Improving Undergraduate Biology Education in a Large Research University

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The campus-wide Undergraduate Biology Research Program (UBRP) at the University of Arizona improves undergraduate science education by expanding student opportunities for independent research in faculty laboratories. Within the supportive community of a research laboratory, underclassmen, nonscience majors, and those aspiring to scientific careers all learn to appreciate the process of science. The Program impacts more than the students, promoting departmental cooperation, interdisciplinary collaborations, and improvements in undergraduate science education throughout a Research I University.

Literature abounds describing the decline in science literacy in this country, citing as problems the projected shortage of scientists, the nation's slipping technological competitiveness, and the supposed insensitivity of university research faculty to undergraduate education (Sykes, 1988; Green, 1989; National Science Foundation, 1989; The Coalition for National Science Funding, 1989; American Association for the Advancement of Science, 1990; Krieger, 1990; Levine, 1990; National Research Council, 1990; Koshland, 1991, 1992; Healy, 1992; Mooney, 1992). In response to these problems, at the University of Arizona we have developed an undergraduate research program that excites student interest in biology and faculty interest in teaching by enabling as many students as possible to do research in faculty laboratories. The goals of this program are to increase students' understanding of the process of scientific research and to prepare those who are interested for research careers. In this article we describe this program's design, administration, and discuss its impact on students and on increasing faculty involvement in undergraduate education.

PROGRAM APPROACH

Large research universities have been criticized for their mass production approach to science education. Classroom contact between research faculty and students is often less significant than that of graduate student teaching assistants. The criticism of classroom teachers overlooks the advantages a research university can offer undergraduates: numerous research laboratories headed by faculty in which graduate students, postdoctoral fellows, and technicians pursue sophisticated scientific

problems. Such a laboratory is a research community that can provide a unique learning environment for undergraduates. Undergraduates flourish when they join such a community where they are respected and expected to be effective members of a research team. They may begin with little scientific background and few experimental skills, but they learn rapidly when surrounded by faculty, postdoctoral fellows, graduate students, and technicians who instruct, guide, and mentor them. This mentoring can be particularly effective in supporting minority and women students. Thus, we believe the best way a research university can enhance undergraduate science education is to maximize undergraduate access to these research laboratories.

Enterprising undergraduate students have always found ways into research laboratories. Most research universities encourage this participation. Exemplary programs for undergraduate research include Cal Tech's Summer Undergraduate Research Fellowship program, begun in 1979 (California Institute of Technology, 1988), and many others (Siebert, 1988; Tieszen *et al.*, 1988; Allen and Hoopes, 1989; Tobias, 1992a). The National Science Foundation (NSF) supports undergraduate research through their Research Experience For Undergraduates (REU) program initiated in 1987 (Fitzsimmons *et al.*, 1991). The National Institutes of Health and other federal agencies support undergraduate research through supplements to research grants. A large fraction of the Howard Hughes Medical Institute's recent investment in biology education has been to support undergraduate research programs in colleges and universities (Howard Hughes Medical Institute, 1992). We have drawn on the experience of such programs to establish the UBRP at the University of Arizona, adding

a number of distinctive features that contribute to its success.

UBRP PROGRAM DESCRIPTION

The University of Arizona is a public, Research I, Land Grant institution composed of 11 colleges, including the state's only Colleges of Agriculture, Pharmacy, and Medicine. It ranks 18th among Research I Universities in extramural funding (National Science Foundation, 1992). The 1993 enrollment is 35 279 students, 26 558 of whom are undergraduates. The admissions standards are modest: state residents must be in the top 50% of their high school graduating class or have a minimum grade point average (GPA) of 2.5 or a combined SAT score of 930 (slightly above than the national mean). Thus, the University serves students with a wide range of preparation and ability, including many excellent students. The program we describe here shows how the research programs of the university can provide an outstanding science education to these students.

UBRP began in the Department of Biochemistry in the summer of 1988 when 19 undergraduates worked in 13 faculty labs. Aided by educational grants from the Howard Hughes Medical Institute, the NSF, and others, but primarily funded by faculty research grants, UBRP has expanded to support 120 students during the summer and nearly 100 during the school year (Figure 1). The students, whose number is limited only by program grant support, can choose to work with any of 185 participating faculty from 37 different departments. Many additional students work in these and other laboratories but are not paid through UBRP.

From the outset UBRP was designed to be accessible not just to students destined for top medical or science graduate schools but to students with varied ability and unfocused career goals. For the first two years, the program accepted all the students who applied, but it has subsequently become more competitive, as described later.

A program director, supported by an administrative associate and bookkeeper, administers the program. Paperwork and bookkeeping have been minimized so the faculty can concentrate on research training. The director reports to a department head and to a faculty executive committee, who set program policy. A student committee advises the director and executive committee. Student ideas and opinions have guided much of the program's evolution, reinforcing a sense of common intellectual purpose. Communication among faculty, students, and program alumni is promoted through a monthly newsletter.

An innovative introductory biology course serves as the foundation upon which the program is based. This two-semester course, revised eight years ago, now incorporates experimental approaches to biology and provides a strong preparation in molecular and cellular biology as well as ecology and organismal biology. Cur-

Figure 1. UBRP growth, summers 1988–1993. This graph shows the total faculty sponsors, number of new student applications, and the number of students accepted into UBRP since its inception in 1988. The leveling off of accepted students reflects limitations of program funding.

rent biological issues such as human genetics, acquired immunodeficiency syndrome, cancer, and environmental preservation provide context for core concepts in biology. Unlike some introductory science courses that can discourage pursuit of science (Tobias, 1992b), this course is remarkably popular. Enrollment has increased from 200 to 1700. The course is a springboard for students to become interested in biology, which leads them to participate in UBRP.

DISTINCTIVE FEATURES OF UBRP

Participation is restricted to University of Arizona undergraduates because we have a large pool of excellent students. This differs from many NSF REU Sites, where most students come from outside the research university (Fitzsimmons *et al.*, 1991) but is consistent with a previous NSF program (National Science Foundation, 1990). By focusing on our own undergraduates, students can extend their work beyond one summer in a laboratory and can thus complete significant research projects. Overlapping program participants also provide continuity and help develop a sense of community and spirit among all participants. The UBRP students become the best recruiters of other students and of additional faculty sponsors.

Students are recruited as early as the summer after their freshman year through a simple application process that includes a listing of science courses, grades, and a personal statement of interest. They are not required to submit a research proposal. This enables participation by students who may have never considered a scientific career.

Students with any major may apply. Although 75% of the UBRP students are in biology, we have accepted

students majoring in other sciences as well as nonscience majors. They add diversity to UBRP and bring distinctive perspectives into their laboratories. We believe an understanding of the process of scientific research is essential in many nonscientific careers.

Once admitted, students themselves are responsible for finding a faculty laboratory through interviews. Because personality matches can play a large role in learning, faculty and students choose one another.

All students must begin laboratory work in the summer and not in the school year. We learned that a period of full-time effort is necessary for students to acquire enough expertise to do independent research, which they can then continue part time during the school year. Most college students must earn money during the summer, so we pay all students.

Faculty sponsors pay half of the students' wages and for all of their supplies. This ensures that all students work in active successful laboratories that have secured research funding, and it provides extra assurance of faculty commitment because research dollars that faculty could have spent elsewhere are invested in students. This also leverages program funding so that UBRP has many more students than a typical NSF REU Site with 11 students (Fitzsimmons *et al.*, 1991). We have developed supplemental support for faculty in poorly funded areas such as ecology and systematics, so our students would have a wide range of research choices.

We define biology broadly. This provides a large pool of faculty participants, now 185, in 37 departments from the Colleges of Arts and Sciences, Medicine, Agriculture, Engineering, Pharmacy, and from the School of Health Related Professions. It also has the benefit of generating political and financial support for the program from six separate colleges. Because students sometimes change laboratories among this large pool of faculty, students themselves have stimulated interdisciplinary interaction among faculty sponsors.

Each year a research conference enables the students to present their accomplishments. They put extraordinary effort into their poster presentations, working with members of their laboratory to learn the art of scientific presentation. Many presentations are indistinguishable in style, clarity, and sophistication from those at major scientific meetings. The conference attracts many faculty, students, and campus administrators, as well as State Regents and legislators, and engages them in scientific discussions with undergraduates. This has increased program visibility and is leading to similar programs in other disciplines.

SUMMARY OF STUDENT CHARACTERISTICS AND COST

Student applicants are self-selected because they already are seeking an independent research experience and thus tend to be the more dedicated students. They learn

about UBRP from faculty advisors, students, class announcements, and fliers. For half the UBRP students we have SAT and ACT scores, although these played no role in admission to UBRP. For UBRP students the mean combined verbal and quantitative SAT score was 1167, placing them in the top 25% of all students who take the SAT. The mean GPA for students accepted to the program increased from 3.2 in 1988 to 3.6 in 1992 as UBRP became more widely known and thus more competitive. However, the range of GPAs for all years for students admitted to the program has been 1.9–4.0. By standardized test scores and by GPA, most UBRP students are among the top fifth of University of Arizona students (University of Arizona, 1993). To date, 369 students have participated. Fifty-three percent of the UBRP students are women and 14% come from minority groups underrepresented in science (Hispanic, Native American, African American).

Students work full time for 12 weeks in the summer and roughly 20 hours per week during the academic year. The program cost in wages per student is \$1400 for the summer and about the same for the academic year, which is matched by an equal amount from the faculty sponsors. Thus, students can earn up to \$5600 per year. When laboratory supplies used by students are included, faculty sponsors pay more than half of the program's expenses.

PROGRAM EVALUATION

We track students' authorship of scientific papers, participation at scientific meetings, subsequent classroom performance, and career choice. In addition, program data come from questionnaires completed by both faculty and students at the end of each summer and academic year. Faculty rate students' performance in terms of effort, productivity, learning, and interaction with others in the laboratory, whereas students rate the educational effectiveness of the program. These assessments were designed to help us improve the program and not to provide a rigorous analysis of its educational influence, and they offer insights into the design of an effective undergraduate research programs.

Faculty Evaluation of Students' Performance

On a scale of 1–5, 5 being best, the faculty sponsors' average overall assessment of student performance was 4.4. There was a negligible correlation between the faculty sponsor's assessment of student performance and the student's GPA or standardized test scores. Although the range of these variables is not large in our sample, within the student group selected for participation, the quality of their laboratory performance is not predicted by GPA or standardized test scores.

Student Evaluation of the Program

More than 75% of UBRP students have returned evaluations. Again on a scale of 1–5, the mean rating of

whether the program met their expectations was 4.3. The mean rating of its effectiveness in teaching them about biological research was 4.6. More than 70% of students responded that being paid was important, and the majority indicated that they could not afford to participate without pay.

Many students enter UBRP with vague career goals. They hope the experience will help them clarify these goals. Figure 2 shows the influence of one summer in UBRP on career goals and also shows what the 201 UBRP students who have graduated have done.

Program involvement leads to an increased interest in graduate school and 27% actually pursue graduate studies. Interest in medical school remains fairly constant, at slightly higher than 35%. Many students (19%) continue to work in the laboratory after graduation and apply to graduate or medical school.

Additional information on career choices comes from the Biochemistry Department. Although the Department has required a senior research thesis of students earning the B.S. degree since 1980, the number of biochemistry majors choosing to go on to Ph.D. or M.D./Ph.D. programs before initiation of the UBRP was small. Of 91 students who received a B.S. degree in biochemistry between 1986 and 1988, only three entered doctoral programs. Of 98 students who were graduated between 1989 and 1991, 17 entered doctoral programs. We believe there are two reasons for this increase. Although independent research has been required for the B.S. in biochemistry since 1980, the research experience came in the students' senior year, often after a career choice was made. Second, the research took place during the academic year and thus was part time. Students never had the opportunity to immerse themselves in research full time. UBRP alters this by encouraging full-time participation from the time the student is an underclassman.

Another metric of success is the number of professional presentations and publications that include UBRP students. To date, 129 presentations at professional meetings have included the undergraduates' work; the majority of these have been made by the undergraduates themselves. UBRP students have coauthored 73 publications.

The program's philosophy, that even freshmen with little laboratory experience can start work in a laboratory and become skilled and knowledgeable enough to make real research contributions, has been questioned by colleagues at other institutions. They argue that only upper classmen with several laboratory courses should participate in independent research. The UBRP students do participate in an orientation that includes the University laboratory and radiation safety training before beginning work, but we do not provide common preparation classes or laboratories for the students. Roughly 25% of the students begin the program at the end of their freshman year.

Figure 2. Student career goals before and after UBRP. This histogram shows the anticipated career goals of students before and after participation in UBRP in the summer of 1991 and also includes the actual postgraduate activities of the 201 students who have been graduated from the program. We have lost track of 14% of UBRP graduates as indicated in the shaded column on the far right.

Faculty experience supports our philosophy. In 1990, 83% of the least experienced students (i.e., freshmen) received the highest faculty rating, in contrast to 39% of the sophomores, 45% of the juniors, and 33% of the seniors. Fifty-five faculty responded to a 1992 survey to assess attitudes toward inexperienced students and to learn how faculty actually trained these students. More than 80% of these faculty responded "yes or maybe" when asked if inexperienced freshman contribute to the research effort of the laboratory as well as more advanced undergraduates. Some faculty sponsors noted that inexperienced students start at a different level but learn quickly because motivation, an inquisitive mind, thoughtful observation, and the ability to analyze and construct hypotheses are more important than experience. Many reported that underclassmen provide enthusiasm to the laboratory group that is sometimes lacking in more advanced students so that everyone in the laboratory benefited from their infusion of energy. Some postdoctoral fellows and graduate students who were directly supervising UBRP students, however,

commented that inexperienced undergraduates took too long to train.

Two thirds of faculty respondents believed that inexperienced undergraduates benefit from the research experience as much as more advanced undergraduates; several commented that they benefit more because they have more to learn. Faculty echoed what we heard from students about the synergism in learning that occurs in a research community: being part of a laboratory group combats the impersonal atmosphere of a large research university by establishing a home base for the students. Other faculty commented that the research experience makes the students want to learn the material in their science and math classes because it has more relevance.

Individual laboratories develop substantial and personalized training for beginning students. Many laboratories introduce students to research by first requiring them to read papers and textbooks for background. Students then begin with a simple laboratory procedure likely to yield results and move on to more difficult experiments that the student is responsible for designing. Some laboratories assign students to work with a specific postdoctoral fellow or graduate student, but other laboratories insist that students not be tied to one person and instead utilize multiple members of the laboratory team as resources.

MINORITY RECRUITMENT

The program has a particular responsibility to provide research experience to underrepresented minority students. Because of our location in the Southwest, the University has many Hispanic and Native American students. To encourage more minority students into the science pipeline, we have extended UBRP to high school students. Students from throughout Arizona are invited to apply for paid summer research opportunities. So far, 61 students have participated, three quarters of them minorities. Initial faculty scepticism about the effectiveness of high school students in the laboratory was dispelled by the success of the initial students. Now many faculty accept these students, so this program is expanding. Several of the high school students have matriculated at the University of Arizona and continue to participate in research in UBRP. We also have a program designated for minority freshmen called "Up With Biology" that pays students to work in the laboratories of UBRP faculty. The students can apply to UBRP during the spring semester of their freshman year and continue their research. We believe that the emphasis in UBRP on research communities that include all ethnic groups is important to its success, as has been argued in general elsewhere (Gibbons, 1992).

EFFECTS OF UBRP ON UNDERGRADUATE EDUCATION

Between 1989 and 1992, the UBRP and the introductory biology course contributed to a 42.8% increase in bi-

ology majors (from 1217 to 1737), in spite of a 6.7% decrease in overall undergraduate enrollment (University of Arizona, unpublished data, 1992; University of Arizona, 1992).

One of the most gratifying results of UBRP has been the enthusiastic support from the ever increasing number of faculty sponsors. The only faculty members who have departed from the program have left the university or assumed other responsibilities. Faculty members sometimes withdraw temporarily if they are between grants or on sabbatical, but all have returned to active participation in the program. Program loyalty is striking in light of the faculty's significant financial contribution to their undergraduate students. It is their students' success that has caused faculty to recognize that the undergraduates are a valuable resource, particularly in departments with small graduate programs. In spite of all the rhetoric criticizing research universities, the research faculty do have a genuine concern with undergraduate instruction. Research I universities can offer students a science education in their laboratories that is available nowhere else.

UBRP has also increased faculty interest in classroom education of undergraduates even in units that do not have undergraduate degree programs, such as the College of Medicine. Faculty hear first hand from students about difficulties with requirements and enrollments or about problems with poor classes. They now have a vested interest in the quality of undergraduate courses, because these courses provide the background for the students working with them. Students experienced in laboratory research also bring new excitement to their courses. The questions they ask, the discussions they initiate, and the interest they show are all improved by their research experiences. Other students benefit from cooperative learning with classmates experienced in independent research. These students remind faculty of the need to keep their teaching up to date and to present research discoveries and experimental reasoning in their classes.

In summary, undergraduate research programs in research universities help many students appreciate the importance of scientific research. They also prepare students well for graduate or professional schools. The impact of such programs can spread far beyond these outcomes to promote cooperation among departments, interdisciplinary collaborations, and improvements in undergraduate science education throughout research universities.

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