Maths for Biosciences

Towards Developing an Innovative E-learning Resource for Post-GCSE Students

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At a two-day conference in January 2005, participants from university biological sciences departments were asked to write down three words or phrases which summed up their perceptions and feelings about the maths knowledge and skills of life science undergraduates. Participants' answers are summarised in Table 1.

Life science undergraduates were described as...	Life science undergraduates' maths knowledge & skills were described as...	Bioscience academics...
Innumerate	Inadequate	Feel sympathetic - students often didn't expect the demands
Fearful, phobic & disengaged with numeracy	Pathetic	Are horrified at how little students recall and at the hints of poor teaching
Unwilling to try	Surprising	Wish more could be done
Avoiding maths where possible	Worrying	Feel there's potential and hope
Over-relying on calculators	Dangerous	Recognise the diversity of problems amongst students of similar qualification
Lacking confidence in skills learned prior to HE	Variable, often weak	Feel an overview of the problem is lacking
Lacking logical reasoning and a thoughtful approach	Poor	
Lacking interest	Inflexible	
Lacking understanding		
Lacking the ability to apply their knowledge to problems		

Table 1 Summary of some bioscientists' views

There is undoubtedly concern within the sciences about students' mathematical abilities. From engineering, through physics, to chemistry, to medicine and through all the life sciences the problems are well documented [1, 2, 3, 4, 6, 7, 9]. Universities have been forced to expand and the cohort of students arriving each year is not only larger but in many disciplines is also much more diverse in terms of the students' prior academic experiences. There are students coming not only from conventional schools and FE colleges, but also from a variety of work-related backgrounds. Consequently, their qualifications range very widely from GCSE, through AS and A2 levels, to HNDs and tailored 'access' courses. Older colleagues will remember a time when the undergraduate population was more homogeneous, and a higher education environment where teaching was something of an adjunct to learning rather than the driving force. Today's students need new ways of learning, new routes to the subject, and to be offered a different view of things. Learning maths is a particular conundrum of overlapping skills, conceptual understanding and contexts, where relevance jostles with charm and difficulty.

For those teaching in the life sciences the task of ensuring that students possess the necessary mathematical knowledge and skills for the discipline is not an easy one. The minimum mathematics entrance qualification for many undergraduate life science programmes remains grade C at GCSE. However, changes to secondary level mathematics syllabuses in the 1980s and 1990s have allowed students at GCSE to achieve good grades without having been taught the harder algebraic skills. In addition, Lenton and Stevens [6] suggest that difficulties with mathematical concepts in science lessons may arise from the teaching of facts and skills, as opposed to teaching through conceptual understanding, by science teachers and unqualified teachers of mathematics;

the latter situation has been compounded by the difficulties associated with finding sufficient professionally qualified mathematics teachers [8].

In the life sciences, which encompass a wide range of disciplines from molecular biology to ecology and from microbiology to medicine, the range and level of mathematical skills required of undergraduates vary, although all require a core of numerical ability [7]. Many life science students enter their degree programmes possessing only GCSE Mathematics (or its equivalent) and only a minority possess a higher mathematics qualification (e.g. at AS or A2-level). Concerns have been expressed that changes to GCSE mathematics curricula over the years have reduced the expected level of ability of students entering life science degree courses. But even allowing for this, university departments should be able to assume that most students can manipulate fractions and decimals, handle powers of ten and be able to plot and interpret graphs. Many students, however, lack confidence in their ability to deal with basic mathematical concepts and are unable to calculate accurately and efficiently even when using a calculator. They are often unable to manipulate or appreciate numbers and equations, to use scientific notation or to explain and make predictions from data presented in graphs, charts and tables [5, 7, 9, 10, 11].

Our challenge is to do something that goes a long way in a short time to address this deficit in students' confidence, knowledge and skills, and that engages students in the process. In short, we aim to produce a national learning resource to support post-GCSE pupils and students in their acquisition, practice and application of those mathematics skills essential to the life sciences. Since the life sciences include a plethora of specific disciplines, our initial questions when formulating a strategy to meet this challenge have been *'Which life sciences?'* and *'What mathematics?'* Plotting maths topics against individual life science disciplines can yield a cat's cradle of relationships where, if you're not careful, everything becomes relevant and essential to everything! *(See Fig 1)*

At the January conference attendees were asked to relate broad topics in maths to selected biological applications. There are, of course, many combinations but Fig 1 illustrates examples of just a few of the relationships that emerged.

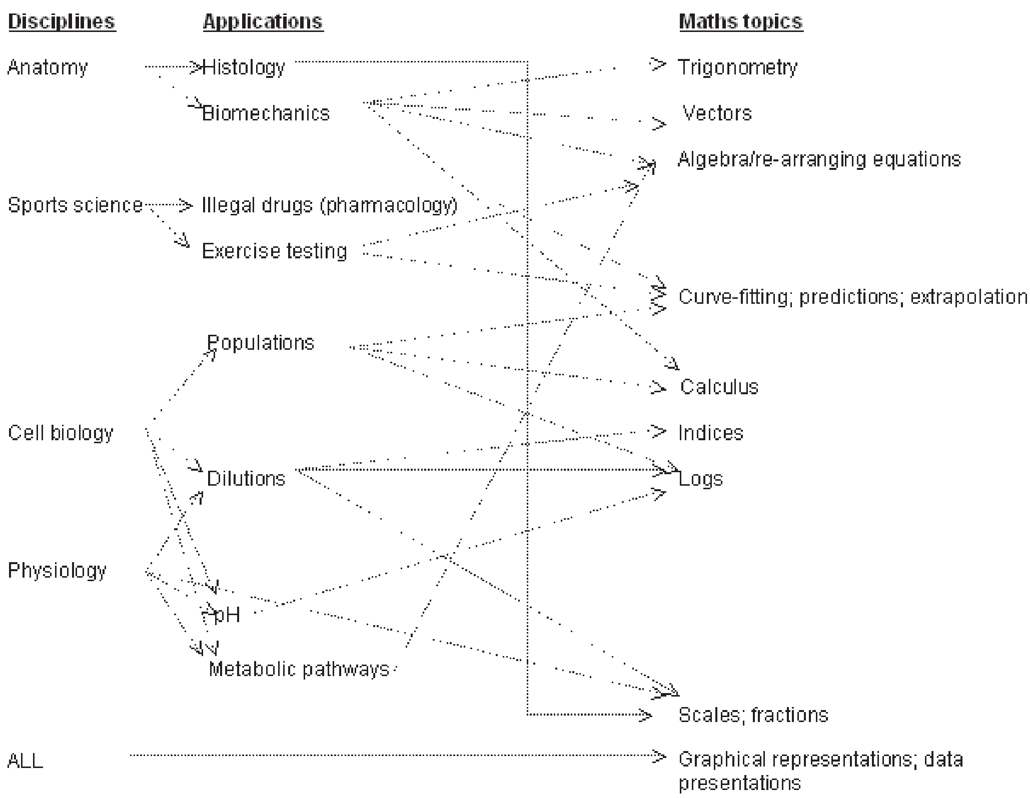

Fig 1 Examples of some relationships between life science disciplines and maths topics

Few would argue that it is possible to identify a core level of mathematical ability required by all students embarking on life science programmes. Nobody would quarrel with the essentiality of basic arithmetic for all areas; the interpretation of graphs is as essential a skill in molecular biology as it is in behavioural psychology; and if students are going to understand movement and rates of change and predict outcomes with confidence they will have to get to grips with algebra and elements of calculus.

Our proposal

So what can we do to try and remedy this situation? How can we get the message across to students that maths is exciting and increasingly relevant to all the life sciences? Perhaps the maths should be taught in such a way that it complements the biology rather than being presented as a turgid necessity. So rather than begin with the maths and then demonstrate how relevant it is to biological topics, might it not be better to start with a series of biological topics, case studies and scenarios and explore the mathematics within each? The latter would be supported by online video-led maths tutorials, to assist students to understand and master the maths contained within each biological topic. For argument's sake we could develop fifty biological case studies, each one of which would relate to a particular life science discipline. Each case study would demand mastery of one or more particular skills in maths. There would of course be overlap and reinforcement; several case studies might demand the same mathematical skills and there might be several maths topics in any one case study. The principle of this approach is that the 'context' (i.e. case study) drives the learning. This should appeal to students of the life sciences who would see their own subject area as interesting and distinct from others, and who would therefore be inclined to want to delve into a particular subject story. Our approach will therefore include:

- setting the mathematics in context
- capturing students' imagination by motivating them to want to learn the mathematics inherent in the disciplines
- providing brief straightforward case studies and problem based scenarios
- providing the opportunity for extensive practice
- ensuring clear and enjoyable navigation through the resource
- evaluating the usefulness of a pilot resource in schools and universities.

The authors' experiences of developing video-led teaching in pure and applied maths have convinced them that the power of web and disk delivery should be exploited in designing a new learning resource for the biosciences. With DVD-ROM anything can be included: high quality film, animations, video tutorials, interactive exercises – and we propose to lead into each component of the resource with a specially filmed case study of a biological event or phenomenon and to include within that case study the maths essential for a full understanding of the biology presented. Links will enable the student to navigate from each case study to video-led tutorials on the relevant maths topics, as well as to practice exercises and printable textual support.

The project will build on the experience of developing ***math****tutor*, a new web and disk-based resource designed to teach maths between GCSE and 1st-year undergraduate levels. ***math****tutor* delivers pure maths and contains more than 100 video tutorial and extension films. Together with 80 diagnostic tests and about 1300 interactive exercises, the disks represent an easily navigable forest of maths packaged for clear and easy access. ***math****tutor* is being generally praised as a unique approach which will do much to repair inadequacies in students as they embark on courses where maths is required and also those students studying at AS and A2-levels where they need help. Those who work in the biosciences are already considering ***math****tutor* as an additional plank in the fight for biological numeracy, but recognise the limitations of such a pure maths resource in supporting a predominantly maths-phobic population of students.

The case study approach – biology with embedded maths and then focussing on the maths – is similar to that used in the earlier project *Maths for Engineers* which was structured around 15 films of mathematical modelling of mechanical events in the real world. But in *Maths for Engineers* the maths was 'up front'. In *Maths for Biosciences* the maths will be less obvious and more an underlying theme, since bioscience students tend to be more apprehensive about maths. That said, the whole structure of the teaching will follow a pattern where the route to the maths is through the biology rather than the other way round, the normal approach in many textbooks and courses.

The project will endeavour to embrace most of the principal disciplines within the life sciences and the maths necessary for a full understanding of all case studies. As an additional aspect we suggest that the project could contain extended materials of a research kind – we are keen to stretch the brightest students as well as those most in need of support. We plan to make everything very visual, real and full of movement and exciting.

A pilot

In order to develop a project of this size, it is necessary to develop and test a sample first. We envisage the whole product consisting of about fifty short biological films and believe it may be more sensible to divide the product into major biological fields, with perhaps ten topic films in each. For the purposes of the pilot we propose to produce two filmed case studies within the broad field of cell biology, since this forms a significant component of AS/A2-level specifications, as well as many undergraduate programmes.

- **Case study 1:** A patient with anaemia. A sample of blood is taken and diluted to a stage when a count can be made. This results in a diagnosis. The same blood sample is used to count the bacteria within it. This is a more complex process needing dilution followed by plating out samples and measuring colony numbers.
- **Case study 2:** Population growth in bacteria, birds or people, involving observation and forecasting.

These two filmed case studies will be linked to associated maths topics:

Case study	Examples of maths topics
Counting cells	Powers, decimals, addition, multiplication, fractions
Population growth	Sampling, sequences and series, estimation, calculus

The maths will be supported by six to eight video-led tutorials, printable text, exercises and diagnostic tests. The pilot will draw on materials already recorded for ***math****tutor*, but will be tailored for this very different audience. The practice exercises will be designed to attract biologists as well as the more mathematically inclined. It is envisaged that as the pilot is designed and developed, other ideas will surface which will complement each case study.

And further...

The pilot will inform full development of approximately fifty case studies across four or five major life science disciplines. We believe it is important that bioscience students not only be encouraged to embrace the maths contained within their chosen programmes, but also be encouraged to explore how maths can impinge on the frontiers of biological research. The following examples might stimulate, inspire and open the eyes and ears of individuals who have never really imagined how closely the disciplines of biology and maths are linked.

1. How do birds fly?
The answer could be illustrated with a film of birds flying, incorporating slow motion and overlaid graphics illustrating the forces involved. The maths models would include an analysis of flight into components and simple modelling of these. The maths topics include forces, vectors, velocity/acceleration, mechanics, graphs. Links could be provided to other examples of movement, including dolphins, pterodactyls, worms and bacteria.

2. When will I die?
The answer could be illustrated with longevity data for men and women, highlighting why people die, the factors affecting lifespan, as well as demographic changes, providing students with the opportunity to calculate the potential time of their own demise! The maths models would include forecasts from observation, birth and death rates, futures. Maths topics include sequences and series, probability, logarithms, statistics, distribution curves and calculus. Links could be provided to bacterial growth, the spread and decline of disease, Malthus and war, Napoleon and the march on Moscow.

3. Why is DNA a double helix?
The answer could be illustrated with films of Watson and Crick, the dimensions of the model and forces on the various chemical groups. The maths models would include real models of the molecule and the necessity to express molecular interaction in mathematical terms. Maths topics include geometry, trigonometry and Fourier analysis. Links could be provided to biochemical reaction times, protein structure and enzymology.

The project we propose to embark upon is obviously a very large one, embracing most of the principal disciplines within the life sciences and the maths necessary for a full understanding of all the case studies presented. This online and disk-based learning resource, with its associated support materials, will offer an alternative course in maths for students of the life sciences. The emphasis will be on contextualised learning, with highly visual and exciting examples from the life sciences encouraging students to *want* (rather then *need*) to understand the underlying mathematical principles.

Maths for Biosciences is a topic for discussion at the conference
Helping Everyone Learn Mathematics, 14-15 September 2005 (see page 7)

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