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Beyond *Bio2010*: If We Build It, Will They Come?

A Curriculum for the New Biology

The 21st Century is a time of unprecedented opportunities in the life sciences. The opportunities transcend the disciplines and arise at the intersections among disciplines. The strategies developed in chemistry, mathematics, computer science, physics, and engineering will be applied to biological problems. Equally, biology will inspire solutions to problems arising in other disciplines. The leaders of the post-genomics age will effectively integrate biological information – including rapidly expanding databases of genomes and macromolecular structures – with an intimate understanding of the complexity of dynamic living systems and the ability to think across disciplines. As we develop the next generation of leaders, we are guided by four principles. Modern biology is derivative; it is based on a clear understanding of mathematics, chemistry, physics, and computational sciences. Modern biology is learned experientially; students should begin inquiry-based, active learning as soon as possible. Modern biology is integrative; the goal should be to erase the boundaries between disciplines. And modern biology depends on its leaders to clearly communicate their ideas and discoveries across disciplines.

Bio2010 (National Research Council, 2003) translates these guiding principles into a transformative curriculum for the “new biology.” The new biology is interdisciplinary. The new biology requires a foundation in the physical and quantitative sciences; and it should attract students trained in other disciplines to apply their ideas and skills to problems in biology. The new biology emphasizes chemistry, mathematics, physics, engineering principles, and the ability to use computers to acquire and process data; and it includes interdisciplinary laboratories, seminar courses, independent research, and courses that explore the relevance of science to society.

An Opportunity to Look Beyond *Bio2010*

Many institutions will find that their present curriculum is far from the model prescribed in *Bio2010*, and their challenge will be to determine how best to revamp the curriculum to meet the objectives of the new biology. However, the ideas presented in *Bio2010* are already in place at Harvey Mudd College. This presents an important opportunity to look beyond *Bio2010*, to see what challenges may lie ahead.



Annie Tan and Sarah Rodenburg, who did summer and senior thesis research with Marta Bechtel and Elizabeth Orwin, become familiar with the confocal fluorescence microscope. Photo courtesy of Harvey Mudd College/Kevin L. Mapp.



Holly Johnsen, who did summer research with Cathy McFadden on molecular systematics, sets up a PCR reaction. Photo courtesy of Harvey Mudd College/Kevin L. Mapp.

Harvey Mudd College has the talent pool and the curriculum prescribed by *Bio2010*. HMC attracts students with strong quantitative skills. No matter what the major, all students complete a curriculum that is approximately equal parts of three components. A rigorous scientific technical core is completed during the first two years: four semesters of mathematics (single and multi-variable calculus, discrete dynamical systems, linear algebra, differential equations, and probability and statistics); two semesters of chemistry, which include an introduction to organic chemistry, and two chemistry laboratories; three semesters of physics and two physics laboratories; and one semester each of computer programming, systems engineering, and cell biology and genetics. Another one-third of the curriculum is devoted to courses in the humanities and social sciences. The remaining coursework is in the student's major. All HMC students are required to participate in Integrative Experience courses that explore the connections among science, technology, and society. All students complete a year-long capstone research or design experience.

The special opportunities presented at Harvey Mudd – talented students, a curriculum that provides a foundation for interdisciplinary thinking, and the clear relevance of biology – compelled us to implement strategies that maximize these opportunities. One obstacle to the full realization of the goals of *Bio2010* is the “silo effect” of departmental boundaries between disciplines. By purposefully working to build bridges between departments, these boundaries can be lessened. At Harvey Mudd, we have focused on

developing strategies that integrate student learning and discovery across disciplines. We have the advantage that our very small size facilitates collaborations. However, it is also important to develop formal strategies designed to blur the boundaries between disciplines. Here we share five ideas we are trying at HMC.

Integrating the Freshman Laboratory

Although modern biology depends on a foundation of other disciplines, it is also important to capture the interests of students early in their careers. Several years ago with the support of an NSF AIRE grant, we developed the freshman Interdisciplinary Lab (ID Lab) in which students engaged in experiments in chemistry, physics, and biology (described in *Bio2010*). Because of staffing constraints, we were able to offer ID Lab to only 1/5 of the freshman class (ca. 36 students) every year. Assessment of student learning outcomes revealed that ID Lab students, as compared to a control group of freshmen not in ID Lab, had significantly greater understanding of the skills underlying hypothesis-driven scientific inquiry.

This year we explored a different way to include biology early in the first year for all students at HMC. As part of the required first semester freshman Chemistry lab, students engaged in a three-week experiment aimed at mapping the restriction sites on a plasmid. This experiment was part of the earlier ID Lab. The biology module was directed by Cathy McFadden in Biology. Working in pairs, students were given pBR322 plasmid DNA and three restriction enzymes. In the first week, the students performed single- and double-digestions of the DNA. While they waited for the reactions to be completed, the students used RasMol to visualize the structure of DNA and the way it interacts with a restriction enzyme. In the second week, the students electrophoresed the various digests in agarose gels, then measured the migration of each DNA fragment. In the final week, the students generated a restriction map of the plasmid and wrote up the report of the experiment. In an end-of-the-semester survey, the students reported an increased understanding and appreciation of biology because of the module. Many students expressed an increased interest in taking more biology courses at HMC. An important and ongoing challenge is to staff this added course. This year, three faculty members (of a department of 6.4 FTEs) and a postdoc were assigned the course. We would like to eventually expand this idea to include a second module – perhaps one that involves genetics – but at present we do not have the person power.

Interdisciplinary Learning

One way that HMC has brought departments together is by creating jointly administered degree programs. There are currently three joint majors: Mathematical Biology, Chemistry and Biology, and Mathematics and Computer Science (<http://www.biology.hmc.edu/academics/biomath.html>, <http://www.biology.hmc.edu/academics/chembio.html>, <http://www.cs.hmc.edu/major/joint-major.html>). In each case, the joint major is co-administered by the two participating departments. Students take coursework in both departments, have co-advisors in each department, attend colloquia in both departments, and have their senior thesis read by faculty from both departments. Required capstone courses for the joint major are co-taught by faculty from the participating departments. In these capstone courses, the intersection of the two disciplines is purposefully examined and studied. For example, Topics in Biochemistry and Molecular Biology is a seminar-styled senior-level course taught by Karl Haushalter and David Asai. Last fall, the seven students in the course focused on recent research papers on (i) mitotic checkpoints, (ii) DNA repair, and (iii) apoptosis. Over the course of the semester, each student gave two one-hour PowerPoint lectures on primary literature papers, wrote a grant proposal using the American Cancer Society format, provided peer-review of two other grant proposals, and participated in a mock study section.

Interdisciplinary Discovery

The collaborative mentoring of research students working on a common problem builds bridges between faculty members. We offer small research grants to promote interdisciplinary research. Funded through our grant from the Howard Hughes Medical Institute, these interdisciplinary grants go to two or more faculty members, one of whom is a biologist and the other from another discipline. The awards, which are reviewed and selected by the College faculty committee on research, are intended to enable the investigators to explore new ideas. We hope that the pilot grants will lead to extramural funding.

In its first year, we supported four projects. LizardNet was led by Steve Adolph in Biology and Michael Erlinger in Computer Science. A team of three students developed remote sensing technology to monitor environmental conditions and lizard behavior in the Bernard Field Station. A second project led by Marta Bechtel in Biology and Elizabeth Orwin in Engineering and Biology focused on the cell biology of corneal transplants. A team of three students evaluated the



Maddalena Jackson, who did summer research with Steve Adolph on animal behavior, gets personal with her experimental subject. Photo courtesy of Harvey Mudd College./Kevin L. Mapp.

changes in gene expression in cultured corneal fibroblasts in response to growth factors. Four students worked on a project led by Richard Haskell and Dan Petersen in Physics, Elizabeth Orwin in Engineering and Biology, and Mary Williams in Biology. The team refined the optical coherence microscope to image the dynamics of frog gastrulation and tissue-engineered corneal cells grown in a chamber that mimics intraocular pressure. A fourth project, led by Elizabeth Sweedyk in Computer Science, Marianne deLaet in Humanities and Social Sciences, and David Asai in Biology, explored the use of a computer game as a pedagogical agent in biology. A team of two students created a computer-based adventure game, *Elixir Vitae*, using as a metaphor the central dogma of molecular biology (<http://insidehighered.com/news/2005/10/26/games>).

Promoting Faculty and Student Learning Across Disciplines

An integrative curriculum as prescribed by *Bio2010* requires the active participation of faculty across disciplines. It is essential for faculty to learn the strategies and languages of other disciplines. By teaching each other, biologists and non-biologists can gain the skills and background necessary to teach our students at the boundaries between disciplines. For example, we hope to forge new alliances among mathematicians, computer scientists, and biologists by developing and co-teaching a multi-disciplinary course that will include a laboratory component. The idea is for faculty members to teach one another and then to co-teach the course to students.

A few years ago, Harvey Mudd College instituted a program that encourages faculty members to audit a colleague's course outside of the primary field of the auditor. Funded through an institutional grant for faculty development from the Mellon Foundation, the program

provides honoraria to auditing faculty members. For example, faculty members from Computer Science, Engineering, and Physics have audited the introductory biology course offered in the HMC Core, and thus have had the opportunity to gain an appreciation for the challenges and opportunities in modern biology.

Clearly, a critical challenge is to find time for busy faculty members to create and participate in new courses, to learn across disciplines, and to audit other courses. Indeed, despite the widespread recognition of the value of the auditing program, only a relatively small number of faculty members have participated. Informal feedback indicates that the reason for the modest participation is the lack of time and not the size of the honorarium.

And there are bigger opportunities ahead. We would like to develop a new lecture/laboratory course co-taught by faculty from Biology, Computer Science, and Mathematics. The aim of the course will be to educate participants – students AND faculty members – across disciplines. The course would present key concepts from each discipline and then engage people in applications of the concepts. For example, a project could combine genomics, bioinformatics, molecular biology, and mathematical modeling. In order to create meaningful connections, “course releases” and honoraria are not sufficient. We think that it is necessary to find the additional resources that will be used to give current faculty members half-year or one-year “sabbaticals” (though they would not count against the official sabbatical allocation) in order that they may pursue these interdisciplinary efforts. In the case of the Biology-Computer Science-Mathematics course, our goal will be to hire three visiting faculty members – one for each department – in order to release current faculty members so that they may develop and then teach the course. The resources – more than \$250K per year – for such a project will need to come from combinations of extramural sources, including federal and foundation grants. The potential impact of cross-training faculty is extraordinary and is well worth the resources that will be expended.

Joint Faculty Appointments

Another mechanism for building bridges is the hiring of faculty members with joint appointments between departments. The scholarship and teaching of such a faculty member can effectively bridge the boundaries between disciplines and can facilitate interdisciplinary research and courses. In addition, the sharing of faculty

creates new channels of communication and broadens the understanding of the participating departments. At Harvey Mudd, we currently have two joint appointments: Elizabeth Orwin in Biology and Engineering, whose teaching includes courses in tissue engineering and biomechanics (co-taught with Anna Ahn in Biology); and Karl Haushalter in Biology and Chemistry, whose teaching includes courses in biochemistry and molecular biology. And we hope to recruit a computational biochemist in the near future. Joint appointments present special administrative challenges, especially in the areas of promotion and tenure. The joint appointments can work best when the expectations and procedures for the joint faculty member are agreed upon in advance by both departments and made clear to the prospective faculty member. We think it best that the faculty member have the majority of her/his appointment in one department (e.g., 80:20).

Final Comments

The new biology is interdisciplinary. It is quantitative and based on a firm foundation of physical and chemical principles. It requires leaders who can pursue open-ended problems through the applications of different disciplines. It requires leaders who can communicate effectively. It requires leaders who are able and willing to explore the many connections between their work and society.

The opportunities ahead are extraordinary, and there is no question that the life sciences will continue to attract talented students. So the question is no longer, "If we build it will they come?" Rather, we should ask, "When they come, will we be ready? Will we have built the incentives and the structures and the opportunities to engage our students across disciplines?" This is our grand challenge.

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