N/A, univariate, bivariate, trivariate or multivariate. Of all the classification axes, this was the one which was specified least precisely and was therefore used least consistently. As an example of how the confusion arose, consider the Nernst equation:

$$E_{ion} = 62 \text{ mV} \left(\log \frac{[ion]_{outside}}{[ion]_{inside}} \right)$$

Mathematically, this equation has three variables. Physically, $[ion]$ is a single variable that has different values in different regions of space, so this equation could be considered to have two variables only. In fact, the researcher scored this equation as univariate because he deemed that in the context that the equation was presented, the only variable of interest was the equilibrium potential, E_{ion} . There was some confusion over how recording the number of variables in a given item actually contributed to the aim of this investigation.

Intensity

Finally, each item was scored on an intensity scale. Each item was given an intensity of 1, 2 or 3 based on how important the researcher deemed the given mathematical topic for the purpose of understanding the material presented. An intensity of one meant that the mathematical topic was used peripherally or that a shallow understanding of the topic would suffice, whereas an intensity of three meant that a clear understanding of the topic was critical to understanding the concepts presented on the page.

This investigation set out to gather data, not to educate the researcher on every detail of tertiary-level biology. The researcher was not required to pore over the page until he could make a well-considered decision as to how important a given mathematical topic was to the biological topic in question. The intensity values recorded are judgements based on a simple evaluation of the context.

In order to provide a clearer indication of what is meant by intensity, this document's Appendix contains examples of items recorded with the same topic but different intensities.

What counts as mathematical

There has to be some limit to what is and is not counted as worth recording. As an example, page 12 of Campbell et al says "This enormous diversity of life includes approximately 5,200 known species of prokaryotes". If the researcher had recorded every piece of rough numerical information in the textbook, not only would the work of the researcher have been significantly increased, but this extra data would not have served the purpose of the investigation. The principal aim of the investigation is to gather data to help inform the discussion of what mathematics should be taught in tertiary biology courses. Knowing how often tertiary biology students are required to recognise simple numerical information would seem pointless as it is hard to imagine that any significant number of biology students would reach a tertiary level and still need to be taught how to read numbers.

On the other hand, one must be careful not to carry this logic too far. Part of the very reason for this study is that tertiary biology students have been observed to have little grasp of mathematics which they have apparently been taught at a secondary level.

In order to be consistent in the recording of data, the researcher did not record any of the following: scales on diagrams and rough numerical information (except in contexts which make use of other mathematical concepts).

Similarly, while graphs are a means to present quantitative information, presentation of such information may not require significant mathematical understanding. We assume that students know how to read basic graphs. This includes graphs which compare different groups. Of course if a statistical comparison is used, this would be recorded.

The list of mathematical topics includes a topic entitled "fractions, ratios, percentages". The researcher recorded every occurrence of a fraction, ratio or percentage in that category with an intensity of one. Higher intensities under this topic were used for situations which required a deeper understanding of fractions, ratios or percentages. In hindsight, it would have been more sensible not to record simple numerical percentages and fractions in cases where no more understanding is required than to read the number. For consistency however, these things were recorded throughout the textbook. This resulted in a large number of pages which had an intensity of one in the "fractions, ratios, percentages" topic. These may be taken as an indication of how thoroughly the pages were covered.

While there is a topic for units, this topic was not used to record every instance of a unit being used, only cases where a unit was introduced or explained, or where unit manipulation was required. The introduction and definition of a unit was consistently considered to have a purpose of data presentation rather than presentation of a principle.

Other notes

Specifics of method

Every page in the textbook was sampled with the exception of pages which contained only questions. Pages which contained both teaching material and questions were sampled, but only the sections of the page containing teaching material was examined. The same researcher sampled and scored the entire textbook.

Uniqueness and unit of analysis

The unit of analysis for this investigation is a page. This was chosen partly so that the researcher did not have to try to decide how many times a particular mathematical concept was used. It was either present on a given page, or absent. Since there are several axes of classification, this concept should be specified more precisely. Within a given page, each combination of mathematical topic, style, purpose and intensity was recorded only once. Number of variables was not included because it was not defined precisely and caused some confusion. So for instance, if there were two graphs presenting data and demonstrating logarithms deemed to have an intensity of one, only a single entry would be made for that page. If logarithms were demonstrated both in a graph and in the text, two entries would be made, one with graphical style and one with simple analytical style.

Sometimes a single phrase, graph or formula would fall under more than one mathematical topics. In this case, multiple entries would be recorded for that particular page.

Results and analysis

In this section the results of the investigation are presented graphically. The results are presented grouped by topic, style and purpose, as well as topic/style and topic/purpose combinations.

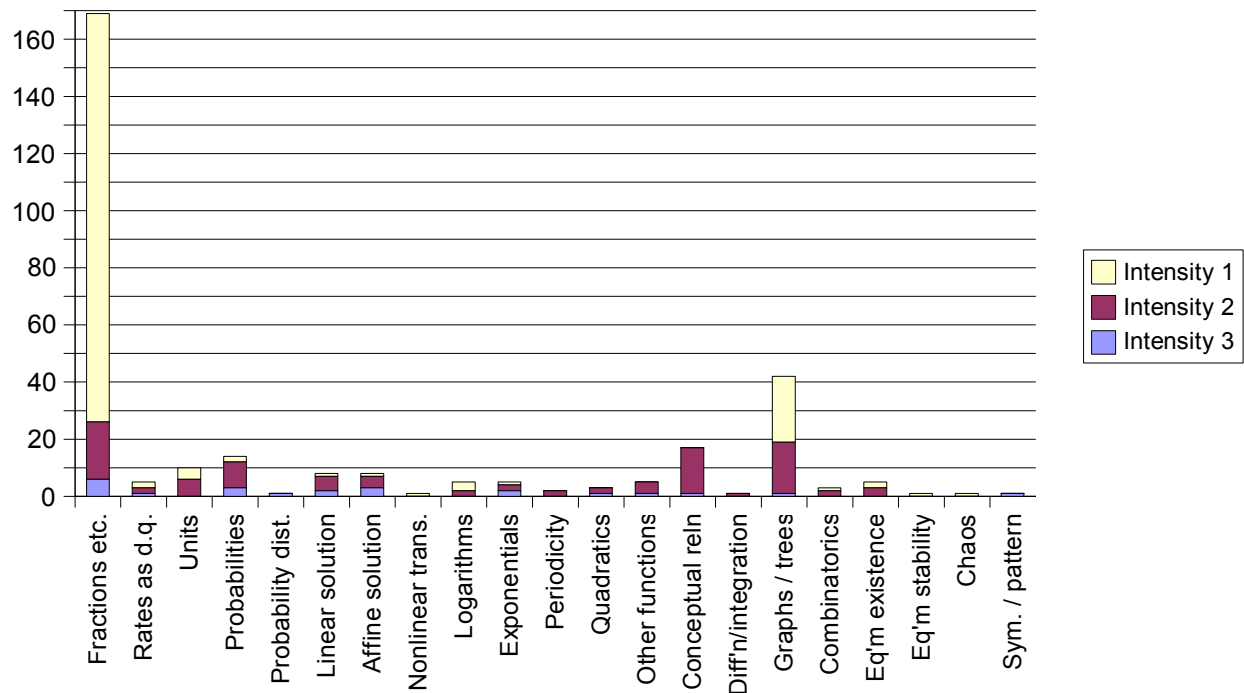
Not all mathematical topics were encountered during the investigation. Every topic which is included in the list of topics earlier in this report but does not appear in the graphs below was not encountered by the researcher during the investigation. Because the chosen unit of analysis for the investigation was a page, results are all presented in terms of number of pages.

The results in a number of the graphs below are grouped based on intensity. In these cases, the grouping is based on the greatest intensity of all items of that topic, style or purpose on that page. For instance, if a page contained two items within the fractions topic, of intensities two and three, the page would be displayed on the topics graph with an intensity of three. See the discussion on uniqueness and unit of analysis above for further information.

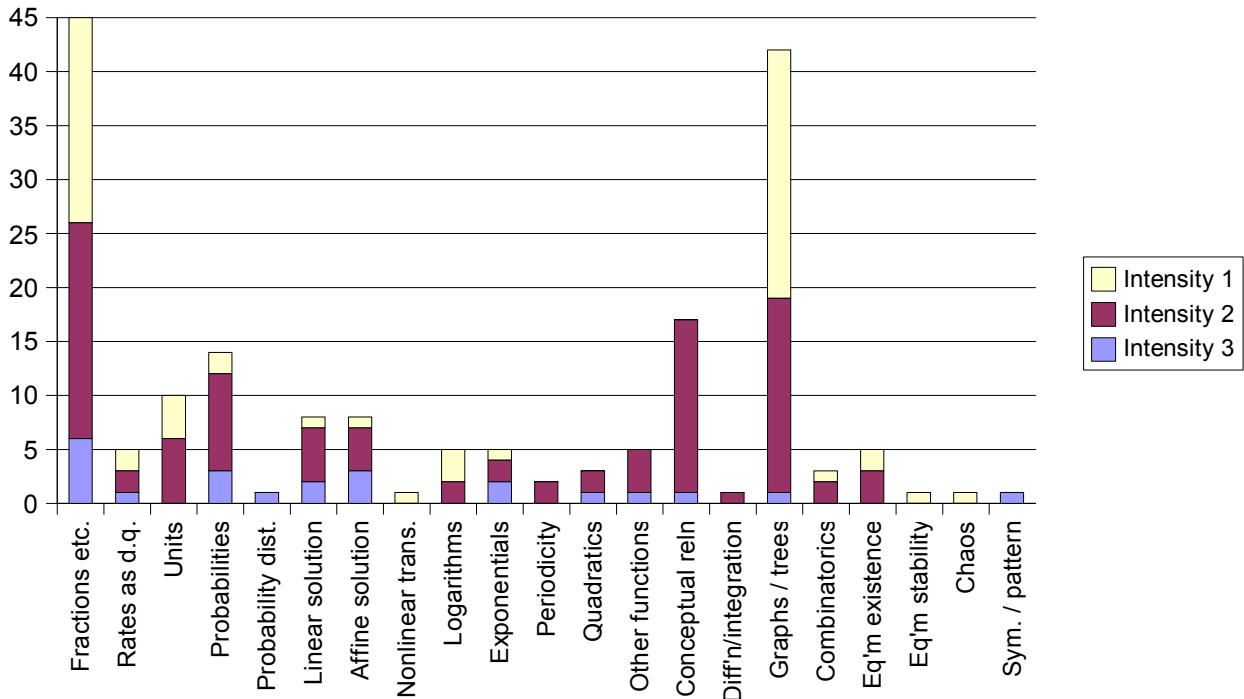
Mathematical Topics

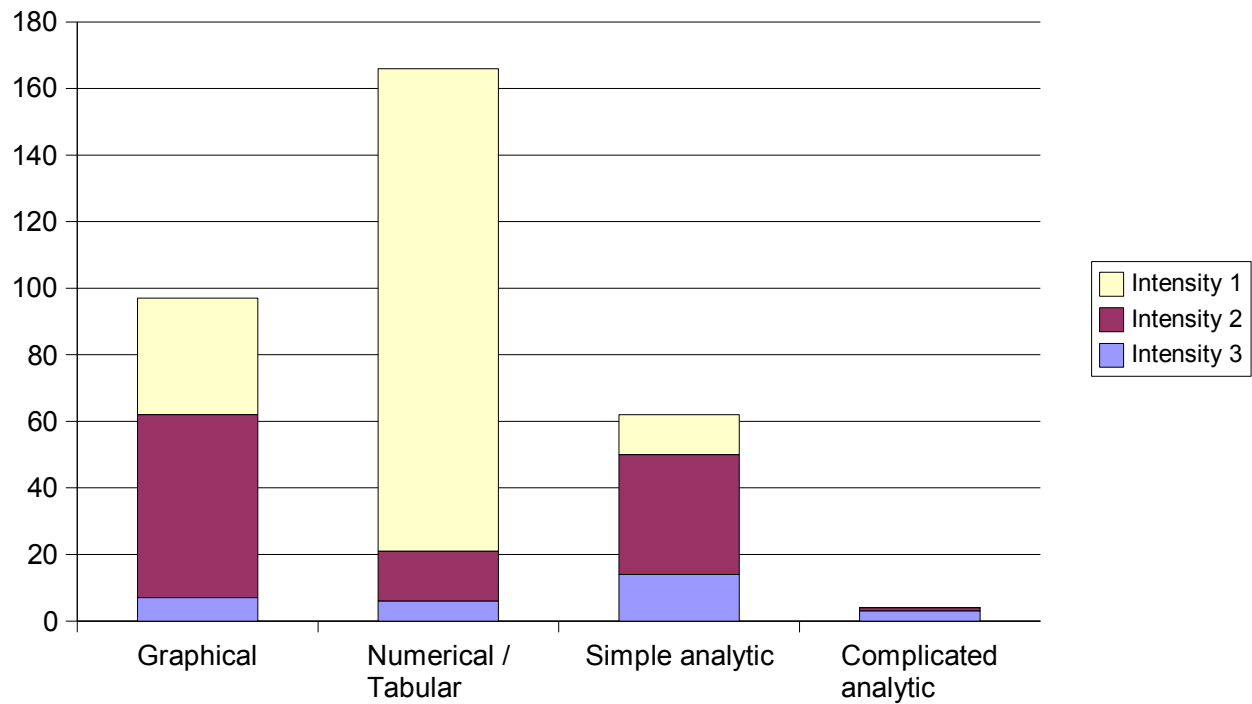
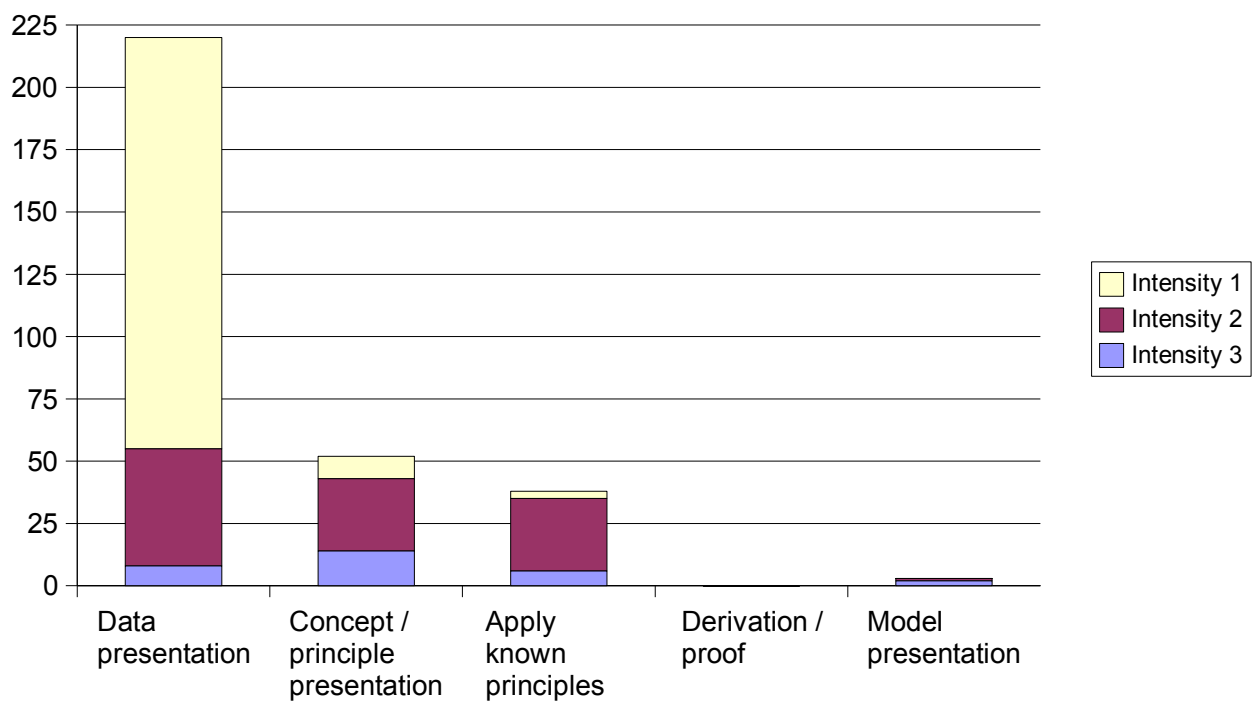
As discussed previously, there were many results with an intensity of one and a topic of fractions, ratios and percentages. For this reason, two graphs have been presented. The second is simply a closer view of part of the first.

Number of Pages by Topic



Number of Pages by Topic

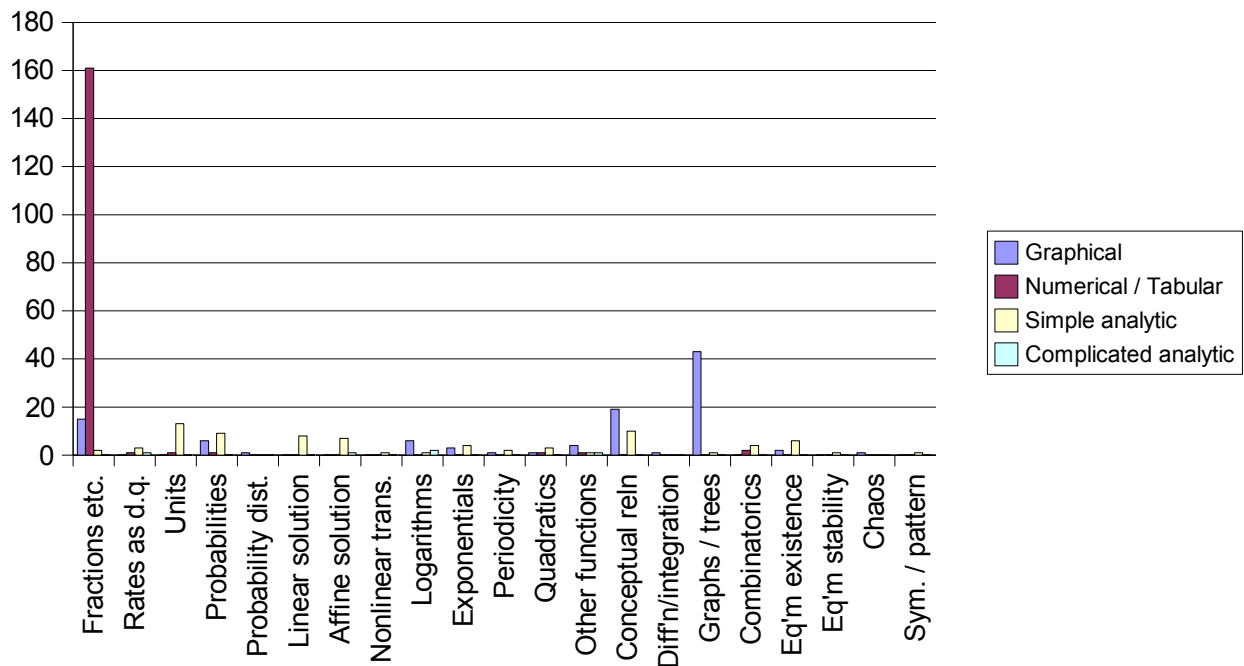


Style**Number of Pages by Style****Purpose****Number of Pages by Purpose**

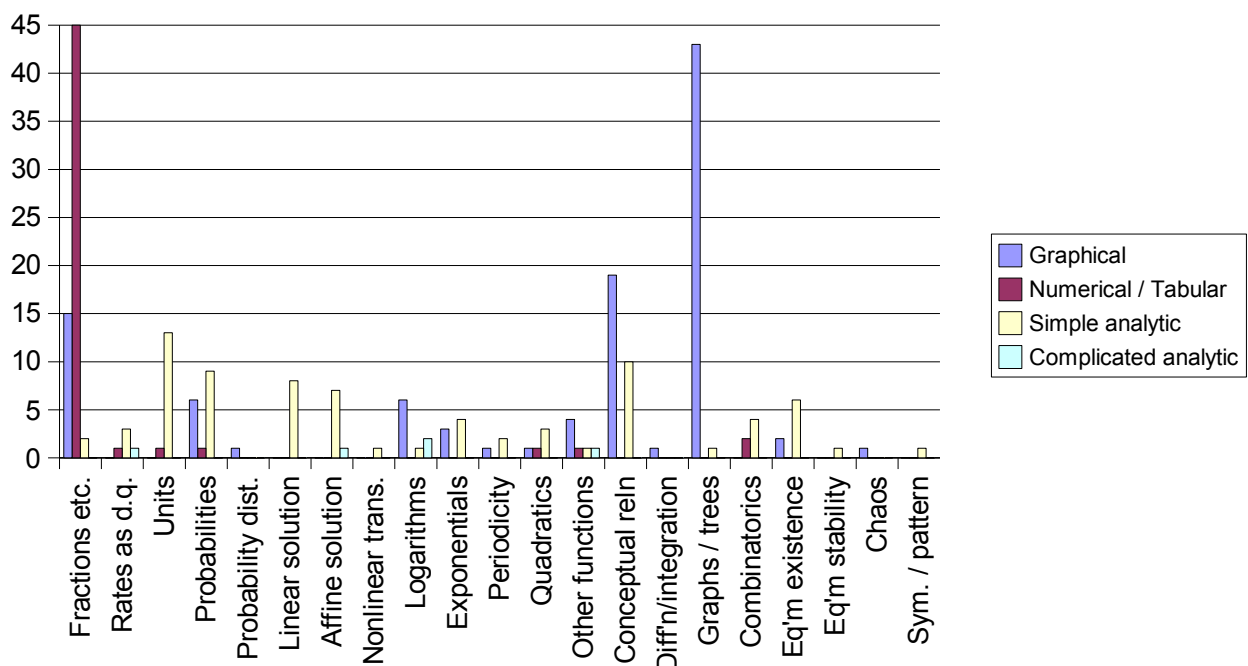
Topic and style

In this section the results are presented grouped by both topic and style. A given page is counted once for every unique topic/style combination which was recorded on that page. The two graphs present the data in the same way except that the second shows a closer view in order to show more detail.

Number of Pages by Topic and Style



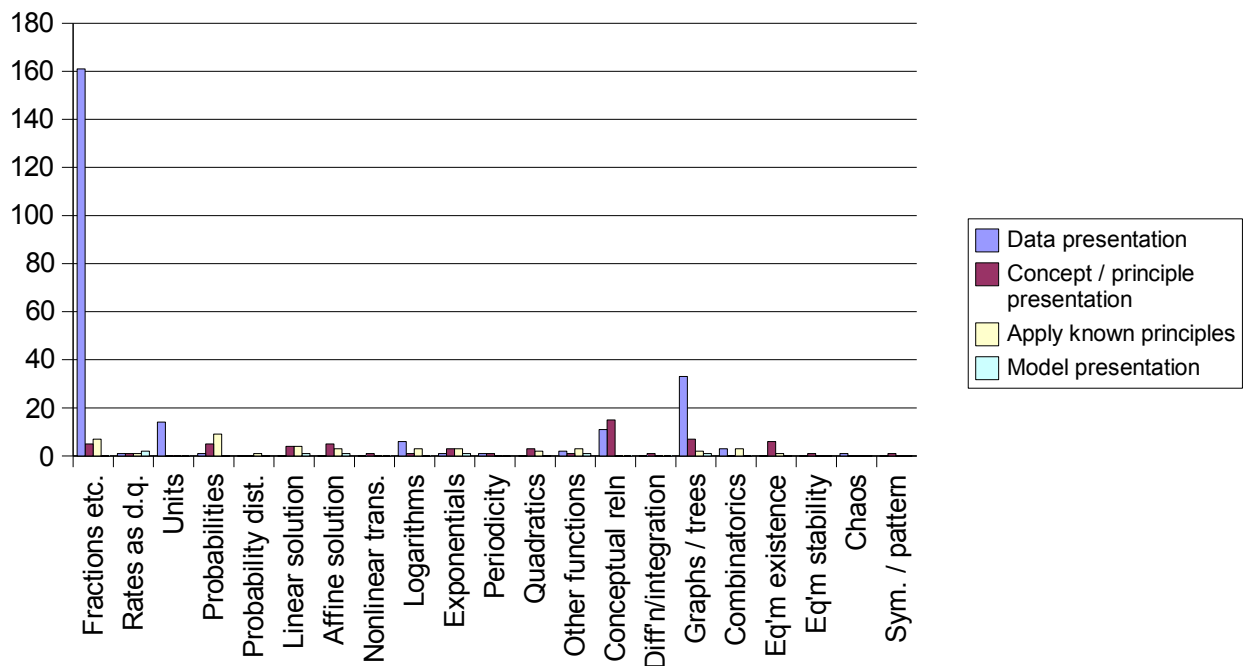
Number of Pages by Topic and Style



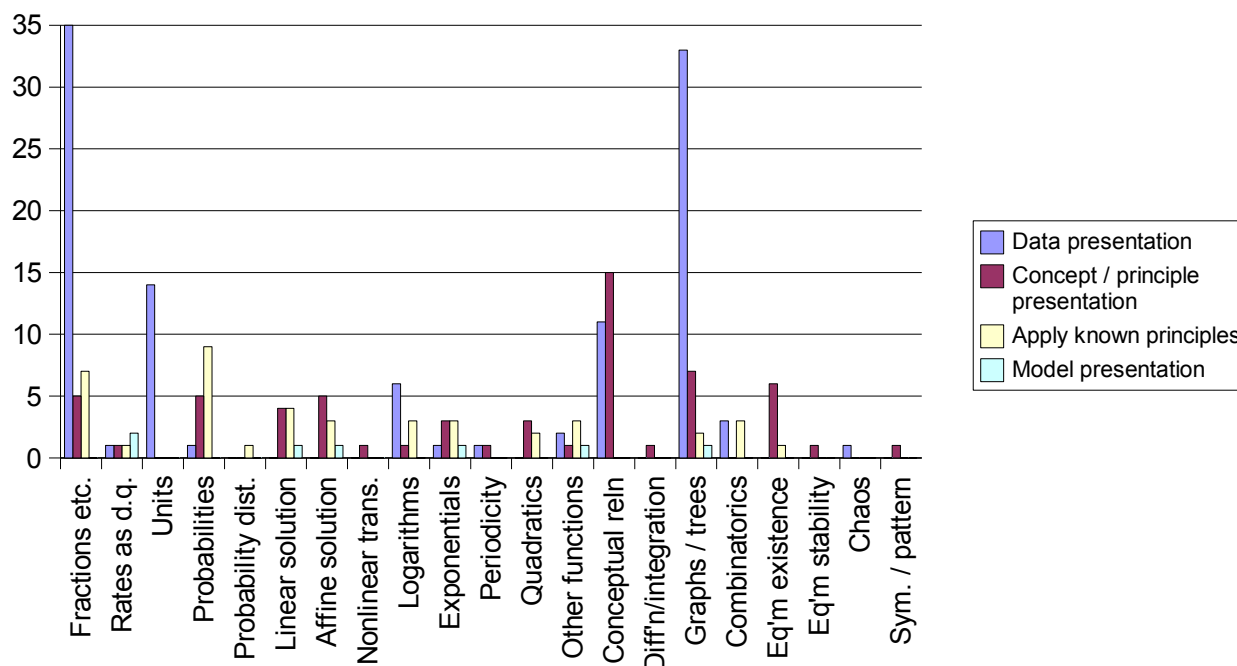
Topic and Purpose

In this section the results are presented grouped by both topic and purpose. A given page is counted once for every unique topic/purpose combination which was recorded on that page. The two graphs present the data in the same way except that the second shows a closer view in order to show more detail. The derivation/proof purpose has been omitted from these graphs because no results were recorded with that purpose.

Number of Pages by Topic and Purpose



Number of Pages by Topic and Purpose



Conclusion

We set out to gain quantitative data about what mathematical techniques are used and taught as part of an introductory tertiary-level biology programme. This data was gathered and indicates that tertiary-level biology only makes use of concepts from a specific subset of mathematics. In order to draw balanced conclusion from this data with regard to what mathematics should or should not be taught to biology students, a similar study should be done on journals and other literature which researchers in the field of life science are expected to read and understand, and the results of the study should be compared with these results.

Appendix: Example data demonstrating intensity

In order to demonstrate more clearly what is meant by intensity, the following examples were chosen from the data set. These examples are meant to illustrate the differences between the different intensity values. For each of two topics, examples of items of each different intensity value were chosen. For each of these items, a scan of the page and a brief description of the item is provided.

preservation of genetic variation provides the opportunity for natural selection to act over many generations.

Let's apply the Hardy-Weinberg theorem to our hypothetical wildflower population. Recall that 80% (0.8) of the flower-color alleles in the gene pool are C^R and 20% (0.2) are C^W . Because each gamete produced by the flowers is haploid, it carries only one allele for flower color. The chance that a gamete will carry a C^R allele is 0.8, and the chance that it will carry a C^W allele is 0.2. The allele frequencies in all the gametes produced by the population will be the same as in the original population. Provided that gametes are contributed to the next generation at random, allele frequencies will be unchanged.

Hardy-Weinberg Equilibrium

Suppose that the individuals in a population not only donate gametes to the next generation at random but also mate at random—that is, all male-female matings are equally likely. Not only will this population have the same allele frequencies from one generation to the next, but its genotype frequencies can be predicted from the allele frequencies. Such populations are in a state of **Hardy-Weinberg equilibrium**.

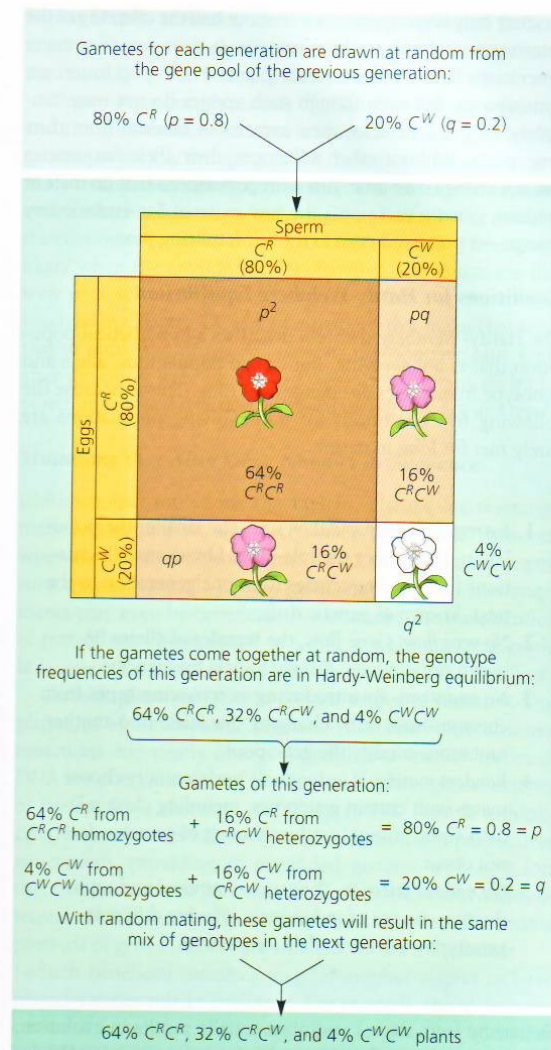
It turns out that our wildflower population is in Hardy-Weinberg equilibrium (Figure 23.5). Using the rule of multiplication (see Chapter 14), we can calculate the frequencies of the three possible genotypes assuming random unions of sperm and ova. The probability that two C^R alleles will come together is $0.8 \times 0.8 = p \times p = p^2 = 0.64$. Thus, about 64% of the plants in the next generation will have the genotype $C^R C^R$. The frequency of $C^W C^W$ individuals will be about $0.2 \times 0.2 = q^2 = 0.04$, or 4%. $C^R C^W$ heterozygotes can arise in two different ways. If the sperm provides the C^R allele and the ovum provides the C^W allele, the resulting heterozygotes will be $0.8 \times 0.2 = 16\%$ of the total. If the ovum provides the C^R allele and the sperm the C^W allele, the heterozygous offspring will make up another $0.8 \times 0.2 = 16\%$. We can summarize these unions of gametes in an algebraic equation:

$$\begin{array}{ccccc} (p + q) & \times & (p + q) & = & p^2 + 2pq + q^2 \\ \text{Allele} & & \text{Allele} & & \text{Genotype frequencies} \\ \text{frequencies of} & & \text{frequencies of} & & \text{in the next generation} \\ \text{male gametes} & & \text{female gametes} & & \end{array}$$

As with allele frequencies, all of these genotype frequencies sum to 1. Thus, the equation for Hardy-Weinberg equilibrium states that at a locus with two alleles, the three genotypes will appear in the following proportions:

$$p^2 + 2pq + q^2 = 1$$

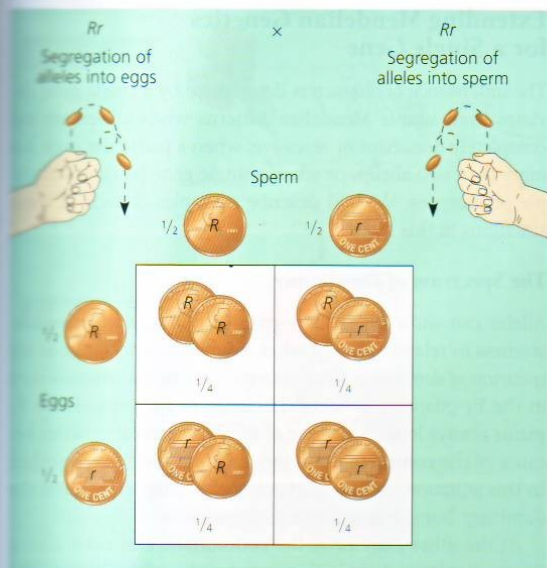
If a population were in Hardy-Weinberg equilibrium and its members continued to mate randomly generation after generation, allele and genotype frequencies would remain constant. The system operates somewhat like a deck of cards: No matter how many times the deck is reshuffled to deal out new hands, the deck itself remains the same. Aces do not grow more numerous than jacks. And the repeated shuffling of a population's



▲ **Figure 23.5 The Hardy-Weinberg theorem.** In our wildflower population, the gene pool remains constant from one generation to the next. Mendelian processes alone do not alter frequencies of alleles or genotypes.

gene pool over the generations cannot, in itself, change the frequency of one allele relative to another.

Note that a population does not need to be in Hardy-Weinberg equilibrium for its allele frequencies to remain constant. Many species, such as the peas that Mendel used in his experiments, do not mate randomly. Since pea pollen normally matures before the flower opens, it fertilizes the same flower that contains it. (Mendel could cross his pea plants only by artificial fertilization.) Because of self-fertilization, pea populations are far from Hardy-Weinberg equilibrium. All the homozygous plants



▲ Figure 14.9 Segregation of alleles and fertilization as chance events. When a heterozygote (Rr) forms gametes, segregation of alleles is like the toss of a coin. We can determine the probability for any genotype among the offspring of two heterozygotes by multiplying together the individual probabilities of an egg and sperm having a particular allele (R or r in this example).

the egg and the recessive allele from the sperm—is $1/4$. The probability for the other possible way—the recessive allele from the egg and the dominant allele from the sperm—is also $1/4$ (see Figure 14.9). Using the rule of addition, then, we can calculate the probability of an F_2 heterozygote as $1/4 + 1/4 = 1/2$.

Solving Complex Genetics Problems with the Rules of Probability

We can also apply the rules of probability to predict the outcome of crosses involving multiple characters. Recall that each allelic pair segregates independently during gamete formation (the law of independent assortment). Thus, a dihybrid or other multi-character cross is equivalent to two or more independent monohybrid crosses occurring simultaneously. By applying what we have learned about monohybrid crosses, we can determine the probability of specific genotypes occurring in the F_2 generation without having to construct unwieldy Punnett squares.

Consider the dihybrid cross between $YyRr$ heterozygotes shown in Figure 14.8. We will focus first on the seed-color character. For a monohybrid cross of Yy plants, the probabilities of the offspring genotypes are $1/4$ for YY , $1/2$ for Yy , and $1/4$ for yy . The same probabilities apply to the offspring genotypes for seed shape: $1/4$ RR , $1/2$ Rr , and $1/4$ rr . Knowing these

probabilities, we can simply use the multiplication rule to determine the probability of each of the genotypes in the F_2 generation. For example, the probability of an F_2 plant having the $YYRR$ genotype is $1/4 \times 1/4 = 1/16$. This corresponds to the upper left box in the Punnett square on the right in Figure 14.8. To give another example, the probability of an F_2 plant with the $YyRR$ genotype is $1/2$ (Yy) $\times$ $1/4$ (RR) = $1/8$. If you look closely at the Punnett square on the right in Figure 14.8, you will see that 2 of the 16 boxes ($1/8$) correspond to the $YyRR$ genotype.

Now let's see how we can combine the multiplication and addition rules to solve even more complex problems in Mendelian genetics. For instance, imagine a cross of two pea varieties in which we track the inheritance of three characters. Suppose we cross a trihybrid with purple flowers and yellow, round seeds (heterozygous for all three genes) with a plant with purple flowers and green, wrinkled seeds (heterozygous for flower color but homozygous recessive for the other two characters). Using Mendelian symbols, our cross is $PpYyRr \times Ppyyrr$. What fraction of offspring from this cross would be predicted to exhibit the recessive phenotypes for at least two of the three characters?

To answer this question, we can start by listing all genotypes that fulfill this condition: $ppyyRr$, $ppYyrr$, $Ppyyrr$, $Ppyyrr$, and $ppyyrr$. (Because the condition is at least two recessive traits, the last genotype, which produces all three recessive phenotypes, counts.) Next, we calculate the probability for each of these genotypes resulting from our $PpYyRr \times Ppyyrr$ cross by multiplying together the individual probabilities for the allele pairs, just as we did in our dihybrid example. Note that in a cross involving heterozygous and homozygous allele pairs (for example, $Yy \times yy$), the probability of heterozygous offspring is $1/2$ and the probability of homozygous offspring is $1/2$. Finally, we use the addition rule to add together the probabilities for all the different genotypes that fulfill the condition of at least two recessive traits, as shown below.

$ppyyRr$	$1/4$ (probability of pp) $\times$ $1/2$ (yy) $\times$ $1/2$ (Rr) = $1/16$
$ppYyrr$	$1/4 \times 1/2 \times 1/2$ = $1/16$
$Ppyyrr$	$1/2 \times 1/2 \times 1/2$ = $1/16$
$Ppyyrr$	$1/4 \times 1/2 \times 1/2$ = $1/16$
$ppyyrr$	$1/4 \times 1/2 \times 1/2$ = $1/16$
Chance of at least two recessive traits = $5/16$ or $3/8$	

With practice, you'll be able to solve genetics problems faster by using the rules of probability than by filling in Punnett squares.

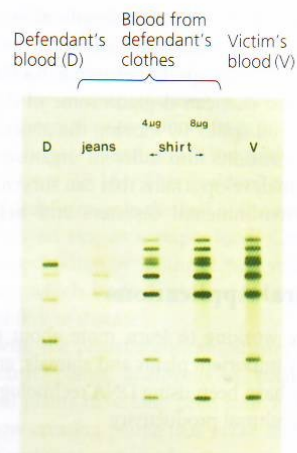
We cannot predict with certainty the exact numbers of progeny of different genotypes resulting from a genetic cross. But the rules of probability give us the *chance* of various outcomes. Usually, the larger the sample size, the closer the results will conform to our predictions. The reason Mendel counted

DNA testing, on the other hand, can identify the guilty individual with a high degree of certainty, because the DNA sequence of every person is unique (except for identical twins). RFLP analysis by Southern blotting is a powerful method for detecting similarities and differences in DNA samples and requires only tiny amounts of blood or other tissue (about 1,000 cells). In a murder case, for example, this method can be used to compare DNA samples from the suspect, the victim, and a small amount of blood found at the crime scene. The forensic scientist usually tests for about five RFLP markers; in other words, only a few selected portions of the DNA are tested. However, even such a small set of markers from an individual can provide a **DNA fingerprint**, or specific pattern of bands, that is of forensic use, because the probability that two people (who are not identical twins) would have the exact same set of RFLP markers is very small. The autoradiograph in **Figure 20.17** resembles the type of evidence presented to juries in murder trials.

DNA fingerprinting can also be used to establish paternity. A comparison of the DNA of a mother, her child, and the purported father can conclusively settle a question of paternity. Sometimes paternity is of historical interest: DNA fingerprinting has provided strong evidence that Thomas Jefferson or one of his close male relatives fathered at least one of the children of his slave Sally Hemings.

Today, instead of RFLPs, variations in the lengths of certain repeated base sequences in simple sequence DNA within the genome are increasingly used as markers for DNA fingerprinting. These repetitive DNA sequences are highly variable from person to person, providing even more markers than RFLPs. For example, one individual may have the repeat unit ACA repeated 65 times at one genome locus, 118 times at a second locus, and so on, whereas another individual is likely to have different numbers of repeats at these loci. Such polymorphic genetic loci are sometimes called *simple tandem repeats (STRs)*. The greater the number of markers examined in a DNA sample, the more likely it is that the DNA fingerprint is unique to one individual. PCR is often used to amplify particular STRs or other markers before electrophoresis. PCR is especially valuable when the DNA is in poor condition or available only in minute quantities. A tissue sample as small as 20 cells can be sufficient for PCR amplification.

Just how reliable is DNA fingerprinting? In most forensic cases, the probability of two people having identical DNA fingerprints is between one chance in 100,000 and one in a billion. The exact figure depends on the number of markers compared and on the frequency of those markers in the general population. Information on how common various markers are in different ethnic groups is critical because these marker frequencies may vary considerably among ethnic groups and between a particular ethnic group and the population as a whole. With the increasing availability of frequency data, forensic scientists can make extremely accurate statistical



▲ **Figure 20.17 DNA fingerprints from a murder case.**

This autoradiograph shows that DNA in blood from the defendant's clothes matches the DNA fingerprint of the victim but differs from the DNA fingerprint of the defendant. This is evidence that the blood on the defendant's clothes came from the victim, not the defendant. The three DNA samples were subjected to Southern blotting using radioactive probes (see Figure 20.10). The DNA bands resulting from electrophoresis were exposed to probes for several different RFLP markers in succession, with the previous probe washed off before the next one was applied.

calculations. Thus, despite problems that can still arise from insufficient data, human error, or flawed evidence, DNA fingerprints are now accepted as compelling evidence by legal experts and scientists alike. In fact, DNA analysis on stored forensic samples has provided the evidence needed to solve many "cold cases" in recent years.

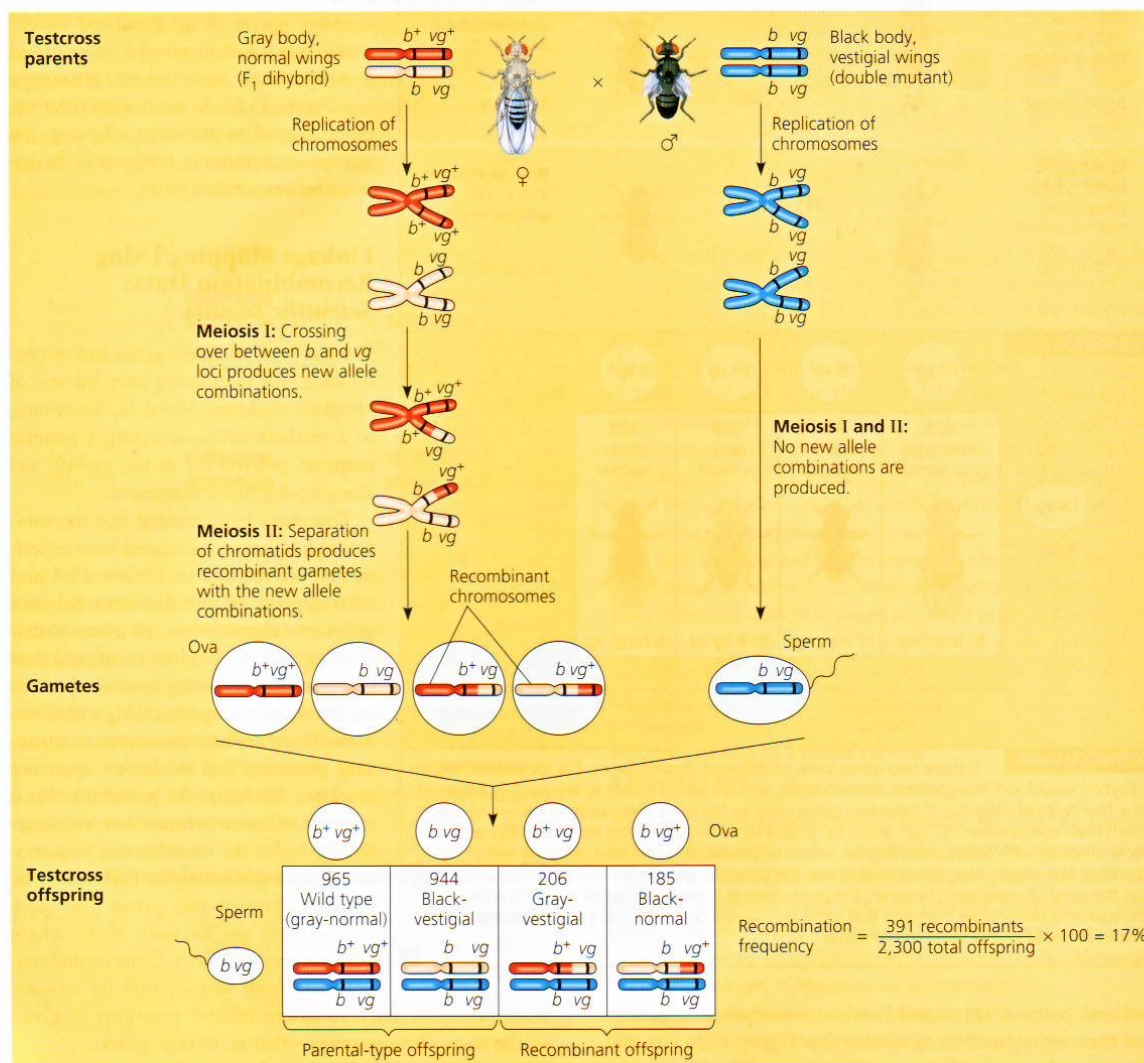
Environmental Cleanup

Increasingly, the remarkable ability of certain microorganisms to transform chemicals is being exploited for environmental cleanup. Scientists are now engineering these metabolic capabilities into other microorganisms, which are then used to help treat some environmental problems. For example, many bacteria can extract heavy metals, such as copper, lead, and nickel, from their environments and incorporate the metals into compounds such as copper sulfate or lead sulfate, which are readily recoverable. Genetically engineered microbes may become important in both mining minerals (especially as ore reserves are depleted) and cleaning up highly toxic mining wastes. Biotechnologists are also trying to engineer microbes that can degrade chlorinated hydrocarbons and other harmful compounds. These microbes could be used in wastewater treatment plants or by manufacturers before the compounds are ever released into the environment.

affecting eye color. Cinnabar eyes, a mutant phenotype, are a brighter red than the wild-type color. The recombination frequency between *cn* and *b* is 9%; that between *cn* and *vg*, 9.5%; and that between *b* and *vg*, 17%. In other words, crossovers between *cn* and *b* and between *cn* and *vg* are about half as frequent as crossovers between *b* and *vg*. Only a map that locates *cn* about midway between *b* and *vg* is consistent with these data, as you can prove to yourself by drawing alternative maps.

Sturtevant expressed the distances between genes in **map units**, defining one map unit as equivalent to a 1% recombination frequency. Today, map units often are called *centimorgans* in honor of Morgan.

In practice, the interpretation of recombination data is more complicated than this example suggests. For example, some genes on a chromosome are so far from each other that a crossover between them is virtually certain. The observed



▲ **Figure 15.6 Chromosomal basis for recombination of linked genes.** In these diagrams re-creating the testcross in Figure 15.5, we track chromosomes as well as genes. The maternal chromosomes are color-coded to

distinguish one homologue from the other. Because crossing over between the *b* and *vg* loci occurs in some, but not all, ovum-producing cells, more ova with parental-type chromosomes than with recombinant ones are produced in the

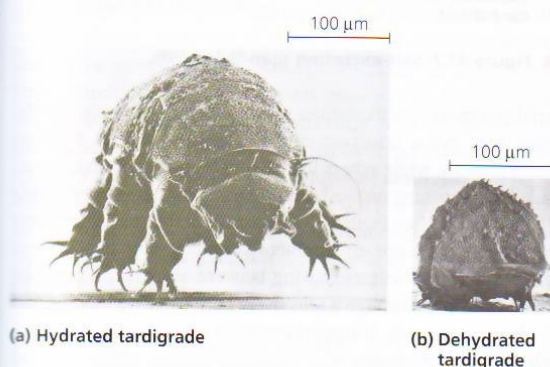
mating females. Fertilization of the ova by sperm of genotype *b vg* gives rise to some recombinant offspring. The recombination frequency is the percentage of recombinant flies in the total pool of offspring.

Salmon and other euryhaline fishes that migrate between seawater and fresh water undergo dramatic and rapid changes in osmoregulatory status. While in the ocean, salmon osmoregulate like other marine fishes by drinking seawater and excreting excess salt from the gills. When they migrate to fresh water, salmon cease drinking and begin to produce large amounts of dilute urine, and their gills start taking up salt from the dilute environment—just like fishes that spend their entire lives in fresh water.

Animals That Live in Temporary Waters

Dehydration is fatal for most animals, but some aquatic invertebrates living in temporary ponds and films of water around soil particles can lose almost all their body water and survive in a dormant state when their habitats dry up. This remarkable adaptation is called **anhydrobiosis** (“life without water”). Among the most striking examples are the tardigrades, or water bears, tiny invertebrates less than 1 mm long (Figure 44.4). In their active, hydrated state (see Figure 44.4a), these animals contain about 85% water by weight, but they can dehydrate to less than 2% water and survive in an inactive state (see Figure 44.4b), dry as dust, for a decade or more. Just add water, and within minutes the rehydrated tardigrades are moving about and feeding.

Anhydrobiotic animals must have adaptations that keep their cells’ membranes intact. Researchers are just beginning to learn how tardigrades survive drying out, but studies of anhydrobiotic roundworms (phylum Nematoda) show that dehydrated individuals contain large amounts of sugars. In particular, a disaccharide called trehalose seems to protect the cells by replacing the water that is normally associated with membranes and proteins. Many insects that survive freezing in the winter also utilize trehalose as a membrane protectant.

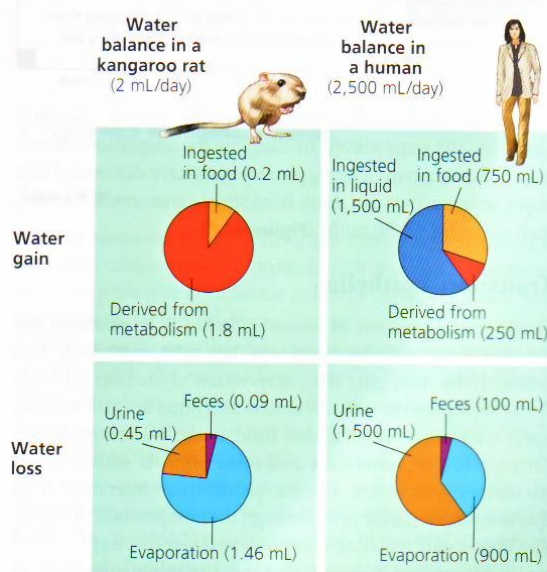


▲ **Figure 44.4 Anhydrobiosis.** Tardigrades (water bears) inhabit temporary ponds and droplets of water in soil and on moist plants (SEMs).

Land Animals

The threat of desiccation is a major regulatory problem for terrestrial plants and animals. Humans die if they lose about 12% of their body water; mammals that evolved in dry environments, such as camels, can withstand about twice that level of dehydration. Adaptations that reduce water loss are key to survival on land. Much as a waxy cuticle contributes to the success of land plants, the body coverings of most terrestrial animals help prevent dehydration. Examples are the waxy layers of insect exoskeletons, the shells of land snails, and the layers of dead, keratinized skin cells covering most terrestrial vertebrates. Many terrestrial animals, especially desert-dwellers, are nocturnal; this reduces evaporative water loss by taking advantage of the lower temperature and higher relative humidity of night air.

Despite these adaptations, most terrestrial animals lose considerable water from moist surfaces in their gas exchange organs, in urine and feces, and across their skin. Land animals balance their water budgets by drinking and eating moist foods and by using metabolic water (water produced during cellular respiration). Some animals, such as many insect-eating desert birds and other reptiles, are so well adapted for minimizing water loss that they can survive in deserts without drinking. Kangaroo rats lose so little water that they can recover 90% of the loss by using metabolic water (Figure 44.5), gaining the remaining 10% from the small amount of water in their diet of



▲ **Figure 44.5 Water balance in two terrestrial mammals.** Kangaroo rats, which live in the American southwest, eat mostly dry seeds and do not drink water. A kangaroo rat loses water mainly by evaporation during gas exchange and gains water mainly from cellular metabolism. In contrast, a human loses a large amount of water in urine and regains it mostly in food and drink.

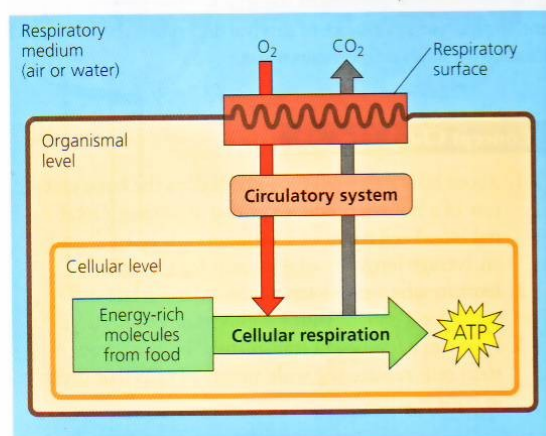
Concept 42.5

Gas exchange occurs across specialized respiratory surfaces

In the remainder of this chapter, we will focus on the process of **gas exchange**. Although this process is often called respiration, it should not be confused with the energy transformations of cellular respiration. Gas exchange is the uptake of molecular oxygen (O_2) from the environment and the discharge of carbon dioxide (CO_2) to the environment (Figure 42.19). These exchanges are necessary to support the production of ATP in cellular respiration and usually involve both the respiratory system and the circulatory system of an animal.

The source of O_2 , called the **respiratory medium**, is air for terrestrial animals and water for most aquatic animals. The atmosphere is Earth's main reservoir of O_2 and is about 21% O_2 (by volume). Oceans, lakes, and other bodies of water contain O_2 in dissolved form. The amount of O_2 dissolved in a given volume of water varies considerably, but is always much less than in an equivalent volume of air.

The part of an animal's body where gases are exchanged with the surrounding environment is called the **respiratory surface**. Animals do not move O_2 and CO_2 across membranes by active transport, so movement of these gases between the respiratory surface and the environment occurs entirely by diffusion. The rate of diffusion is proportional to the surface area across which diffusion occurs and inversely proportional to the square of the distance through which molecules must move. As a result, respiratory surfaces tend to be thin and have a large surface area, structural adaptations that maximize the rate of gas exchange. Additionally, all living cells must be bathed in water to maintain their plasma membranes. Thus,



▲ Figure 42.19 The role of gas exchange in bioenergetics.

the respiratory surfaces of terrestrial as well as aquatic animals are moist, and O_2 and CO_2 diffuse across these surfaces after first dissolving in water.

The respiratory surface must supply O_2 and expel CO_2 for the entire body, and a variety of solutions to the problem of providing a large enough surface have evolved. The structure of a respiratory surface depends mainly on the size of the organism and whether it lives in water or on land, but it is also influenced by metabolic demands for gas exchange. Thus, an endotherm generally has a larger area of respiratory surface than a similar-sized ectotherm.

Gas exchange occurs over the entire surface area of most protists and other unicellular organisms. Similarly, for some relatively simple animals, such as sponges, cnidarians, and flatworms, the plasma membrane of every cell in the body is close enough to the external environment for gases to diffuse in and out. In many animals, however, the bulk of the body does not have direct access to the respiratory medium. The respiratory surface in these animals is a thin, moist epithelium separating the respiratory medium from the blood or capillaries, which transport gases to and from the rest of the body (see Figure 42.19).

Some animals use their entire outer skin as a respiratory organ. An earthworm, for example, has moist skin and exchanges gases by diffusion across its general body surface. Just below the earthworm's skin is a dense net of capillaries. Because the respiratory surface must remain moist, earthworms and many other skin-breathers, including some amphibians, must live in water or damp places.

Animals whose only respiratory organ is moist skin are usually small and are either long and thin or flat, with a high ratio of surface area to volume. For most other animals, the general body surface lacks sufficient area to exchange gases for the whole body. The solution is a respiratory organ that is extensively folded or branched, thereby enlarging the available surface area for gas exchange. Gills, tracheae, and lungs are the three most common respiratory organs.

Gills in Aquatic Animals

Gills are outfoldings of the body surface that are suspended in the water. In some invertebrates, such as sea stars, the gills have a simple shape and are distributed over much of the body (Figure 42.20a). Many segmented worms have flaplike gills that extend from each segment of their body (Figure 42.20b) or long, feathery gills clustered at the head or tail. The gills of scallops (Figure 42.20c), crayfish (Figure 42.20d), and many other animals are restricted to a local body region. The total surface area of the gills is often much greater than that of the rest of the body.

As a respiratory medium, water has both advantages and disadvantages. There is no problem keeping the plasma membranes of the respiratory surface cells moist, since the

Appendix B: Evaluation



1. What degree program are you enrolled in?

		Response Percent	Response Count
BA		0.0%	0
BBiomed(4)		26.6%	112
BBiomed(T)		1.0%	4
BBiotech		7.8%	33
BBiotech(T		1.9%	8
BCom/BSc		0.7%	3
BEnvSc		0.0%	0
BInfT/BSc		0.2%	1
BInfTech		0.7%	3
BMarSt		3.6%	15
BPsySc		0.2%	1
BSc		52.7%	222
BSc/BA		1.0%	4
BSc/BJ		0.2%	1
BSc/LLB		0.2%	1
BSc/MBBS		2.6%	11
BusMan/BSc		0.2%	1

2. I am			
		Response Percent	Response Count
male		46.6%	197
female		53.4%	226

3. I am			
		Response Percent	Response Count
a domestic student		86.8%	369
an international student		13.2%	56

4. I am			
		Response Percent	Response Count
under 21 years of age		92.5%	393
21 years of age or old		7.5%	32

5. Think about your whole experience of this course.							
	Very Poor	Not so good	Satisfactory	Good	Outstanding	Rating Average	Response Count
Overall, how would you rate this course?	1.4% (6)	6.8% (29)	19.8% (84)	53.6% (228)	18.4% (78)	3.81	425

7. How often did you attend the following?								
answered question								424
skipped question								2
	None	1% - 25%	26% - 50%	51% - 75%	76% - 99%	All	Rating Average	Response Count
Lectures	0.0% (0)	1.4% (6)	4.2% (18)	8.3% (35)	51.4% (218)	34.7% (147)	5.14	424
Tutorials	0.0% (0)	4.6% (19)	6.3% (26)	8.7% (36)	35.6% (148)	45.0% (187)	5.10	416
Computer labs	1.2% (5)	6.5% (27)	7.0% (29)	14.0% (58)	35.2% (146)	36.1% (150)	4.84	415

8. What area of science currently interests you most? Choose ONE		
	Response Percent	Response Count
Biomedical science	44.4%	183
Chemistry	7.0%	29
Computer science	0.7%	3
Ecology	9.2%	38
Earth science	3.6%	15
Geographical science	0.2%	1
Mathematics	9.7%	40
Physics	4.4%	18
Psychology	5.1%	21

8. What area of science currently interests you most? Choose ONE			
	Zoology	7.8%	32
	Other	7.8%	32

9. How important do you think mathematics is in science?			
		Response Percent	Response Count
Very important		57.2%	243
	Important	40.2%	171
Neither important nor important		1.9%	8
	Unimportant	0.5%	2
Very unimportant		0.2%	1

10. How much did the following aspects of the course HELP your LEARNING?								
	no help	a little help	moderate help	much help	great help	Didn't experience this	Rating Average	Response Count
Having a small teaching team	1.2% (5)	4.3% (18)	16.5% (69)	31.3% (131)	42.5% (178)	4.3% (18)	4.14	419
Attending lectures	0.9% (4)	1.7% (7)	9.0% (38)	24.1% (102)	63.9% (271)	0.5% (2)	4.49	424
Attending the tutorials	1.9% (8)	8.3% (35)	21.3% (90)	27.2% (115)	40.2% (170)	1.2% (5)	3.97	423
Attending the computer labs	3.5% (15)	13.2% (56)	24.5% (104)	26.4% (112)	30.0% (127)	2.4% (10)	3.68	424

10. How much did the following aspects of the course HELP your LEARNING?								
The lecture notes	0.2% (1)	1.9% (8)	10.8% (46)	31.4% (133)	55.2% (234)	0.5% (2)	4.40	424
Performing the calculations during class	1.2% (5)	3.3% (14)	8.3% (35)	26.7% (113)	59.7% (253)	0.9% (4)	4.42	424
Asking questions during class	2.4% (10)	4.0% (17)	16.4% (69)	23.5% (99)	35.1% (148)	18.7% (79)	4.04	422
The discussion forums on Blackboard	4.0% (17)	7.3% (31)	13.0% (55)	18.9% (80)	46.8% (198)	9.9% (42)	4.08	423

11. HOW MUCH did each of the following ASSESSMENT tasks HELP YOUR LEARNING?								
	No help	Some help	Moderate help	Much help	Great help	Didn't experience this	Rating Average	Response Count
The philosophy assignment	15.8% (67)	22.8% (97)	29.4% (125)	21.4% (91)	10.6% (45)	0.0% (0)	2.88	425
The quantitative reasoning assignments in tutorials	9.9% (42)	24.0% (102)	30.6% (130)	22.1% (94)	13.2% (56)	0.2% (1)	3.05	425
The science, mathematics and computing assignments	2.1% (9)	5.6% (24)	18.1% (77)	35.5% (151)	38.6% (164)	0.0% (0)	4.03	425
Using feedback on my assignments to correct mistakes in the tutorials	2.6% (11)	9.9% (42)	15.1% (64)	27.1% (115)	42.1% (179)	3.3% (14)	4.00	425
The big project	5.9% (25)	13.6% (58)	21.6% (92)	29.2% (124)	29.6% (126)	0.0% (0)	3.63	425

12. What did you think of the assessment tasks overall?

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Rating Average	Response Count
My knowledge, understanding and skills were adequately assessed	1.2% (5)	3.8% (16)	16.9% (72)	59.3% (252)	18.8% (80)	3.91	425
Helpful feedback on assessment was given within a reasonable time to facilitate further learning	0.9% (4)	5.6% (24)	22.1% (94)	48.7% (207)	22.6% (96)	3.86	425
Assessment was spread appropriately across the semester, rather than being concentrated at the end of the course	2.4% (10)	9.9% (42)	16.7% (71)	44.9% (191)	26.1% (111)	3.83	425
Assessment requirements and marking criteria were made clear at the beginning of this course	0.7% (3)	6.1% (26)	16.9% (72)	49.9% (212)	26.4% (112)	3.95	425
There was an appropriate match between the learning objectives and assessments	1.2% (5)	4.0% (17)	17.7% (75)	50.9% (216)	26.2% (111)	3.97	424
The workload was appropriate given the unit value of the course	6.1% (26)	16.3% (69)	23.6% (100)	39.2% (166)	14.7% (62)	3.40	423

13. These questions refer to how you feel you were SUPPORTED through the program							
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Rating Average	Response Count
Teaching staff were accessible for consultation	0.5% (2)	2.6% (11)	13.9% (59)	42.6% (181)	40.5% (172)	4.20	425
The course was well administered (e.g. sufficient resources were available when needed)	0.2% (1)	4.2% (18)	9.2% (39)	48.9% (208)	37.4% (159)	4.19	425
I felt I belonged to a group of students and staff engaged in inquiry and learning in this course	0.7% (3)	5.6% (24)	21.2% (90)	47.1% (200)	25.4% (108)	3.91	425
The learning objectives of the course were clear - I knew what I was supposed to be learning	1.2% (5)	7.8% (33)	18.6% (79)	46.8% (199)	25.6% (109)	3.88	425
The course was intellectually stimulating	1.4% (6)	5.7% (24)	13.0% (55)	40.0% (169)	39.8% (168)	4.11	422
The Philosophy lectures help my understanding of science and how it works	7.3% (31)	14.9% (63)	29.9% (126)	34.4% (145)	13.5% (57)	3.32	422

14. As a result of your work in this class, what GAINS DID YOU MAKE in your UNDERSTANDING of each of the following?								
	No gain	A little gain	Moderate gain	Good gain	Great gain	N/A	Rating Average	Response Count
Connecting how mathematical knowledge can be used to solve scientific problems	3.1% (13)	4.7% (20)	11.4% (48)	36.3% (153)	44.5% (188)	0.0% (0)	4.14	422

14. As a result of your work in this class, what GAINS DID YOU MAKE in your UNDERSTANDING of each of the following?								
Applying what I learned in SCIE1000 in other courses I take in my degree program	5.5% (23)	7.6% (32)	22.3% (94)	35.5% (150)	28.4% (120)	0.7% (3)	3.74	422
Using a critical approach to information and arguments I encounter in daily life	2.6% (11)	10.0% (42)	22.7% (96)	38.2% (161)	25.6% (108)	0.9% (4)	3.75	422

15. As a result of participating in this course, rate the LEVEL to which you FEEL								
	Low		Middle		High	Doesn't apply to me	Rating Average	Response Count
Enthusiastic about science	1.9% (8)	2.6% (11)	15.8% (67)	32.3% (137)	46.9% (199)	0.5% (2)	4.20	424
Enthusiastic about mathematics	8.3% (35)	8.7% (37)	24.8% (105)	32.4% (137)	24.8% (105)	0.9% (4)	3.57	423
Enthusiastic about computing	29.5% (125)	18.2% (77)	20.5% (87)	17.0% (72)	13.9% (59)	0.9% (4)	2.67	424
Enthusiastic about philosophy	25.2% (107)	20.3% (86)	25.7% (109)	16.0% (68)	11.8% (50)	0.9% (4)	2.69	424
Interested in taking or planning to take additional quantitative science-based courses	17.5% (74)	13.7% (58)	31.1% (132)	25.2% (107)	11.1% (47)	1.4% (6)	2.99	424

16. These statements refer to what other students have thought could be IMPROVED in SCIE1000. How much do you agree with them?							
	answered question						421
	skipped question						5
	Strongly Disagree	Disagree	Don't care	Agree	Strongly Agree	Rating Average	Response Count
Incorporate Keepad "clickers" into the lectures	17.6% (74)	19.0% (80)	34.4% (145)	20.2% (85)	8.8% (37)	2.84	421
Have special guest lecturers	9.0% (38)	18.1% (76)	36.3% (153)	28.3% (119)	8.3% (35)	3.09	421
Divide the two hour tutorial/computer tutorial into two sessions (resulting in different tutors and different classmates)	22.5% (94)	34.4% (144)	21.1% (88)	14.1% (59)	7.9% (33)	2.50	418
We should stop the QR assignments in tutorials	11.7% (49)	30.5% (128)	31.0% (130)	16.2% (68)	10.7% (45)	2.84	420
We should stop giving students a choice of topics for the big project	46.0% (193)	31.0% (130)	11.4% (48)	6.2% (26)	5.5% (23)	1.94	420

22. In this course, how interesting do you generally find							
	Never interesting	Rarely interesting	Sometimes interesting (half the time)	Usually interesting	Always interesting	Rating Average	Response Count
what you are learning?	1.0% (4)	6.2% (26)	21.1% (88)	58.1% (243)	13.6% (57)	3.77	418

22. In this course, how interesting do you generally find							
the course activities you are doing?	1.7% (7)	9.3% (39)	33.7% (141)	48.1% (201)	7.2% (30)	3.50	418

23. How much do you feel your coursework is emphasizing...							
	Very Little	A little	Somewhat	Quite a bit	A lot	Rating Average	Response Count
Memorising	30.0% (127)	35.2% (149)	24.3% (103)	9.0% (38)	1.4% (6)	2.17	423
Understanding	0.7% (3)	1.9% (8)	7.5% (32)	35.4% (150)	54.5% (231)	4.41	424
Analysing	0.5% (2)	1.7% (7)	9.0% (38)	40.3% (171)	48.6% (206)	4.35	424
Applying	0.5% (2)	2.1% (9)	9.0% (38)	31.7% (134)	56.7% (240)	4.42	423
Synthesising	1.2% (5)	7.1% (30)	22.2% (94)	40.9% (173)	28.6% (121)	3.89	423
Evaluating	0.5% (2)	4.0% (17)	18.6% (79)	39.4% (167)	37.5% (159)	4.09	424
25. Overall, how much would you say you are...							
	Very Little	A little	Somewhat	Quite a bit	A lot	Rating Average	Response Count
learning?	2.8% (12)	7.3% (31)	20.1% (85)	51.2% (216)	18.5% (78)	3.75	422
"engaged" in the course?	5.2% (22)	11.4% (48)	29.4% (124)	41.0% (173)	13.0% (55)	3.45	422



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