HOW TO SET UP A LABORATORY TEACHING PROGRAM THAT RESULTS IN STUDENT PUBLICATIONS

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Well over 100 student co-authors, mostly undergraduates, appear on scores of publications resulting from work in my laboratory. As a result, these students have been admitted into advanced programs at such major research universities as Harvard, Stanford, and Johns Hopkins, and many of them are now productive biomedical scientists. In addition, the success of the program has led to the award of over $4 million in research and science education grants. In this article, I will outline the major components of the program and explain how it can be easily implemented anywhere. The basic approach is to train large numbers of students (about 20-30 at any one time) in the basic techniques of an experimental system, such as the sea urchin embryo, that lends itself well to simple, easy to accomplish group experiments. Once the students have reviewed the literature and learned the basic experimental techniques, they are assembled into small cooperative research groups that tackle each portion of the larger project. This approach focuses on stimulating student involvement in science through hands-on research and discovery and eliminates the often perceived dichotomy between science research and science teaching.

Unfortunately, many of our brightest students are not choosing careers in research science, in large part because they were not introduced to the excitement of discovery during their formative years (Beardsley 98; Oppenheimer 10). As a result, a decline in the science research efforts of the United States, because of its failure to attract enough bright students from a culturally and ethnically diverse society, is a threat to the future health, welfare, and security of this nation.

Students who have the opportunity to become involved in science research at the college or pre-college level often are the select few who are educationally advanced and upper middle-class. Most of the nation's students, however, are average students, underrepresented students, or students from lower socio-economic backgrounds. These people seldom receive an opportunity to become involved in research, although a variety of programs, including the National Institutes of Health MARC and MBRS programs, the Department of Energy MAERC program, Howard Hughes Medical Institute programs, and NASA's Student Researcher program are involving more and more ethnically diverse students in college level research. At the pre-college level, the National Institutes of Health K-12 program, the National Science Foundation's Young Scholars program, and a variety of teacher training initiatives (such as those funded by the National Science Foundation's Teacher Enhancement program, the Eisenhower Mathematics and Science Education program, the Howard Hughes Medical Institute, and the Urban Community Service program) aim to increase the numbers of underrepresented youngsters who eventually will choose careers in research science.

One obstacle that has hampered efforts to substantially increase the numbers of students who receive worthwhile research experiences in college or earlier is the fact that most research programs can accommodate only one or two students at a time. The nature of most scientific research does not lend itself well to operations involving large numbers of students. We will probably never increase the numbers of students in some of these programs, especially those that lack enough space or those that deal with hazards requiring very close one-on-one supervision.

We have developed, however, other approaches to providing larger numbers of students with...
effective research experiences. One that we find works very well at both the university level and in high school and junior high involves training students in groups of 20-30 in the basic techniques of an experimental system. After the students have reviewed the literature and learned the basic techniques, they are assembled into small cooperative research groups that tackle each portion of the larger project (Beardsley 98; Oppenheimer 10). This approach has been used in my own research lab at the university level for many years, and many pre-college teachers who we train in our National Science Foundation, Howard Hughes Medical Institute, and the Urban Community Service sponsored projects, use it in their classrooms. Objective criteria used to measure the success of the program include numbers of student co-authors on our publications (over 150), admission of these students to advanced degree programs (including those at Harvard, Stanford, and Johns Hopkins), awards of outside support for the program (about $4 million in research and science education grants have been received so far),¹ and local, statewide, and national recognition (from organizations such as the American Association for the Advancement of Science).² In pre-college programs that we run using the same approaches used in our research lab, thousands of students have been introduced to the fundamentals of research by teachers we have trained, leading to the publication of pre-college, student-authored research abstracts, science fair honors, and other awards.

The most important component of research programs that can handle large numbers of students is the choice of the experimental system utilized. One good example of a system we have had success with at my university is the sea urchin embryo, because of the relative ease of maintaining live material year around and the fact that all experiments are conducted in the most inexpensive of media—sea water (Oppenheimer, Science Teacher 40). We maintain adult sea urchins in refrigerated aquaria at all times, so we have a continuous supply of gametes available for student research. Many other experimental systems also fit the bill of easy availability of materials and simplicity of experiments. Experiments with plant seeds (such as Fast Plant seeds and radish or grain seeds) fulfill our criteria for simplicity and availability, as do experiments with baker's yeast. All of these systems are inexpensive to use, simple, and safe, yet if utilized innovatively, they can lead to publishable results.

Our experiments with sea urchins are easy to do and do not require extended periods of time. For example, one of our recent publications, involving 7 students and 1 pre-college teacher as co-authors, appeared in the journal Zygote (Daily 221). The groups of student researchers developed a new procedure to prevent the formation of tough outer coats in sea urchin embryos, facilitating studies that are not possible with embryo surrounded by impenetrable envelopes. This project mostly involved simple procedures, easily done by any college or high school student, such as incubation of sea urchin eggs in sea water containing a specific enzyme, alpha amylase.

In another two of our papers published in the journal Acta histochemica (Latham 89, 373), involving 10 student co-authors, a new method was developed to detect specific receptor molecules on sea urchin cell surfaces. Again, the procedures were simple: for example, mixing cells with small beads that are able to detect the presence of certain sugars on the cell surface.

Another of our articles published in Cryobiology (Spiegler 168) describes a new method to extend the viability of sea urchin sperm and eggs. Here, too, the procedures were remarkably simple, involving maintaining sea urchin eggs and sperm in ice in a refrigerator. A recent presentation of this work by one of our students at the annual national meeting of the American Society for Cell Biology in San Francisco resulted in numerous reprint requests from scientists nationwide. Many of them com-
mented about the utter simplicity and usefulness of the new method.

The examples of projects just presented illustrate the principal themes of our student-involved research programs:

1. experimental systems are simple and easy to maintain;
2. experiments are designed so that many students at all levels can participate; and
3. students work in cooperative research groups.

Our students usually help develop the hypotheses to be tested after they review background literature and receive training in the basic techniques of the experimental system. They also help write the articles that we submit for publication in such journals as Science, Nature, Zygote, Cryobiology, Experimental Cell Research, Acta histochemica, and others.

The approach just described lends itself well to experiments that can involve whole classes at one time. Many scientists do not appreciate the research benefits that can accrue if entire classes participate in such experiments. These benefits are not limited to increased numbers of students who participate in the research; they also can improve the research itself. If the procedure is simple, 30 students can do it at one time, yielding 30 repeated experiments. If, for example, we are testing the effects of a specific compound on sea urchin fertilization, each student in the class can do the test in less than half an hour.

Such group experiments also provide students with camaraderie and communal excitement. I surely would prefer my first research experience to be in an enthusiastic group environment, rather than sitting alone in the corner of a lab waiting for my supervisor to help me out.

Like most of life's endeavors, almost any approach to teaching can be successful if the instructor is dedicated and enthusiastic. But if a major concern is to substantially increase numbers of students who receive enjoyable research experiences, we do not have too many other options, short of dramatically increasing the numbers of research scientists who will take students into their labs.

Our approach, which is successful according to the criteria outlined earlier, is especially useful for those professors and pre-college teachers who wish to increase the numbers of students exposed to quality research experiences and are willing to utilize experimental systems and designs that can accommodate more than just a few students at a time.

Expanding student research opportunities is not the only benefit of implementing such a program. The quality and publishability of the research may be also enhanced by the increased numbers of replicate experiments made possible by this approach to laboratory instruction.

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NOTES

1 Research and science education grants received include those from NSF, NIH, NASA, Eisenhower program, Urban Community Service program, Howard Hughes Medical Institute, Thomas Eckstrom Trust, and Joseph Drown Foundation.

2 Over 20 research and teaching honors have been received for these programs, including election as Fellow of the American Association for the Advancement of Science for research and science education programs, the statewide CSU system Trustees Outstanding Professor Award, American Cancer Society Public Education Award, several in-house university Distinguished Teaching and Distinguished Research awards, and inclusion in many biographical references including Who's Who in the World and Who's Who in America, etc. In addition, hundreds of pre-college student research abstracts have been included in the National Science Foundation sponsored abstracts volumes (TPE 9153981) and the new Journal of Student Research Abstracts, Burgess International publishers, 1995; 1996.

Bibliography


