Biology

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Summary

It is generally agreed that research in biology has become more quantitatively oriented than in the past. At the same time, it is also recognized that the quantitative needs of undergraduate students enrolled in biology courses are diverse and depend largely upon the student audience (e.g., majors versus non-majors) and the variety of disciplinary tracks, ranging from molecular biology to ecology, that students choose to explore. In an already crowded biology curriculum, the panelists agreed that the issue of increasing quantitative emphasis would call for innovative solutions. They suggested solutions ranging from the creation of mathematical courses designed specifically for biology majors to the creation of mathematical modules that could be incorporated into existing biology courses.

To build and require more quantitatively oriented biology courses would be a major, but important, undertaking and would necessitate increased cooperation among biologists and mathematicians. The proposed actions of the MAA in assisting their client colleagues with possible changes and emphasis in the mathematics curriculum could serve not only to increase the quantitative literacy of biologists, but also act as a catalyst for needed changes in the undergraduate biology curriculum. Some common themes that emerged during the workshop were:

1. New areas of biological investigation together with advances in technology have resulted in an increase in quantification of biological theories and models.
2. The collection and analysis of data that is central to biological investigations inevitably leads to the use of mathematics.
3. Mathematics provides a language for the development and expression of biological concepts and theories. It allows biologists to summarize data, to describe it in logical terms, to draw inferences and to make predictions.
4. Statistics, modeling and graphical representation should take priority over calculus.
5. The teaching of mathematics and statistics should use motivating examples that draw on problems or data taken from biology.
6. Creating and analyzing computer simulations of biological systems provides a link between biological understanding and mathematical theory.

Narrative

Introduction and Background

The proposition that is being addressed in this report is how undergraduate mathematics education can better serve students majoring in biology. The comments that follow are predicated on these assumptions:

1. Many undergraduate students taking introductory mathematics courses have educational destinations other than mathematics.
2. The sciences are increasingly seeing students who are quantitatively ill-prepared.
3. The biological sciences represent the largest science client of mathematics educators.
4. Students majoring in biology typically complete only one or two semesters of mathematics.
5. The current mathematics curriculum for biology majors does not provide biology students with appropriate quantitative skills.
6. The field of biology is becoming much more quantitative which will necessitate a change in the mathematics curriculum for biology majors.

One particular challenge facing biology educators is the range of mathematical backgrounds of professors of biology. Many, if not most, biology educators have completed only calculus and one course in statistics. The limited mathematical background of most biologists is clearly reflected in the correspondingly limited quantitative components of both biology textbooks and curricula. As we begin to expand the quantitative backgrounds of our students we will also have to provide opportunities for the biology faculty to increase their own facility with mathematics.

Understanding and Content

Surveys of quantitative skills needed for biologists frequently include college algebra, introductory calculus and statistics. Among these three areas of mathematics, statistics is the most commonly mentioned and the most extensively used. Other content areas that are mentioned include mathematical modeling, discrete mathematics and matrix algebra.

1. **College Algebra*:*** Biology students need to understand the meaning and use of variables, parameters, functions and relations. They need to know how to formulate linear, exponential and logarithmic functions from data or from general principles. They must also understand the basic periodic nature of the sine and cosine functions. It is fundamentally important that students are familiar with the graphical representation of data in a variety of formats (histograms, scatter plots, pie charts, log-log and semi-log graphs.)
2. **Introductory Calculus:** The topics from introductory calculus that were mentioned at the workshop included integration for the purpose of calculating areas and average value, rates of change, optimization, and gradients for the purpose of understanding contour maps.
3. **Statistics:** It is here where the list of necessary topics is the longest and encompasses descriptive statistics, conditional probability, regression analysis, multivariate statistics, probability distributions, simulations, significance and error analysis.
4. **Discrete Mathematics and Matrix Algebra:** The topics most frequently mentioned were qualitative graphs (trees, networks, flowcharts, digraphs), matrices (Leslie, Markov chains), and discrete time difference equations. Other topics included equilibria, stability and counting techniques.

Technology

The pervasive presence of computers together with their ever-increasing computational power encourages biologists to apply statistical methods to analyze data that is collected in the laboratory or the field. One important software application used by biologists is the spreadsheet. Increasingly, spreadsheet applications contain sophisticated statistical tools sufficient for use with undergraduate biology majors. The panelists were unanimous in their observation that *the graphing calculator is not the tool of choice* for biology students. Technological tools must be capable of producing graphs that can be incorporated into printed and

presentation documents. They must allow students to apply modeling techniques to large data sets and they must also support simulation of models that are stochastic, discrete or continuous.

Implementation

There is a variety of ways to implement curricula containing the recommended mathematical topics. It should be noted that responsibility for student competence with mathematics should not rest solely in the hands of the mathematics faculty. The biology faculty must incorporate the use of mathematics into their courses in order to reinforce and verify the importance of mathematics to their students. To this end, the quantitative courses must be taken early so that the topics introduced can be used in subsequent courses in biology. Collaborative efforts to design and deliver the quantitative courses should be encouraged. Some possible curricular options considered by the panel include:

1. Mathematical requirements may be completed in a one-semester course. The panel does *not recommend* this option, however if only one course in mathematics is required, they suggest that the emphasis of this course be on statistics.
2. Mathematical requirements may be completed in a two-semester sequence. In this scenario, the panel recommends that one course focus on topics in statistics and the other course include topics from calculus and mathematical modeling. A yearlong course integrating these three topics would be preferable.
3. Mathematical requirements may be completed in a three-semester sequence. This option would include a course in statistics and a course integrating topics from calculus and mathematical modeling. The third course might come later in the curriculum as a project-based course oriented toward modeling applications and could also include topics from matrix algebra and discrete mathematics.
4. Mathematical requirements may be completed by an integrated approach. An interdisciplinary approach could be used to embed mathematical modules into biology courses. This approach has the advantage of teaching the mathematical concepts in the context of biological applications. The challenges to this approach are the usual difficulties that arise in the design and delivery of interdisciplinary courses.

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