Two models for an effective undergraduate research experience in physiology and other natural sciences

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Randall, David C., Frank H. Wilbur, and Timothy J. Burkholder. Two models for an effective undergraduate research experience in physiology and other natural sciences. Adv Physiol Educ 28: 68–72, 2004; 10.1152/advan.00051.2002.—There are compelling arguments for offering undergraduate students majoring in the sciences an opportunity to experience research first hand. Direct exposure to meaningful research stimulates interest in the material and enhances understanding (11, 20), fosters the development of critical thinking (2, 26), helps develop research skills (17), and generally stimulates an interest in science (13). Students who participate in an undergraduate research experience, particularly including racial minorities, are more likely to pursue graduate education (14). In a more practical sense, such an experience can help prepare students for their careers who otherwise possess quantitative and intuitive skills but lack a vision of the more practical aspects of technical and scientific occupations (5). Foos (11) concludes that research is an essential component of higher education; that it benefits the students, the faculty, the institution, and society at large; and that a research experience should be part of every curriculum, including those at undergraduate teaching campuses.

It may generally be feasible to offer a “hands-on” research experience to students at a large school with a research-oriented faculty, but it is often difficult to do so at undergraduate schools, particularly at four-year liberal arts colleges, whose faculty are hired with a primary expectation of excellence in teaching rather than in research. We describe here two approaches that we have found to be effective introductions to research for students in two different colleges. Each model is presented separately, although both schools have a number of characteristics in common. For example, each is a private, liberal arts school with a total enrollment of <2,000 students (Table 1). In particular, an essential element in both situations is the close involvement with the undergraduate faculty of an individual with extensive research experience. The first program is at Taylor University, in Upland, IN. Upland is a small rural community some distance from the nearest research university. The second is at Asbury College, in Wilmore, KY, within an easy drive to the University of Kentucky in Lexington, KY. This contrast in the physical locations of the two schools largely accounts for the most significant difference in how the two programs are organized: the Taylor program is coordinated by a full-time, resident “Research Professor” and Program Director; as such, the school supplies a large percentage of the resources required for successful research projects. Conversely, no member of the Asbury faculty has a primary research assignment, but the science faculty includes a part-time member who has a full-time appointment at the University of Kentucky (D. C. Randall). Asbury faculty are able to partner with colleagues at the nearby University of Kentucky to train students in research. Although both research training programs are multidisciplinary, the illustrations included in this report are taken primarily from the authors’ own direct experiences in training students in physiology research.

Undergraduate research programs are particularly beneficial if they require the students to prepare in advance for the experience, to present their results outside their own school, and to publish their findings (25). Accordingly, both programs described here have several common features, which speak to their effectiveness and academic viability. First among these is the ultimate publication in reputable, widely circulated journals of abstracts and/or, in many cases, full articles of which the
students are bona fide coauthors. These publications are based, at least in part, on experiments to which the students contributed intellectually in terms of design and/or execution, data analysis, and writing. Second, funding for the programs has been stable, or growing, in each case. Third, the program at each of the schools has stood the test of time, having been active for more than 10 years. Finally, both programs have expanded to incorporate additional faculty at the undergraduate institution who previously had only modest ongoing research but have now developed their own active lab interests.

THE TAYLOR UNIVERSITY PROGRAM

*Institution.* Taylor University is a four-year liberal arts school whose primary campus in Upland, IN, is situated in rural Indiana approximately midway between Fort Wayne and Indianapolis (http://www.taylor.edu). Taylor’s science building (Table 1) includes a room that was remodeled to house animals as part of the initial development of the research training program.

*Program establishment.* The Science Research Training Program began as a summer student research training effort initiated in 1988 by Walter C. Randall, one of the authors (T. J. Burkholder), and three students. Walter Randall retired in 1987 from an active research career in the Department of Physiology at Loyola University, Maywood, IL, and moved to Upland. He had received his bachelor’s degree from Taylor and had been a member of the Board of Trustees since 1971. This close link with the college made it natural for him to accept an appointment as the college’s first Research Professor in 1987 and to use this platform to bring his expertise in research to help establish the Science Research Training Program. This very close working relationship between an experienced investigator and the undergraduate faculty was an essential element in establishing today’s successful program. Encouraged by the initial success of the program, upon Dr. Randall’s death in 1993 Taylor hired the current Research Professor, Dr. Henry Voss, who, like his predecessor, had an extensive, practical background in research. Both Drs. Randall and Voss held/hold full-time, 12-month appointments.

*Program funding.* The financial resources that helped establish the program were provided when W. Randall transferred to Taylor a National Institutes of Health (NIH) RO1 grant he initially held at Loyola. Because this support was clearly short-term, one of the Taylor biology faculty (T. J. Burkholder) successfully applied for an NIH Academic Research Enhancement Award (i.e., an R15 or AREA). AREA grants support research in the biomedical and behavioral sciences conducted by faculty, and involving their undergraduate students, who are located in schools that have not been major recipients of NIH research grant funds (see http://grants2.nih.gov/grants/funding/area.htm). Taylor’s AREA grant was crucial in providing a financial base for the program during its early years. In addition, a husband and wife, both alumni of the college, were identified who were interested in the new research training program and were willing to establish a modest Endowed Research-Training Fund in the Environmental-Related Sciences. The document specifying the purpose of the fund reads, in part:

> The fund [will] stimulate scholarly research, foster development of new knowledge by Taylor faculty, and provide baccalaureate experience and training for students considering careers in science. It supports new and/or expanded research projects by faculty members, and creates opportunity for qualified science majors to achieve an in-depth, “hands-on,” laboratory experience in collaboration with a senior, experienced faculty mentor. [The fund] will establish a legacy of excellence which will strengthen and enliven an innovative research and scholarly environment within each involved department, as well as encourage crossover interactions between participating departments. The outcome will contribute importantly to a spirit of inquiry, pursuit of state-of-the-art insights in existing scientific literature, stimulate more attractive, enthusiastic, and current faculty teaching, and encourage greater interest for post-baccalaureate pursuit of graduate training in environmental, biomedical, chemical, mathematical, and physical sciences.

Part of the responsibility of the Research Professor is to develop his/her own research funding and to coach other faculty in obtaining extramural support. During Dr. Voss’s tenure, financial resources for the program have grown to the point that granting agencies over the past decade have included NIH, the National Aeronautics and Space Administration, the National Science Foundation, the Department of Defense, Lockheed Martin Research Corp., the Southwest Research Institute, the Environmental Protection Agency, the Indiana Space Grant Consortium, the Applied Physics Laboratory, the East Central Indiana Solid Waste District, and others.

Most experiments are performed during the summer, when the students and faculty can devote full-time attention to the

Table 1. *Comparison between Taylor University and Asbury College*

<table>
<thead>
<tr>
<th>Physical location</th>
<th>Taylor University</th>
<th>Asbury College</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of student body (2003)</td>
<td>1,900</td>
<td>1,191</td>
</tr>
<tr>
<td>Number of science faculty</td>
<td>33</td>
<td>19</td>
</tr>
<tr>
<td>Physical facilities in sciences</td>
<td>Science building: 57,000 ft²&lt;br&gt;Environmental ctr: 19,000 ft²&lt;br&gt;arboretum: 65 acres</td>
<td>Science building: 48,960 ft²&lt;br&gt;environ. studies area: 74 acres</td>
</tr>
<tr>
<td>Dedicated animal holding facility?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Science majors offered</td>
<td>Biochemistry, Biology, Chemistry, Computer Science, Earth &amp; Environmental Science, Mathematics, Physics; pre-dental, pre-medical, pre-nursing, pre-veterinary</td>
<td>Biochemistry, Biology, Chemistry, Computer Science, Mathematics, Physics, pre-dental, pre-medical, pre-nursing, pre-veterinary</td>
</tr>
<tr>
<td>No. of students majoring in science, math, computer</td>
<td>409</td>
<td>129</td>
</tr>
</tbody>
</table>
work. The Endowed Research-Training Fund, or funds from an individual mentor’s grant, provides $2,500 summer stipends for those students who devote their summer to a project. During the summer of 2002, for example, 17 students worked on seven different projects in biology, chemistry, computing, engineering, environmental science, mathematics, and physics.

Program faculty. The faculty directly involved in the summer research program currently include members from all departments within the Science Division, including computer science (see http://www.taylor.edu/academics/research/index.htm for a listing of current members and a short summary of their research).

Animal care and use considerations. NIH and many other funding agencies require that all research using animals supported by their grants be reviewed and approved by an Institutional Animal Care and Use Committee (IACUC; see Ref. 24); adequate veterinary care must also be available. Under the guidance of the Research Professor, who had extensive prior experience with issues of animal care and protocol review, Taylor formulated an IACUC that met twice yearly for this purpose during the time when experiments that required such review were active. The college established an IACUC that consisted of a Taylor faculty member, a veterinarian at Eli Lilly in Indianapolis, and graduates of the college who held a PhD degree and were actively involved in their own animal research at other institutions; all volunteered their time and travel to participate in the committee. A local veterinarian was on call for more immediate clinical needs. As also required by law, a member from the local community was recruited. The animal facility at Taylor was then subject to unannounced visits by an inspector from the US Department of Agriculture. The rat and the opossum were the primary animals used in those experiments that were reviewed by the IACUC.

Program operation. Students are selected on the basis of interest and course work necessary to understand the research with which they are involved. For example, those students whose interests focus on physiology must have completed courses in comparative anatomy and animal physiology as well as introductory chemistry and physics courses. The research thrust in this mentor’s laboratory (T. J. Burkholder) is the comparative physiology of the nervous control of the heart and cardiovascular system. The two or three undergraduate students working on this project begin their studies with a four-day training period introducing them to principles of animal care. For the next approximately 40 days, the students and T. J. Burkholder test various hypotheses related to autonomic control of the heart. Since the summer of 1988, 41 undergraduate students have been trained in cardiovascular research.

Program success. One important metric of the program’s success in exposing students to realistic research is presentation of data by students at scientific meetings and the ultimate publication in meritorious journals of papers including the students as authors. Using the physiology work as an example, since the inception of the program Taylor undergraduates have presented their work at the Indiana Academy of Science (e.g., Refs. 3, 21) and/or at national meetings (e.g., Ref. 22), and have been authors on papers published in peer-reviewed journals (e.g., Refs. 4, 9, 23). Every student who participated in the summer training program at Taylor University went on for further training after completing his/her undergraduate degree. Of the physiology students, 16 were accepted to, and graduated from, medical school since 1988. One student went into veterinary medicine, and one went into chiropractic medicine; 10 other students went on to graduate programs of various sorts. Two of our current students are making application to medical school for the fall of 2004. Another example, among many, is that students in the physics program, with their mentor, have designed and fabricated a detector array for NASA’s IMAGE satellite. The instrument was one of the four onboard the satellite that was launched in 2000; it has been successfully operating and collecting data on the earth’s magnetic fields.

Another important manifestation of the success of the program is the renewed interest of faculty in scholarly pursuit. Before 1990, the personal involvement of the college’s faculty in research was generally modest, but the creation of an environment where research is actively encouraged and supported has increased scholarly pursuits among the faculty in the sciences. For example, the Environmental Protection Agency and the Indiana Department of Environmental Management (Office of Water Quality, Water Management Section) recently (2001) funded a preliminary three-year study of pollution in the Mississinewa River watershed by Dr. E. Squires (e.g., Ref. 29).

THE ASBURY COLLEGE APPROACH TO RESEARCH TRAINING

Institution. Asbury College is located about 20 miles southwest of Lexington in Wilmore, KY. It, like Taylor, is a private liberal arts school (see Table 1 and http://www.asbury.edu) whose faculty are hired primarily on the basis of their teaching expertise. The Hamann-Ray Science Center houses the departments of biology, chemistry and physics, and mathematics and computer science.

Program establishment. In 1990 the science faculty established a requirement that each individual majoring in any one of the sciences complete an independent research project during the senior year. That requirement has evolved to the point where all science majors must complete a four-course sequence culminating in an oral presentation of their research (see Program operation below).

Program funding. One of the attractive features of the Asbury model is that, unlike Taylor’s program, it does not require the availability of major financial resources from within the college proper. Although students may work directly with their Asbury faculty throughout the year funded by somewhat limited internal resources, many students have pursued an intensive, full-time summer project, often at the University of Kentucky. These latter students have generally been paid by their mentor during the summer; several of these students have successfully applied to the Ohio Valley Affiliate of the American Heart Association for a summer research stipend (current $2,500/8-wk summer effort).

Program faculty. All of the faculty of the Science Division are available to serve as mentors. One of the authors (D. C. Randall) is a full-time faculty member in the Department of Physiology at the University of Kentucky but since 1979 has taught a four-hour evening class, Human Physiology (BIO 352) during the spring semester as a part-time member of the
college faculty. As was the case with W. Randall at Taylor, D. Randall’s active involvement in the life of the undergraduate institution has lead to the development of close personal and professional relationships with the Asbury science faculty. D. Randall’s formal association with both institutions has helped to produce an effective bridge between the schools so that students and faculty have been introduced to host faculty in several laboratories and departments other than physiology.

Program operation. All students enrolled as a science major at Asbury College must complete Science Ethics (CHE/BIO 341) during the sophomore year and Introduction to Research (CHE/BIO 399) during the junior year. The latter course acquaints students with the methods of biological research and writing. As part of this course, Asbury faculty and off-campus faculty who are potentially available as hosts present a seminar of their work appropriate to an undergraduate audience. Because the Asbury students have established a reputation for their work, University of Kentucky faculty with no prior acquaintance with the college have requested the opportunity to present these seminars. During their junior year, students make appropriate arrangements with an individual who will serve as their Research Director. If their mentor is outside the college, students must also select a Research Course Advisor from among the Asbury science faculty when they enroll in Senior Research (CHE/BIO 400). During the remainder of their junior year, the Research Director guides the students in reading relevant literature and introduces them to essential laboratory techniques pertinent to the projects they have chosen.

Over the past 10 years, nearly 55% of the Asbury science students have elected to conduct their research under mentors from major research institutions, including state universities, government research facilities such as NASA and NIH, and foreign research laboratories in countries such as Tanzania and India. About 30% of the students conduct their research at the University of Kentucky. The experiments are often conducted during the summer between the junior and senior years. The research course requires completion of a written manuscript. Science majors must also present their research at a state or national scientific meeting or take Senior Seminar (CHE/BIO 475), where they formally present their research to peers and science faculty.

Program success. As with their Taylor counterparts, undergraduates participating in the Asbury summer program have presented their work at the Kentucky Academy of Science (e.g., Refs. 10, 28) and/or at national meetings (e.g., Refs. 12, 15, 16), and coauthored papers published in peer-reviewed journals (e.g., Refs. 1, 6, 7, 27). To use our own students as examples, 12 Asbury students have completed a research rotation in D. Randall’s laboratory; six of these have earned an MD degree or are currently enrolled in a professional school, and one serves as a technician in a laboratory; the two most recent students have applied for admission to medical school.

The success of Asbury faculty in developing their own research program has also been gratifying. Dr. Don E. Burgess, (physics) initially spent two summers working in D. Randall’s laboratory. He then took a year’s sabbatical, plus a one-year leave-of-absence, from the college to pursue a postdoctoral fellowship in that lab; he involved several Asbury students in that research, which yielded several publications (e.g., Refs. 6, 7). Dr. Burgess subsequently returned to Asbury full-time and wrote a successful grant application to the local affiliate of the American Heart Association. He has since developed other collaborations within the Department of Physiology at the University of Kentucky (8) and the University of Auckland, New Zealand (18, 19). More recently, Dr. Bobby Baldridge, DVM, also of the Department of Biology at Asbury College, has joined D. Randall and his colleagues. Dr. Baldridge’s skills, including those as a veterinarian, have proven particularly beneficial to the work being conducted in the major research university (1).

GENERAL CONCLUSIONS

Although the programs we have described are, to some degree, the product of environments unique to each school, we believe that similar success could be enjoyed at other schools using comparable strategies. Development of both programs was facilitated by the intentional involvement of faculty member(s) I with a long history of on-going, funded research and 2 who developed a personal and enduring interest in the college and its students. Most undergraduate institutions could tap a sizeable reservoir of practicing and retired researchers who may well be interested in investing time and/or financial resources in an innovative effort that has a clearly conceived plan in place to develop a research training program. Should other colleges seek to institute similar programs, funding may initially be a significant challenge but, in our experience, need not prove to be an insurmountable problem. With proper guidance, the undergraduate faculty can be successful in acquiring support such as an NIH AREA grant or from national and/or regional funding agencies. Finally, reciprocal investments by faculty in undergraduate colleges and research universities, as in the Asbury model, are demonstrably beneficial to both faculties. Both partners in the relationship reap improved access for their students, and for themselves, to the resources of the complementary institution.

REFERENCES


BIO 352 requires that those taking the course conduct several “wet lab” experiments, each of which tests a hypothesis. Students share findings derived from their individual preparation with the entire class, so all individuals have sufficient data for meaningful statistical tests. Each student must then write a manuscript in the style of the American Journal of Physiology (including a review of the relevant literature, etc.). This has been a useful initial exposure to scientific writing and assists them in preparing their senior report (see Program operation).


