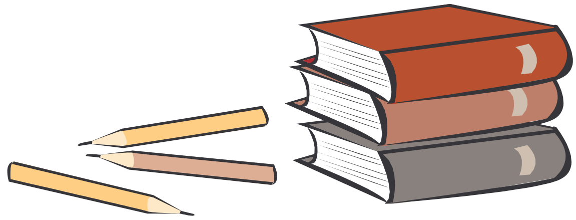
COLLABORATIVE PROGRAMS

Genome Consortium for Active Teaching (GCAT)



A. Malcolm Campbell,[1,2*†] Todd T. Eckdahl,[2,4] Edison Fowlks,[2,5] Laurie J. Heyer,[2,3] Laura L. Mays Hoopes,[2,6] Mary Lee Ledbetter,[2,7] Anne G. Rosenwald[2,8]

A supportive network of scientists and faculty brings sophisticated microarray experiments to the undergraduate lab and classroom.

Biological research has been transformed in recent years by substantial advances in efficient data accumulation. The transcription output for every gene in a genome now can be measured in an afternoon; before it might have taken years. However, the recent advances in technology have yet to be incorporated into many biology classrooms (*1*). Most undergraduates are taught the same way their instructors were taught, which seldom reflects leading-edge research practices. Training faculty in the latest research methods is not well supported on most campuses (*2*). Worse yet, when students with outdated undergraduate science experiences become primary and secondary school teachers, they condemn future generations to inadequate preparation for college. Today's teachers may also neglect the more quantitative aspects and increased interdisciplinary involvement of modern biology (*3*–*5*). Educational options that reflect quantitative, interdisciplinary, and technological trends would provide students with experiences that mirror today's scholarship.

GCAT in the lab. Undergraduates prepare samples and scan microarrays as part of their research at Davidson College.

CREDIT: DAVIDSON COLLEGE

We have developed the Genome Consortium for Active Teaching (GCAT) (*6*) to engage undergraduates in genomics experimental design and data analysis. GCAT faculty use DNA microarrays to bring the excitement of interdisciplinary research to students. Students discover the importance of quantitative data analysis, and the faculty are reinvigorated by the opportunity to learn new technology.

Origins of GCAT

GCAT was formed in 1999 with the intent of bringing genomics into undergraduate curricula, primarily through student research (*7*, *8*). Leading scientists donated materials and equipment. Undergraduates designed and performed experiments (see photograph above), mailed their microarrays for scanning, and then downloaded and analyzed their data (*9*).

Two limiting factors, long-term scanner access and a growing appetite for microarrays, were addressed by grant support and further donations from scientists (*10*–*12*). GCAT thus grew in size and expertise. GCAT supports free access to information and results through its Web site (*6*) and a listserv of more than 200 subscribers.

GCAT projects replaced student laboratory methods less prevalent in today's research, such as cloning and sequencing a gene and Northern blotting.

Rapid Growth

GCAT is committed to enabling any institution to adopt the use of microarrays in its undergraduate curriculum at affordable prices. To date, about 5000 undergraduates from 120 schools have used about 3400 microarrays. For the 2005–2006 academic year, GCAT provided more than 750 microarrays of nine plant, animal, and microbial species to students on 64 different campuses (*6*, *9*). Tested protocols and teaching aids are available from GCAT. Continued grant support (*11*) covers the cost of microarrays.

Schools pay a nominal fee to GCAT for microarrays and scanning. Students produce and hybridize their own probes. Other than the scanners, only standard molecular biology equipment is required; the software is free. The summer workshop costs, which are currently covered by grant support, are about $2300 per participant.

The number of interested faculty continues to grow. Although this enthusiasm is more a measure of the importance of the microarray method in molecular biology today than of GCAT itself, it also serves as a testament to GCAT's user-friendly format.

GCAT faculty use the microarrays in various ways. Some analyze existing data sets, such as the yeast diauxic shift data (*13*) that shows how yeast switch from one metabolic route to another. Other faculty members offer courses in which students collect their own microarray data. Students have studied the effects of environmental conditions on growth, aging in yeast, chromatin structure, and the cellular side effects of chemotherapy (*6*). Microarrays offer a view of the connections between different pathways in a cell in ways that are hidden by many other methods. For example, one student project looked for expression changes in DNA replication mutants and found cell wall assembly changes, thus linking cytokinesis to mitosis.

Dissemination Through Faculty Development

GCAT has sponsored data generation (wet lab) and data analysis (dry lab) workshops in various settings (*14*). Wet and dry lab sessions work best when they run 2 and 3 days, respectively. Participants learn data analysis using MAGIC Tool freeware (*15*). MAGIC Tool works on any computer platform and is designed to enhance student understanding of

[1]Department of Biology, [2]Genome Consortium for Active Teaching, [3]Department of Mathematics, Davidson College, Davidson, NC 28035, USA. [4]Department of Biology, Missouri Western State University, St. Joseph, MO 64507, USA. [5]Department of Biology, Hampton University, Hampton, VA 23668, USA. [6]Department of Biology, Pomona College, Claremont, CA 91711, USA. [7]Department of Biology, College of the Holy Cross, Worcester, MA 01610–2395, USA. [8]Department of Biology, Georgetown University, Washington, DC 20057, USA.

*Authors are listed alphabetically.

†Author for correspondence. E-mail: macampbell@davidson.edu

microarray and data analysis techniques.

In 2004, 35 faculty attended NSF-funded data analysis or combined data generation and analysis workshops at Georgetown University. Assessments demonstrated that combined training had a greater impact on undergraduate courses than the analysis workshop alone. The 23 who participated in the combined workshops reported that 800 undergraduates subsequently used microarrays (~35 students per teacher). In 2005, 64 faculty received microarrays. With similar rates, the microarrays might reach as many as 2200 undergraduates.

GCAT Students Participate in Various Aspects of the Scientific Process
85% hybridize probes to microarrays
78% produce cDNA probes
58% analyze their own data
53% design their experiments
25% analyze published microarray data
63% write a paper for course credit
35% present a poster of findings

Diversity

Historically black colleges and universities (HBCUs) are often left behind the technology curve. Two-thirds of attendees at the 2005 GCAT workshop at Morehouse College represented schools with substantial populations of underrepresented students, including African Americans, Native Americans, Hispanics, and nontraditional students attending community colleges. These populations are critical for diversifying the population of scientists in the United States. Faculty from biology, chemistry, mathematics, and computer science have attended GCAT workshops. GCAT activities have attracted diverse populations of students: 21% of GCAT students are non-Caucasian, 64% are female, 21% are majoring in a discipline other than biology, and 44% are interested in pursuing research careers in biology. GCAT implements BIO2010 recommendations (*1*) by teaching genomics through student research, which excites students across disciplines and ethnicities.

Keys to Success

GCAT's success is due to the people involved. The early GCAT faculty took a collective leap of faith by teaching genomics while simultaneously learning it themselves. Today's GCAT users can avoid much of the risk by taking a workshop before beginning with microarray analysis. GCAT faculty demonstrate their dedication by voluntarily leading the consortium's efforts (*16*). Working as a community maximizes efficiency and produces a sense of belonging to a larger effort that transcends a single campus.

Faculty and students participate in assessments of student comprehension, attitudes toward research, and demographic information. Anonymous, open-ended responses from students have been very enthusiastic. Selected comments from students include, "Microarray: GREAT! I am amazed that we can do this! Such an interesting concept yet simple enough to perform" and "What a powerful concept, microarrays. I greatly appreciated the opportunity to use what is quite possibly the most important tool in current analyses of gene expression."

Pre- and posttest results showed that GCAT courses produced significant improvement ($P < 0.001$) in students' abilities to design experiments and interpret data, areas often neglected in traditional teaching laboratories (see table). For example, students learned that whole-pathway changes are more reliable than individual gene changes. Students saw how spot identification must be quantitatively guided and how ratios are more informative than intensities. When faculty explained their learning goals, how they use GCAT resources, and the impact GCAT had on their ability to use microarray technology, they overwhelmingly indicated that they would not be able to do this work without GCAT resources and will continue to participate in GCAT activities.

When participants of the 2004 workshops were surveyed 1 year later, 80% (64% response rate) rated their experiences with the highest category on the survey. Sixty-one percent indicated networking with other faculty was very valuable. Faculty who had attended the combined data generation and analysis workshop altered an average of 1.6 courses to include the new content, whereas those who had attended only the data analysis workshop modified half as many courses (average 0.86). Faculty reported that their students showed an increased interest in mathematics as a result of microarray experiences. Faculty felt their teaching had improved and their classes were more interesting. One faculty member wrote, "… the presentation of this subject makes [students] realize and practice the close interaction biology/genetics has with other fields like mathematics. They enjoyed [being] introduced to a novel genetic technique. They said they can understand better, and can relate their class more to real life…when they watch [news about] health and advances in science." Another faculty member reported, "…many students have come back and said they got jobs or were assigned or allowed to do special projects in graduate schools because of their experience with microarrays."

Future Directions

GCAT wants to reach more faculty, especially at HBCUs, tribal colleges, Hispanic-serving institutions, community colleges, and small institutions. Regional workshops are being developed. GCAT is also working with high school teachers to develop a classroom and laboratory module on DNA microarrays (*9*).

Worrisome data suggest that students in the United States are falling behind students in other countries in the sciences. The National Assessment of Educational Progress "national report card" indicates only 18% of high school seniors were proficient or advanced in science in 2000 (*17*). Our educational system must prepare both future scientists and science-literate citizens for success in a world of continuing scientific and technological advances. The GCAT approach encourages faculty who focus on undergraduate teaching to become pioneers in incorporating the technological innovations of molecular biology. The GCAT community empowers faculty and students alike to solve educational problems (*1–5*) that seemed too big to tackle individually but were too important to ignore.

References and Notes

1. National Research Council, *Bio2010: Transforming Undergraduate Education for Future Research Biologists* (National Academies Press, Washington, DC, 2003).
2. Project Kaleidoscope, *Investing in Faculty* (Project Kaleidoscope, Washington, DC, 2001); (www.pkal.org/documents/index.cfm?page=3080).
3. L. H. Hartwell *et al.*, *Nature* **402** (suppl.), C47 (1999).
4. L. A. Steen, Ed., *Math & Bio 2010: Linking Undergraduate Disciplines* (The Mathematical Association of America, Washington, DC, 2005).
5. National Research Council, *Facilitating Interdisciplinary Research* (National Academies Press, Washington, DC, 2005).
6. Genome Consortium for Active Teaching (www.bio.davidson.edu/GCAT).
7. A. M. Campbell, *Cell Biol. Educ.* **1**, 70 (2002).
8. J. L. Brewster *et al.*, *Biochem. Mol. Biol. Educ.* **32**, 217 (2004).
9. Further discussion is available on *Science* Online.

10. Funded by NSF Multiple User Equipment grant no. DBI-0099720, awarded to A.M.C., L.L.M.H., T.T.E., and L.J.H.
11. Grinnell College, Pomona College, Swarthmore College, and Davidson College contribute funds equally from their 2004 to 2008 Howard Hughes Medical Institute (HHMI) educational grants to support GCAT activities.
12. GCAT members include P. Brown, B. Dunn, and D. Botstein (Stanford University), L. Hood (Institute for Systems Biology), R. Bookman (University of Miami Medical School), F. Blattner (University of Wisconsin–Madison), and E. Johnson (University of Oregon).

13. J. L. DeRisi *et al.*, *Science* **278**, 680 (1997).

14. NSF workshop grants: 2003 (DBI-0305176 and DBI-0408386) and 2005 (DBI-0520908). In 2003, L. Hood, K. Dimitrov, and J. Aitchison (Institute for Systems Biology) and M. Katze (University of Washington) gave talks and shared expert advice.

15. L. J. Heyer *et al.*, *Bioinformatics* **21,** 2114 (2005); (www.bio.davidson.edu/MAGIC).

16. HHMI and NSF funding have funded personnel for assessment and logistical support of scanning, shipping, and bookkeeping. Summer workshops provide honoraria for instructors.

17. National Center for Education Statistics (http://nces.ed.gov/nationsreportcard/).

18. P. Brown (Stanford University) provided chips and L. Hood (Institute for Systems Biology) donated chips and scanner use. GCAT has been funded by the Waksman Foundation for Microbiology, NSF, the Duke Endowment, and HHMI. We thank to B. Lom for help in improving this manuscript and S. Tonidanel and G. Gottfried for help with assessment.

Supporting Online Material
www.sciencemag.org/cgi/content/full/311/5764/1103/DC1

10.1126/science.1121955