MathBench Biology Modules

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**Summary**

The MathBench project consists of a series of interactive, web-based modules through which students are introduced to the mathematical underpinnings of introductory biology in an informal but powerful way.

**Project Goal**

The major goal of this initiative is to integrate quantitative approaches and mathematics more deeply into the undergraduate life sciences curriculum in a way that reinforces biological concepts, increases math literacy, and prepares students to be receptive to more complicated mathematical approaches in upper-level courses.

**Project Design Elements**

The MathBench project involves a suite of online 'modules' that are designed to provide undergraduate students in the life sciences with refreshers (or introductions) to a diversity of quantitative, graphical, and mathematical issues necessary for success in modern biology. Integration of the MathBench modules into fundamental courses across the biological sciences curriculum allows students from diverse educational backgrounds to hone their quantitative skills, preparing them for more complex mathematical approaches in upper-division courses. These modules, which are designed to supplement in-class instruction, use humor, references to popular culture and interactive elements to engage students, but they also build upon the students’ intuitive understanding to help them explore biological concepts using fairly sophisticated mathematical approaches. The modules focus on a series of ten major quantitative skills identified by faculty as being essential for a comprehensive understanding of modern biology. A detailed description of the ten major skills is available at <http://www.mathbench.umd.edu/homepage/top_ten.htm>. Modules have been completed or are in progress for use in five fundamental biology courses at the University of Maryland (UM) and in partner institutions; these include a special set of modules adapted for community colleges. The entire MathBench suite of modules is thoroughly grounded in pedagogical research and enriched with robust interactive elements that fully capitalize on the advantages of technology-enhanced instruction.

We have established a consortium of nine institutions (encompassing research universities, primarily undergraduate institutions and community colleges) to further implement and evaluate the modules in preparation for wider dissemination.

As of January 1, 2010, our complete suite of MathBench elements includes 37 modules, containing over 500 pages of online material, 156 interactive problems, 47 javascript applets, and 21 Flash applets.

**Evaluation and Assessment Strategies**

During 2009, we thoroughly assessed the MathBench modules using a variety of quantitative and qualitative approaches including 1) surveys of students, instructors, and teaching assistants, 2) comparison of pre- and post-test results, and 3) the involvement of an external team of faculty evaluators. We had 4 goals for these assessments, namely to evaluate 1) whether the modules were useful to instructors and easy to implement, 2) whether the modules help students appreciate the relationship between math and biology, 3) whether the modules help students gain a deeper understanding of the mathematical underpinnings of biological phenomena, and 4) whether the modules help students become more adept at applying quantitative skills to new situations.

Survey Results

We administered an anonymous survey to faculty (N=5, all of whom responded) and teaching assistants (N=12) who were actively using MathBench in their courses. Survey results affirmed our impression that instructors desired a more quantitative emphasis for their courses. Nearly half (47%) of those responding indicated that they felt it very important to include quantitative material in their courses and did so whenever appropriate, while another 35% were generally supportive of an increased emphasis on quantitative material. A large majority (88%) felt the topics covered in MathBench modules were useful for their particular class and appropriately rigorous. A similar percentage (82%) found the informal tone and humorous examples helpful, especially for engaging students who were initially uncomfortable with the quantitative emphasis of the modules. Furthermore, instructors noted that students were better prepared for in-class discussions, had a better grasp of terminology and were able to devote more time to wet laboratory activities because the MathBench modules reduced the need for pre-lab lectures. Students that had used MathBench were significantly more likely to state that math was "essential for all fields of biology" or "essential to cutting-edge biology" than were students who had not used MathBench (61% vs. 41%, respectively)(Figure 1).

Fig. 1. Attitudes of Spring 2009 biological sciences graduates in the College of Chemical and Life Sciences regarding the relationship between math and biology (N=307).

Pre- and post-tests of student learning outcomes

Initial analyses indicate that students in introductory biology courses using MathBench show substantial gains in quantitative skill (Fig. 2). These gains are independent of their previous math background and whether or not they are concurrently enrolled in a mathematics course. Gain was negatively correlated with pre-test score (r=-0.638, N=206), indicating that students who initially had weak quantitative skills made greater gains across the semester. Students also showed a decrease in their level of risk aversion when asked to use their quantitative skills (i.e., more comfort with quantitative approaches). The percentage answering "I don't know how to approach this problem" to at least one question decreased from 75% on the pre-test to 29% on the post-test.

Fig. 2. Gains in quantitative skill across a semester in students enrolled in BSCI 105 (Principles of Biology 2: Cell and Molecular Biology) (N=206), as measured by the difference in scores between the pre- and post-test.

Nearly all of the students (93%) reported they improved their quantitative skills in the course, and a large majority of these students attributed their gains to MathBench (Fig. 3).

Fig. 3. Student responses to the question "In this course, which class activity or component most helped you improve your quantitative skills (mathematical and statistical reasoning)?" Percentages sum to >100% because students could select multiple answers.

Our assessment instrument is designed to assess 10 essential skills and concepts mentioned above. Questions on the assessment instrument are specific to 9 of the 10 skills. The 10th skill, “Distilling biology into math,” is the overarching goal of the project, and student performance in this area is assessed using the overall improvement in scores. Thus far, students have shown improvement in almost all of these skill areas, the big exception being probability. However, this gap is understandable because that topic is covered more extensively in the modules for the sophomore level Genetics course which has not yet been incorporated into the MathBench program.

External evaluation

The external evaluators, Drs. Pat Marsteller and Ethel Stanley, reviewed program materials (including all completed and draft modules), focusing on the rigor and quality of the modules, level of interactivity, the feedback system, and the testing system. They also conducted a site visit Dec. 3-4, 2009, during which they met with the project leadership team and instructors representing the University of Maryland and Montgomery College. They were extremely enthusiastic regarding the potential of the project to contribute to the education of biology students in a variety of institutional contexts. Some of their specific feedback and recommendations for future initiatives are summarized below:

They reviewed the current assessment instruments and suggested that the pre-test could be used as a diagnostic and be linked to specific modules for the students to review. This diagnostic could also be used in bridge programs for the high school to college transition as well as community college to four-year transitions, allowing students to gauge where the gaps in their understanding might be. These deficiencies could then be addressed via review of the modules.

Two modules, still in development, were viewed as particularly interesting. The Grow an Experiment module was seen as having utility beyond community college and college courses, in helping high school teachers convey the elements of experimental design. The evaluators felt that college students often need review of the basic elements of experimental design and this module conveys the ideas in an interesting and engaging way. They further felt that the Graphical Zoo, which includes graph families, could provide a superb review of mathematical applications for advanced students and could also be linked to all the modules so that students could review applications.

Examples of Student Feedback

"I loved the whole thing. I'm completely serious. It made the whole idea of diffusion in regards to Ficks' laws absolutely clear. I love how it started off general in terms anyone would understand and slowly built up to the math to make sure it made sense and then applied it to real life and real biological situations."

"I loved the real world examples, the images, the repetition of concepts and ideas, and the way things were broken down."

"It took me an hour to get through the module and take notes and reread parts to make sure I understood it all. However, it didn't seem like too long."

"More classes should do something like this."

Examples of Teaching Assistant Feedback

“I only wish they had something like MathBench for my graduate classes! It is a great resource for quickly brushing up on topics learned long ago in an extremely straightforward manner.”

Examples of Faculty Feedback

"...I again want to thank you and your whole team for the 2007 BioMath modules, which are helping [us] to adopt a more quantitative approach to BSCI 207. The committee that created 207 made the fateful decision to introduce fundamental thermodynamics and diffusion in the first lectures, because these principles appear throughout organismal biology, but the textbooks are decidedly non-quantitative in their treatments. The modules make it much easier to reorient the students toward a more quantitative approach to biology." Dr. Todd J. Cooke, Department of Cell and Molecular Biology

"...I have to tell you FROM THE HIGHEST MOUNTAIN TOP that these modules are FANTASTIC." Dr. Patricia A. Shields, Department of Cell Biology and Molecular Genetics

**Products and Publications**

The primary products of our project are the modules themselves, which can be accessed at [www.mathbench.umd.edu](file:///C:\Documents%20and%20Settings\bfagan\Desktop\Research\Grant%20Proposals\CCLI\www.mathbench.umd.edu).

We have also published a paper about the project:

Nelson, K., Marbach-Ad, G., Thompson, K., Shields, P. & Fagan, W.F. (2009). MathBench Biology Modules: Web-based math for all biology undergraduates. Journal of College Science Teaching: 38, 24-29.

Here is the abstract for this paper.

A brief narrative description of the journal article, document, or resource.Historically, biology has not been a heavily quantitative science, but this is changing rapidly (Ewing 2002; Gross 2000; Hastings and Palmer 2003; Jungck 2005; Steen 2005). Quantitative approaches now constitute a key tool for modern biologists, yet undergraduate biology courses remain largely qualitative and descriptive. Although biology majors are often required to take a full year of calculus, these courses generally use examples unrelated to biology (Gross 1994) and ignore fields of mathematics that may be more relevant to biology, such as liner algebra or theoretical probability and statistics (NRC 2003). In this series of interactive, web-based modules, students are introduced to the mathematical underpinnings of introductory biology in an informal but powerful way.

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