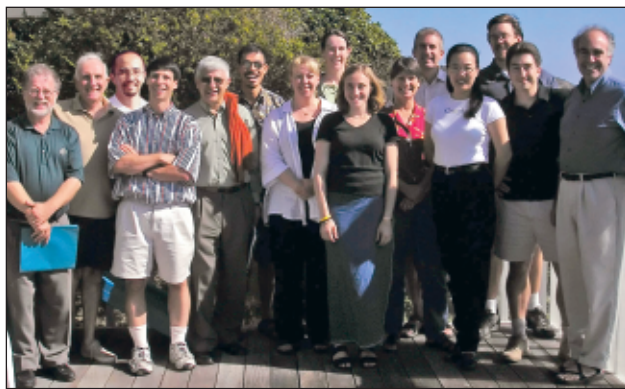# Harvey Mudd Mathematics Department Garners AMS Award

Ten years ago the mathematics department at Harvey Mudd College was a very good department known for excellent teaching and for innovations like its "clinic" in which student teams work on mathematics problems from industry. The department was doing well, and likely there would have been no complaints had it remained as it was. Instead, the department has over the past decade brought itself up to a new level to become one of the best places in the nation to be an undergraduate mathematics major. The quantitative measures of the department's success went through the roof, with the number of majors tripling and more than half of them going on to graduate school. But what really changed is how the department unified itself around its core mission of promoting teaching and scholarship in ways that inspire faculty and students alike to do their best work. For its outstanding performance, the Harvey Mudd mathematics department this year received the first-ever AMS Award for an Exemplary Program or Achievement in a Mathematics Department.

How did the department get to where it is today? One important factor is that it built upon its strengths, one of which is the Harvey Mudd Mathematics Clinic. Professor emeritus Robert

Harvey Mudd mathematics department, fall 2005. Left to right: J. Milton (visitor), H. Krieger, F. Su, A. Benjamin, A. Castro, D. Yong, L. de Pillis, L. Ward, S. Martonosi, S. Frantz, A. Bernoff, W. Gu, J. Jacobsen, M. Orrison, and D. Goroff. Not pictured are M. Raugh, B. Schade, and C. Connelly.

Borrelli was deeply involved with the clinic from its inception in the 1970s, and other faculty—Stavros Busenberg, Courtney Coleman, and Henry Krieger—served as directors of the clinic up to the 1990s. The clinic teams up senior mathematics majors to work on mathematical problems supplied by industry. These are real-life problems, messy and ill posed, and a crucial factor in making the program work was the ingenuity of the Harvey Mudd faculty in figuring out how to distill the problems down to workable projects for the student teams. During the 1970s and 1980s the faculty introduced other innovations as well; for example, Borrelli and Coleman encouraged their students to experiment with software for solving partial differential equations at a time when not much of this kind of software was around. This experimentation evolved into the ODE Toolkit, now available on the Web. Borrelli and Coleman also founded an interdisciplinary student research journal called *Interface*.

In the mid-1990s the department, facing a big wave of retirements, seized the opportunity to reinvent itself. A key step was hiring Michael Moody, a mathematical biologist from Washington State University, to take over as department chair. "He was a wonderful leader, very charismatic, with lots of ideas," noted Lesley Ward, who came to Harvey Mudd in 1997. "He would see what should be done in the future and then lay out the steps to get there." Moody set for the department what he called an "animating goal": To be recognized as one the very best undergraduate programs in the country.

During Moody's six years as chair, from 1996 until 2002, the department hired eight new professors; the total number of faculty is twelve. He and Arthur Benjamin, who had come to Harvey Mudd in 1989, worked as a team to do much of the hiring. Moody recalled that he and Benjamin resonated on what they wanted: "We wanted people who would mesmerize and inspire students in the classroom *and* have a passion for their mathematical work." In addition, the department was lucky in the timing of its hiring. Current chair Alfonso Castro, who came to Harvey Mudd three

years ago, noted that because the 1990s were tough years for job seekers in mathematics, the department was able to hire junior people who under different circumstances would likely have gone to top research universities. "These young faculty not only bought into the mission of quality teaching at the undergraduate level, they also established a first-rate presence in the research community," he said. Some of the candidates sensed the department's newfound dynamism and were attracted by the prospect of contributing to the building of a new department. "That was exciting to me," noted Francis Su, who came to Harvey Mudd in 1996.

Young, newly hired faculty were given big responsibilities early on. Soon after Ward came to Harvey Mudd, she and Su, together with senior faculty member Henry Krieger, took on the task of restructuring the department's core curriculum. This two-year collection of courses is taken by all Harvey Mudd students. After consulting with other departments about what their majors needed to get out of the core mathematics curriculum, Krieger, Su, and Ward reconfigured the four, semester-long courses into eight courses that run half a semester each. They also added to the core a new course in statistics and probability and introduced a strand in discrete dynamical systems. "This bought us huge credibility inside the institution," Moody noted, because the other departments felt that their concerns were heard and taken into account. He took flak from some senior faculty who considered the changes too radical, but he was not perturbed. "I grew up in a system where assistant professors were seen and not heard to a large extent," he noted. "But they have creativity and energy, and if you leaven that with an experienced person who has a light hand on the tiller, they'll do great things. Plus they'll be invested in it."

Also around this time the department revamped the mathematics major. Over the years the major had morphed into a system with several different tracks, and there would sometimes be just one or two students per track, leaving them feeling somewhat isolated. The department now has a single, unified major centered on a core set of six advanced courses. Students take electives to customize their own programs in consultation with faculty advisors. In addition, the department launched two new majors: the joint major in computer science and mathematics that started in 1998 and a major in mathematical biology that started in 2001.

Every senior major in the department must take part in a "senior research experience", which can mean either participating in the mathematics clinic or writing a senior thesis. The strong tradition built up over thirty years of running the clinic served the department well when directorship of the clinic passed in 1999 from Borrelli to then-newly hired faculty member Michael Raugh.

(Raugh also created and serves as the director for a version of the clinic at the Institute for Pure and Applied Mathematics at the University of California, Los Angeles.) The range of topics covered in the Harvey Mudd Mathematics Clinic is enormous; in recent projects, students have worked on such topics as gene expression data, global positioning system algorithms, soliton-like water waves, and cryptography.

In the HMC Mathematics Clinic, teams of students work with faculty and company liaisons to solve open-ended real-world problems. Here Lisette de Pillis (standing, left) supervises a network optimization project for ESRI Corporation.

The department set about revitalizing its senior thesis by raising standards and by introducing additional structure, such as having students participate in a weekly seminar in which they give talks to each other about their work as it progresses. Small changes like preparing hardbound copies of theses and storing them on shelves where students can browse through them help to convey the message that the department believes that writing a senior thesis is a serious and substantial undertaking. At the end of the year, all graduating seniors must participate in "Presentation Days", a three-day, collegewide miniconference in which students from all departments present talks about their work. "The fact that we as a college decided it's more important to have three days of presentations than three more days of lectures says a lot about how the college values undergraduate research," commented Ward.

But is it really possible to involve undergraduates in mathematics research? Absolutely, said Su. "I believe undergraduates at any level can do research," he said. "There are many kinds of research experiences. In terms of serving a student, what is valuable for the student is learning to inhabit the research process." The goal is to give the students an experience in mathematical discovery that allows them to understand what research is like. Su noted that even in a deep field where there are not many easy problems lying around—say, differential geometry—there are nevertheless problems that undergraduates can sink their teeth into. For example, his colleague Weiqing Gu has come up with problems in M-theory and string theory that boil down to specific systems of partial differential equations. Without possessing extensive background, an undergraduate can work on solving such systems

Jon Jacobsen and Francis Su demonstrate the fluid dynamics of a vortex cannon (the stable toroidal ring will blow out the candle Su is holding). Many HMC math faculty use physical demonstrations in their lectures.

Weiqing Gu (standing) advising a team of students on a summer research project concerning tumor modeling and immunotherapy for cancer patients. The project was supervised by Lisette de Pillis.

and make progress on understanding them analytically and geometrically. The proof that the department's approach works is in the publications: Since 2002 at least twenty papers have been published, many of which were based on senior theses and written jointly by faculty and students, and many students have published papers on their own. There are other proofs as well. Harvey Mudd mathematics major Joshua Greene received the 2002 AMS-MAA-SIAM Morgan Prize for outstanding research by an undergraduate, and another Harvey Mudd student, Aaron Archer, was a runner-up for this distinction in 1998.

Of course, for the students to have a meaningful research experience, the faculty themselves have to be engaged in research. And at Harvey Mudd, they are. The department's publication output is impressive, and several faculty are supported by research grants from the National Science Foundation (NSF). The Keck Foundation provided a three-year grant for the Center for Quantitative Life Sciences, which is codirected by mathematics faculty member Lisette de Pillis and a biology faculty member. The center has developed new courses in mathematical biology, hosted research visitors, and funded two dozen multidisciplinary summer research projects. The Harvey Mudd mathematics faculty has also been represented in major research conferences: Gu was an invited speaker at the International Congress of Mathematicians in Beijing in 2002, and four other faculty—Ward, Su, de Pillis, and Andrew Bernoff—have been course lecturers at the Park City Institute for Advanced Study summer mathematics conferences. In 1999 the department began organizing its own annual, one-day regional research conference. With topics ranging over analysis, algebra, geometry, mathematical biology, and scientific computing, the conferences typically attract fifty to seventy-five participants. Although this is a bona fide research conference, with experts in the field presenting their latest work, Harvey Mudd students are encouraged to attend just to soak in the atmosphere. "We always have significant student attendance at the conferences," Moody remarked.

Hand in hand with the emphasis on research and scholarship is the department's strong commitment to excellence in teaching. As Ward put it, at Harvey Mudd "it's okay to spend a lot of time on making your classes great." As at other places, the college is trying to come to grips with how to document good teaching. Student evaluations are used; also, when an individual comes up for promotion or reappointment, he or she must get other faculty members to write letters of recommendation focused on teaching. But what really seems to make the biggest difference in the department's teaching is a highly developed sense of collegiality and collective responsibility. "We are really generous and free in sharing teaching ideas," Su noted. He recalled that when he was teaching a certain course for the first time, his colleague Art Benjamin lent his lecture notes to Su. It has become a tradition to hand down one's lecture notes. Su has developed a large collection of what he calls "Fun Facts", interesting tidbits about a wide variety of mathematical topics that can be presented in about five minutes at the beginning of a lecture to awaken students' interest and expand their ideas of what mathematics is. Su started sharing the "Fun Facts" over the Web, and now other professors are using them. On a daily basis the faculty discuss with each other many teaching issues, large and small. "If we go to lunch, we are as likely to be discussing teaching as research," Ward remarked. The college has no teaching awards, but Harvey Mudd mathematicians have received such awards at the national level: In 2000, Benjamin received the Haimo Award of the Mathematical Association of America, and in 2004 Su received the MAA's Alder Award.

The department's efforts to renew itself have made a big difference in its ability to attract students into mathematics. "The students picked up a different feel" from the mathematics department, Moody noted. "They could tell we really cared about them." The number of mathematics majors increased from a low of ten in 1993 to about thirty per year in recent years. The class of 2006 has forty-one majors, nearly one quarter of Harvey Mudd seniors (this number includes computer science/mathematics and mathematical biology majors). The number of women has also increased, and

women now account for about one third of all mathematics majors, the same proportion in which women are represented in the Harvey Mudd student body. (With the hiring in fall 2005 of Susan Martonosi, the proportion of women in the mathematics department faculty is also one third.) Among students who finished the mathematics major between 2002 and 2005, about 60 percent went on to graduate school, and many were accepted in the top mathematics graduate programs in the country. In the past five years, nineteen Harvey Mudd mathematics majors were awarded the prestigious NSF Graduate Research Fellowships, and another sixteen were named honorable mentions. Majors who do not choose graduate school are heavily recruited by business, industry, and government.

Not only has the department attracted more mathematics majors, it has also attracted more nonmajors to take part in its programs. For example, sixty to seventy students—about 10 percent of the Harvey Mudd student body—take part in the weekly Putnam Seminar, in which the students work on practice problems for the Putnam Competition. The seminar is led by Bernoff and Su, who have put the emphasis on having fun solving problems rather than on honing an elite team. In the process, the department *does* manage to hone an elite team: Harvey Mudd has placed in the top ten nationwide in the Putnam Team Competition in four of the past five years and is the only undergraduate college to have made it into the top five in the last thirty years. High participation by nonmathematics majors also occurs in the Mathematical Contest in Modeling and the Interdisciplinary Contest in Modeling (both of which are sponsored by the Consortium for Mathematics and its Applications). Harvey Mudd has done very well in both competitions, and the winning teams have often combined mathematics majors and nonmajors alike.

Even with all the energy and attention the department puts into its own programs, it nevertheless manages to find ways to reach out beyond the campus. In 2000 mathematics faculty member Darryl Yong, together with three Harvey Mudd faculty from other departments, started an outreach program in Pomona High School, which is in a low-income neighborhood.

Harvey Mudd College students before (above) and after the 2005 Putnam exam.

This program brings Harvey Mudd students into the school's classrooms, which are populated mostly by Latino students, to lead activities designed to inspire interest in mathematics, science, and engineering. In 2004 mathematics faculty members Michael Orrison and Jon Jacobsen traveled to Jamaica to lead a workshop designed to enrich the mathematical background of Jamaican teachers. They plan to offer the workshop again in 2006.

Harvey Mudd recently hired mathematicians in its top two administrative posts: Daniel Goroff came from Harvard University to become vice president and dean of faculty in July 2005, and Maria Klawe will come from Princeton University to take up the post of president in July 2006. And a couple of years back, the college lost a faculty member who went on to an administrative post—namely, Michael Moody, who is now the dean of faculty at Franklin W. Olin College of Engineering, an innovative engineering school that opened its doors in 2002. Moody was thrilled when the department received the AMS Award for Exemplary Achievement and also felt a pang of homesickness. "I'm so proud of the department," he said. "I can't imagine a more deserving group of people—I am completely biased of course!—but they really are incredibly dedicated to mathematics and to the community they have created."

Where does the department go from here? How does it sustain its success? Moody pointed to the need to continue to develop programs that bring faculty together as teams so that they set aside differences and work toward a common good. Su said he has seen exactly this happening organically in the department: One faculty member gets an idea to try something new, and he or she convinces colleagues to come on board. If too many ideas proliferate, the department will have to prioritize, but for now Su is happy to let things develop in this organic way. "But whatever we do, our mission is to engage undergraduates in research and discovery," Su said. "That will always be central."

—Allyn Jackson