

Quantitative Education for Life Sciences: BIO2010 and Beyond

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www.tiem.utk.edu/bioed

Short Courses on the Mathematics of Biological Complexity

<http://www.tiem.utk.edu/courses/>

Designed for biologists without
strong quantitative backgrounds

* next course is

March 30 – April 2

Overview:

A few comments on this workshop

**Overview of the University of Tennessee
projects**

**Future directions: Suggestions to
implement BIO2010 ideas and
impediments**

“To what extent should mathematical courses given to biologists be different from those given to mathematicians? There may be many biologists who may gain from tailored courses. In regard to the training of the mathematical biologist, my feeling is that he should take the courses designed for mathematicians or physicists.”

H. D. Landahl (1961)

“Traditional biology courses lay far too much emphasis on the direct acquisition of information. Insufficient attention is given to the interpretation of facts or to the drawing of conclusions from observation and experience. The student is given little opportunity to apply scientific principles to new situations.”

J. G. Skellam (1961)

The Cullowhee Conference on Training in Biomathematics. H. L. Lucas (Ed.) 1962

(supported by NIH Division of General Medical Sciences)

Had as its goals:

- to stimulate interest in the training of biomathematicians
- to explore the type of training needed, the methods of recruiting trainees, and the means whereby training programs can be implemented most effectively.

**So have we learned
anything in the past 40
years?**

Yes!

Many model programs have been developed;

Lots of curricular material has been put together;

Biologists are much more attuned to the utility of quantitative approaches;

Education research provides guidance on what really works.

Comments on this workshop:

Where are the education researchers! We have much to learn ourselves about what approaches are demonstrably more effective and there are many colleagues who can help us – see (shameless plug) *Integrating Research and Education: Biocomplexity Investigators Explore the Possibilities: Summary of a Workshop* (National Research Council) 2003

AP Courses:

They are not bad! They allow us to incorporate more advanced concepts quicker and by so doing help students see the connections between the math and its applications as long as we provide a means for students to “*renew their acquaintance*” with the topics sometime during their undergraduate career.

Collaborative learning:

Opportunities for joint, cross-disciplinary projects and research experiences already exist for biologists and quantitatively trained students but need expansion to provide exposure to the team efforts common in research and the modern workplace.

Statistical training:

It appears that many more life science programs are incorporating formal statistics courses in their curricula than did a decade ago (need to check this).

Bioinformatics:

Illustrates the need for student exposure to much more than simply experience using software. It is comprehension of the conceptual foundations that will offer them opportunities to be more than just technicians.

Curricular development:

Numerous models exist and one approach does not fit all. A huge amount of material has been developed – there is no need to reinvent the wheel, but rather adopt and adapt for local conditions.

Main components of quantitative life science education:

- (i) K-12, teacher training, and general public outreach.**
- (ii) Undergraduate intro biology courses.**
- (iii) Undergraduate intro quantitative courses.**
- (iv) Upper division life science courses.**
- (v) Undergraduate research experiences.**
- (vi) Graduate training: quantitative → bio,
bio → quantitative.**
- (vii) Faculty, post-doc, MD advanced training.**
- (viii) International cooperative training and research.**

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Key Points:

Success in quantitative life science education requires an integrated approach: formal quantitative courses should be supplemented with explicit quantitative components within life science courses.

Life science students should be exposed to diverse quantitative concepts: calculus and statistics do not suffice to provide the conceptual quantitative foundations for modern biology.

We can't determine *a priori* who will be the researchers of the future – educational initiatives need to be inclusive and not focused just on the elite. Assume all biology students can enhance their quantitative training and proceed to motivate them to realize its importance in real biology.

The CPA Approach to Quantitative Curriculum Development across Disciplines

As a summary of the approach I have taken in this life sciences project, and in hope that this will be applicable to other interdisciplinary efforts, I offer the CPA Approach:

Constraints, Prioritize, Aid

Understand the **Constraints** under which your colleagues in other disciplines operate - the limitations on time available in their curriculum for quantitative training.

Work with these colleagues to **Prioritize the quantitative concepts their students really need, and ensure that your courses include these.**

****Aid** these colleagues in developing quantitative concepts in their own courses that enhance a student's realization of the importance of mathematics in their own discipline. This could include team teaching of appropriate courses.**

Note: The above operates under the paradigm typical of most U.S. institutions of higher learning - that of disciplinary compartmentalization. An entirely different approach involves real interdisciplinary courses. This would mean complete revision of course requirements to allow students to automatically see connections between various subfields, rather than inherently different subjects with little connection. Such courses could involve a team approach to subjects, which is common in many lower division biological sciences courses, but almost unheard of in mathematics courses.

Collaborators

**Drs. Beth Mullin and Otto Schwarz (Botany),
Susan Riechert (EEB)**

**Monica Beals, Susan Harrell - Primer of
Quantitative Biology**

**Drs. Sergey Gavrilets (EEB) and Suzanne
Lenhart (Math) – NIH Short Courses**

**Drs. Thomas Hallam (EEB) and Simon Levin
(Princeton) – International Courses**

**Society for Mathematical Biology – Education
Committee – www.smb.org**

Project activities:

- **Conduct a survey of quantitative course requirements of life science students;**
- **Conduct a workshop with researchers and educators in mathematical and quantitative biology to discuss the quantitative component of the undergraduate life science curriculum;**
- **Develop an entry-level quantitative course sequence based upon recommendations from the workshop;**
- **Implement the course in an hypothesis-formulation and testing framework, coupled to appropriate software;**

- **Conduct a workshop for life science faculty to discuss methods to enhance the quantitative component of their own courses;**
- **Develop a set of modules to incorporate within a General Biology course sequence, illustrating the utility of simple mathematical methods in numerous areas of biology;**
- **Develop and evaluate quantitative competency exams in General Biology as a method to encourage quantitative skill development;**
- **Survey quantitative topics within short research communications at life science professional society meetings.**

The Entry-level Quantitative Course: Biocalculus Revisited

In response to workshop recommendations, a new entry-level quantitative course for life science students was constructed and has now become the standard math sequence taken by biology students. The prerequisites assumed are Algebra, Geometry, and Trigonometry.

Goals:

Develop a Student's ability to Quantitatively Analyze Problems arising in their own Biological Field.

Illustrate the Great Utility of Mathematical Models to provide answers to Key Biological Problems.

Develop a Student's Appreciation of the Diversity of Mathematical Approaches potentially useful in the Life Sciences

Methods:

Encourage hypothesis formulation and testing for both the biological and mathematical topics covered.

Encourage investigation of real-world biological problems through the use of data in class, for homework, and examinations.

Reduce rote memorization of mathematical formulae and rules through the use of software such as Matlab and Maple.

Course 1 Content – Discrete Math Topics:

Descriptive Statistics – Means, variances, using software, histograms, linear and non-linear regression, allometry

Matrix Algebra – using linear algebra software, matrix models in population biology, eigenvalues, eigenvectors, Markov Chains, compartment models

Discrete Probability – Experiments and sample spaces, probability laws, conditional probability and Bayes' theorem, population genetics models

Sequences and difference equations – limits of sequences, limit laws, geometric sequence and Malthusian growth

Course 2 Content – Calculus and Modeling:

Linear first and second order difference equations - equilibria, stability, logistic map and chaos, population models

Limits of functions - numerical examples using limits of sequences, basic limit principles, continuity

Derivatives - as rate of growth, use in graphing, basic calculation rules, chain rule, using computer algebra software

Curve sketching - second derivatives, concavity, critical points and inflection points, basic optimization problem

Exponentials and logarithms - derivatives, applications to population growth and decay

Antiderivatives and integrals - basic properties, numerical computation and computer algebra systems

Trigonometric functions - basic calculus, applications to medical problems

Differential equations and modeling - individual and population growth models, linear compartment models, stability of equilibria

Results:

This sequence is now taken by approximately 150 students per semester, and is taught mostly by math instructors and graduate students in math biology.

In many ways the course is more challenging than the standard science calculus sequence, but students are able to assimilate the diversity of concepts.

It is still necessary to review background concepts (exponentials and logs), but this is eased through the use of numerous biological examples.

Despite much experience with word-processing and game software, students have difficulty utilizing mathematical software and developing simple programs.

Alternative Routes to Quantitative Literacy for the Life Sciences: General Biology

Determine the utility of alternative methods to enhance the quantitative components of a large-lecture format GB sequence using:

Quantitative competency exams developed specifically to evaluate the quantitative skills of students taking the GB sequence for science majors;

Modules comprising a Primer of Quantitative Biology designed to accompany a GB sequence, providing for each standard section of the course a set of short, self-contained examples of how quantitative approaches have taught us something new in that area of biology.

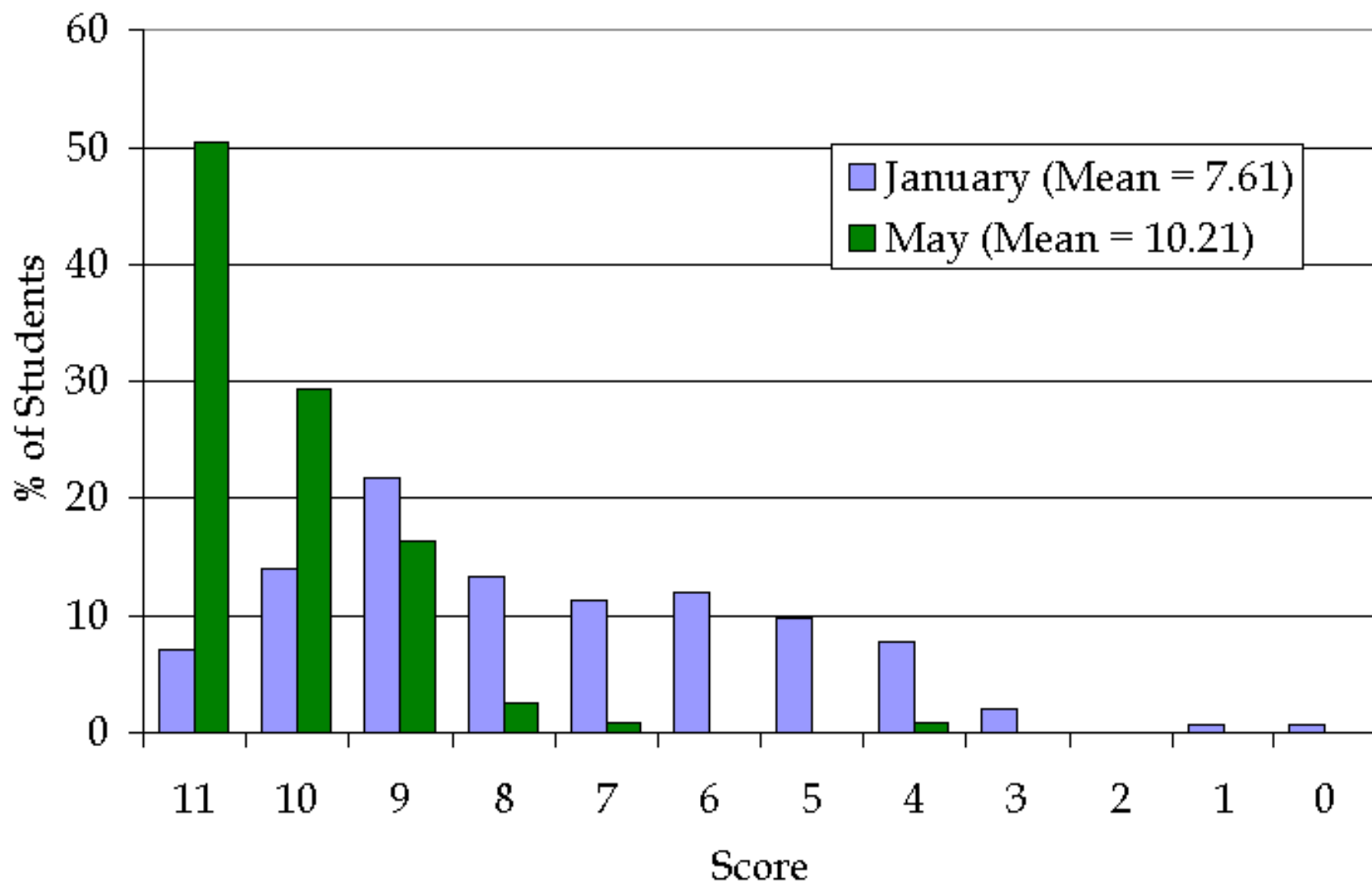
Quantitative Competency Exams:

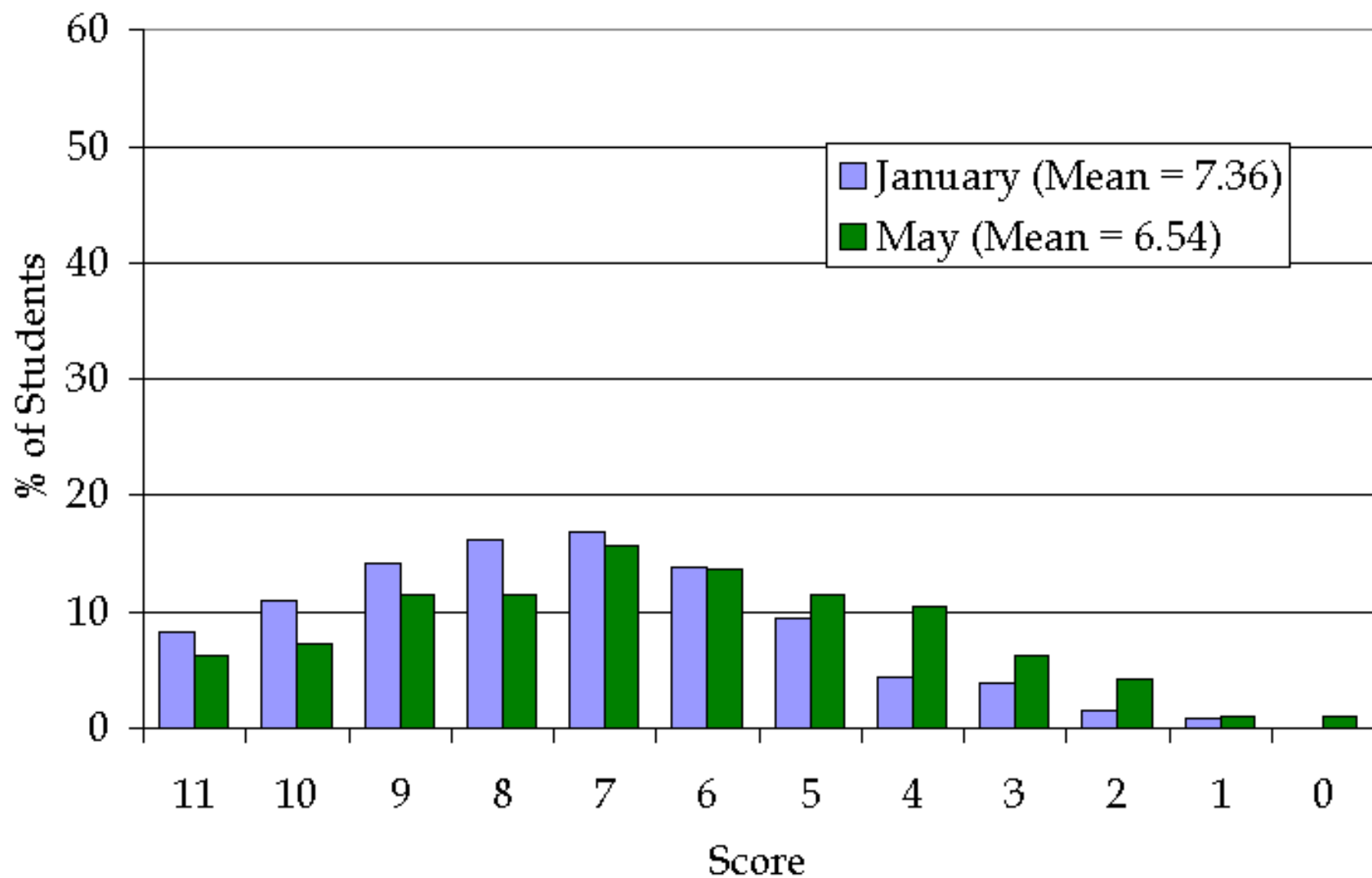
Multiple choice exams based upon the skills and concepts appropriate for the Organization and Function of the Cell and the Biodiversity (whole organism, ecology and evolutionary) components of GB. Given at beginning and end of the course to track changes in skills. Require only high-school math skills, with questions placed in a GB context.

Goals of Competency Exams:

- (i) inform students at the beginning of a course exactly what types of math they are expected to already be able to do;**
- (ii) help students be informed about exactly what concepts they don't have a grasp of, so they can go back and refresh their memory; and**
- (iii) ensure that the class is not held back through having to review material that the students should know upon entering.**

Pre- and post-testing were done in GB sections taught by collaborators on this project, emphasizing quantitative skills, and other sections taught by faculty in a standard manner, as a control.





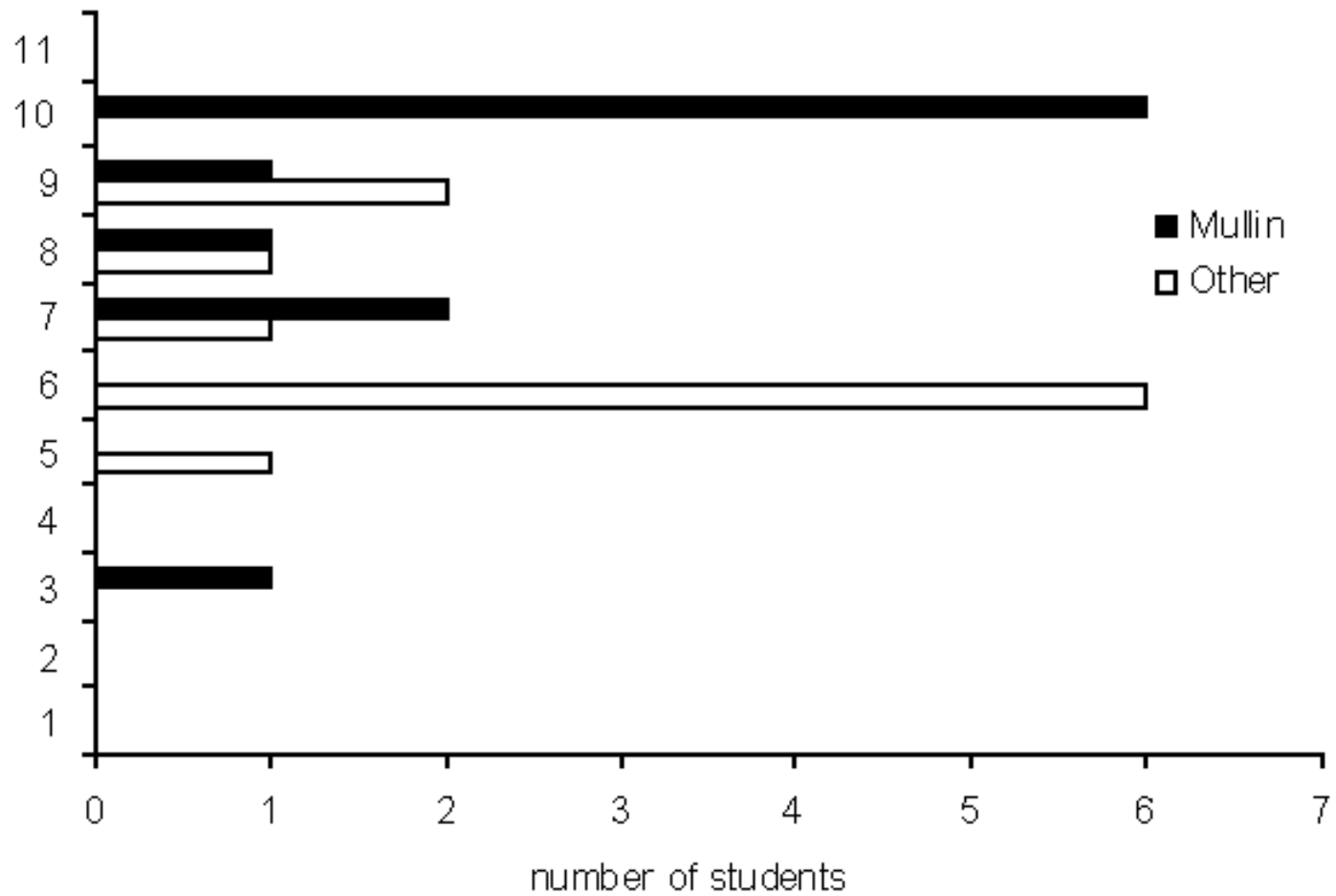
Conclusion:

Inclusion of a quantitative emphasis within biology courses can aid students in improving their quantitative skills, if these are made an inherent part of the course and not simply an add-on.

Do students retain the quantitative skills developed?

We surveyed a sophomore level Genetics class a year after the students had been in the General Biology course, and determined student performance on another quantitative competency exam. We compared exam scores of students who had been in a GB course which emphasized quantitative ideas to those who had been in a standard GB course.

Follow-up Exam in Genetics



Thus the available evidence suggests that students retain quantitative skills obtained within biology courses through later courses.

Modules in GB

The objective is to provide, for each standard section of GB, a set of short, self-contained examples of how quantitative approaches have taught us something new in that area of biology. Most examples are at the level of high-school math, though there are some calculus-level and above examples. A standard format for each module was established and a collection of 57 modules have been developed.

Use of Modules within GB

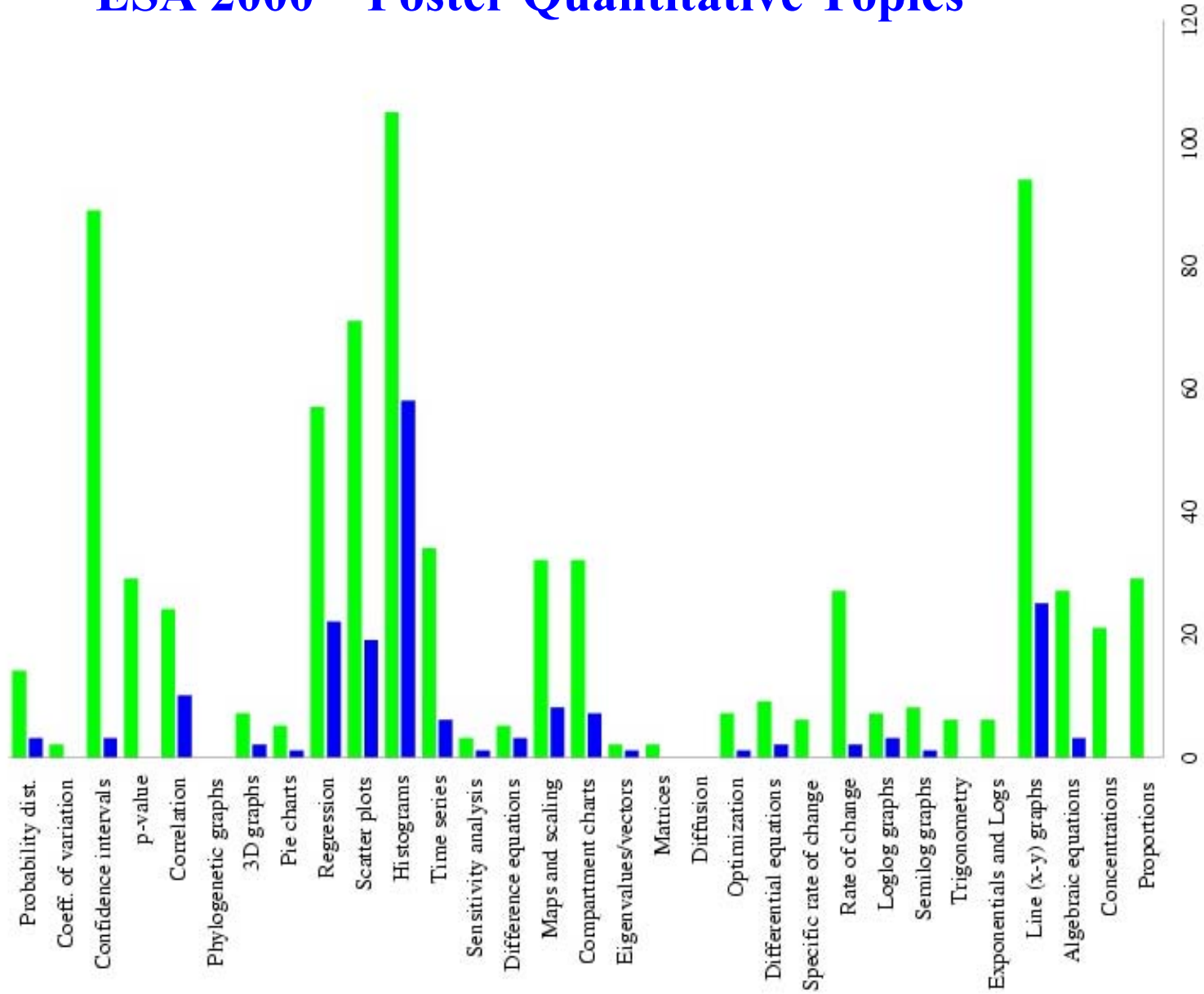
These modules have been implemented in a variety of ways in GB.

- (i) in lectures as a supplement to lecture material.**
- (ii) assigned to students as outside reading assignments.**
- (iii) students have been asked to turn in formal reports as homework assignments based around the additional questions to be answered at the end of each module.**

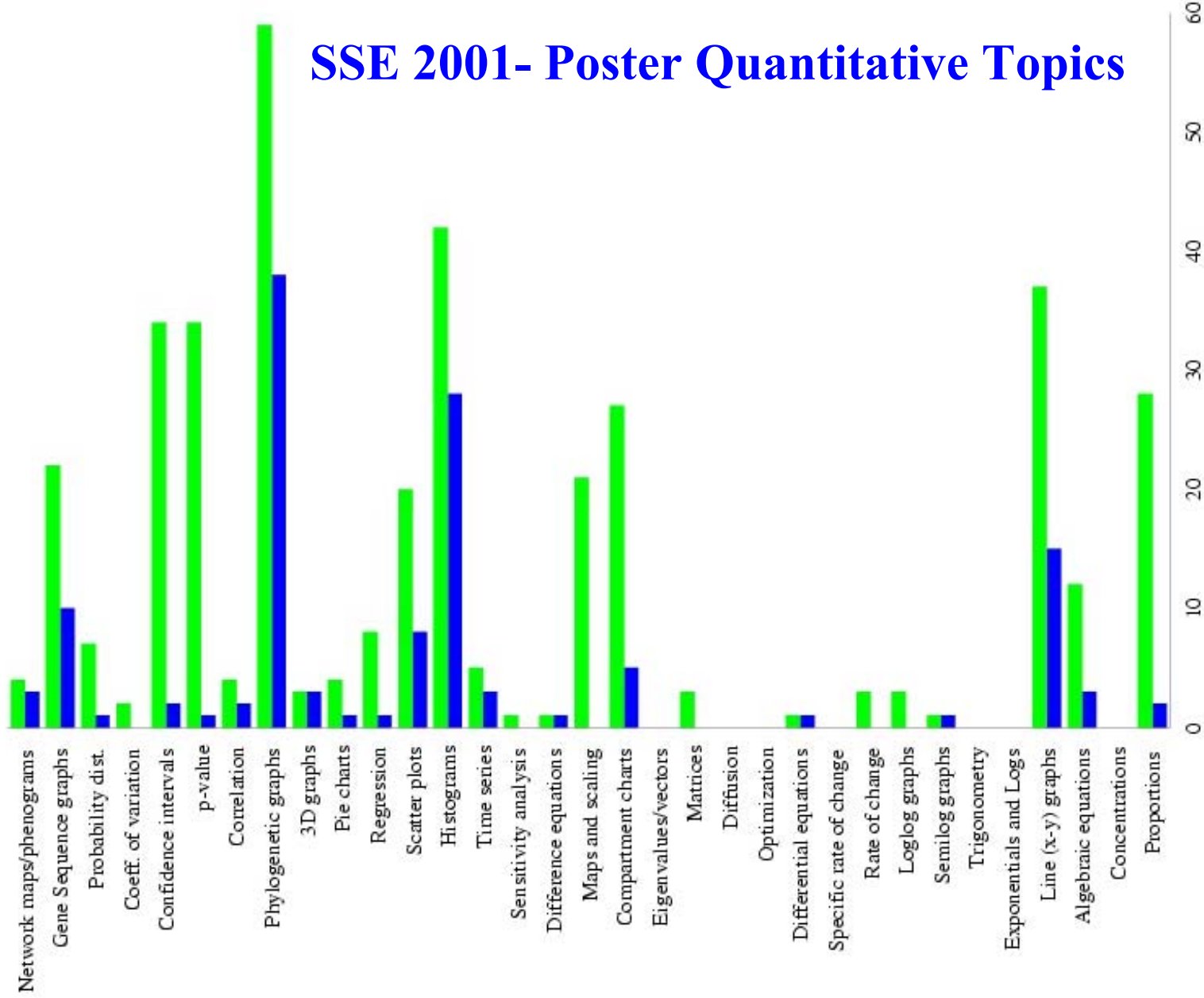
What quantitative topics are used?

Surveys were done at annual meetings of the Ecological Society of America and the Society for the Study of Evolution. The most important quantitative topic for each poster was assessed as well as a listing of all quantitative concepts used for each poster.

ESA 2000 – Poster Quantitative Topics



SSE 2001- Poster Quantitative Topics



Some lessons:

- 1. It is entirely feasible to include diverse mathematical and computational approaches in an entry-level quantitative course for life science students. This can be successful, even though it is in many respects more difficult than a standard science and engineering calculus course, if students see the biological context throughout the course.**

2. Inclusion of a quantitative emphasis within biology courses can aid students to improve their quantitative skills, if these are made an inherent part of the course and not simply an add-on. Evidence suggests that students retain these quantitative skills through later courses.

3. Instructors can utilize quantitative competency exams to encourage students early in a course to focus on skills they should have mastered and see the connection between these skills and the biological topics in the course.

4. The key quantitative concepts that are used in short scientific communications are basic graphical and statistical ones that are typically covered very little in a formal manner in most undergraduate biology curricula. Visualization/interpretation of data and results are critical to the conceptual foundations of biology training and we should give them higher priority in the curriculum. This might include a formal course on Biological Data Analysis, but needs to be emphasized throughout the science courses students take.

Future Directions:

The BIO2010 Report gives numerous recommendations on quantitative skill development. Accomplishing these above can be aided through:

- a. Agreed upon quantitative competency testing across courses.**
- b. Setting up teaching circles involving the key faculty involved in appropriate groups of courses.**
- c. Encouraging projects either formally within courses or as part of labs that require quantitative analysis involving the concepts deemed critical for comprehension.**
- d. Including key quantitative ideas from the beginning in basic entry-level courses - expecting students to utilize skills developed in high school and providing mechanisms to aid those who need remediation.**

Impediments to progress

Few math faculty at research universities have any appreciation (or interest) in real applications of math

Few biology faculty (not including many recently hired) have strong quantitative skills except in statistics

Cultures are different – few undergrads in math are expected to work on research with faculty, while it is expected that the better biology undergrads will have some exposure to research in field/lab situations with faculty

Math faculty prefer rigor (proof) over breadth