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Professional Practices in Undergraduate Research Programs

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The undergraduate research experience (URE) is an important avenue within a college trajectory in which students enhance their critical thinking, learn about the scientific process, and develop the knowledge and values that will guide their future scientific and professional careers. Individual institutions, programs, departments, and faculty administer undergraduate research differently, but each should adhere to a common set of guidelines which govern the research mentoring process. Adherence to standard practices will enhance the research experience for both students and mentors. This article examines standards and guidelines for professional practices involving undergraduate research and scholarship, and will discuss lapses and limitations that students and faculty frequently confront. The growth, support, and proper management of undergraduate research programs (URPs) at primarily undergraduate institutions (PUIs) is important for maintaining a talented pool of young scientists, as students benefit greatly from direct interactions with faculty mentors that predominate at PUIs.

INTRODUCTION

Undergraduate research is an important part of a university education. It provides students with independent, critical, and collaborative learning experiences; research skills; and firsthand experience with scholarly activities and scientific discovery. The costs, benefits, and evaluation of undergraduate research programs (URPs) have been reviewed elsewhere (9). Here we focus on best practices in undergraduate research carried out at primarily undergraduate institutions (PUIs), rather than at research-intensive universities or community colleges, but many aspects of our discussion may apply to undergraduate research at any institution. While authentic research can be incorporated into course labs, our emphasis here is on research projects conducted outside of formal courses.

The resources available for undergraduate research and the challenges of implementing UREs may be different at research-intensive institutions than at PUIs. Research-intensive institutions primarily train doctoral and postdoctoral students and administer well-organized research programs with cutting-edge facilities supported by federal funds. In contrast, PUIs are committed to undergraduate research in parallel with a demanding teaching load and are limited in research facilities and federal funding. Consequently, faculty performance at the time of tenure and promotion is reviewed with a different focus at these institutions. Faculty at research-intensive institutions are evaluated more on research productivity and extramural funding than on teaching, whereas faculty at PUIs are assessed more on teaching than funding and research activities. Thus it is a challenge for PUI faculty to organize structured URPs while adhering to the professional guidelines for students, faculty, and administration, and it requires a dedication to both the scientific endeavor and to the education of the next generation of scientists.

Several institutions have set up guidelines for undergraduate research training with varying levels of detail, such as those of the University of Miami (www.miami.edu/index.php/undergraduate_research_and_community_outreach/faculty_mentors/mentoring_guide/) and Grand Valley State University (http://gvsu.edu/ours/the-mentoring-experience-guidelines-for-effective-undergraduate-mentoring-of-scholarly-endeavors-513.htm). The Council on Undergraduate Research (CUR) has several manuals available (http://cur.org). Moreover, general ethical and professional standards for scientific research must be observed (4).

The CUR and others have summarized the organization and efficacy of undergraduate research experiences (UREs) (6, 10). One common finding is that long-term UREs are much more beneficial than short-term UREs. Early exposure to UREs helps students, including minorities underrepresented in the sciences, perform better in introductory biology courses (5). Students who participate in multiple semesters of UREs have higher grade point averages (GPAs), and correspondingly, reach a higher order of scientific

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thinking through multiple years of undergraduate research (7, 12). A single summer program and/or a few semesters of research do not sufficiently train a student, while students who undertake a research project beginning in their first or second year of college that continues through to graduation advance the most towards realizing a career as a scientist (7, 12). Additionally, UREs contribute significantly to students pursuing biomedical science doctoral degrees (13).

There are many facets to URPs. Here we bring together the topics mentioned above and broaden the discourse by discussing the management, importance, and growth of URPs at PUIs (Fig. 1). These professional practices will make the research mentoring process more productive for both mentors and mentees. We discuss how best to achieve the objectives of a URP, which include providing students with a stimulating research environment, training students to think and work as scientists, encouraging students to present their research findings at conferences and in peer-reviewed publications, and encouraging students to pursue graduate studies and careers in the sciences.

DISCUSSION

URPs

URPs at PUIs may be well structured, loosely structured, or not structured at all. If a URP is funded, e.g., National Science Foundation's (NSF) Research Experiences for Undergraduates (REU), the institution must administer the URP under strict guidelines provided by the funding agency. Some PUIs have an undergraduate research center for administering institutional funds; this research falls under the university's purview.

Undergraduates can participate in UREs through several different routes. Students may volunteer for research without earning course credit. A second route is for students to carry out independent research or an honors thesis, and earn a grade for course credit. Students may be employed as research assistants, a position for which they are paid, but without course credit or a grade. Alternatively, students may participate in a course-based URE as part of a laboratory course offering. We have observed that, whatever their status, student researchers fulfill the objectives of a URE only if their participation is not limited to menial tasks. Furthermore, our view is that faculty should not maintain students as volunteers for more than one semester, during which time the student can acclimate to the laboratory and the mentor can evaluate the students' suitability. After this introductory period, students should receive course credit for their research. Faculty have a responsibility and an obligation not to use students solely as uncompensated workers to perform routine tasks, but to allow them to expand their creative and scholarly potential by participating in independent research projects.

Many students interested in laboratory research plan to enter the health professions. Some of these students may not be interested in long-term research projects, but rather a shorter URE that will garner a recommendation letter for professional school admission. In such cases, students often carry out a project for only one or two semesters. Because

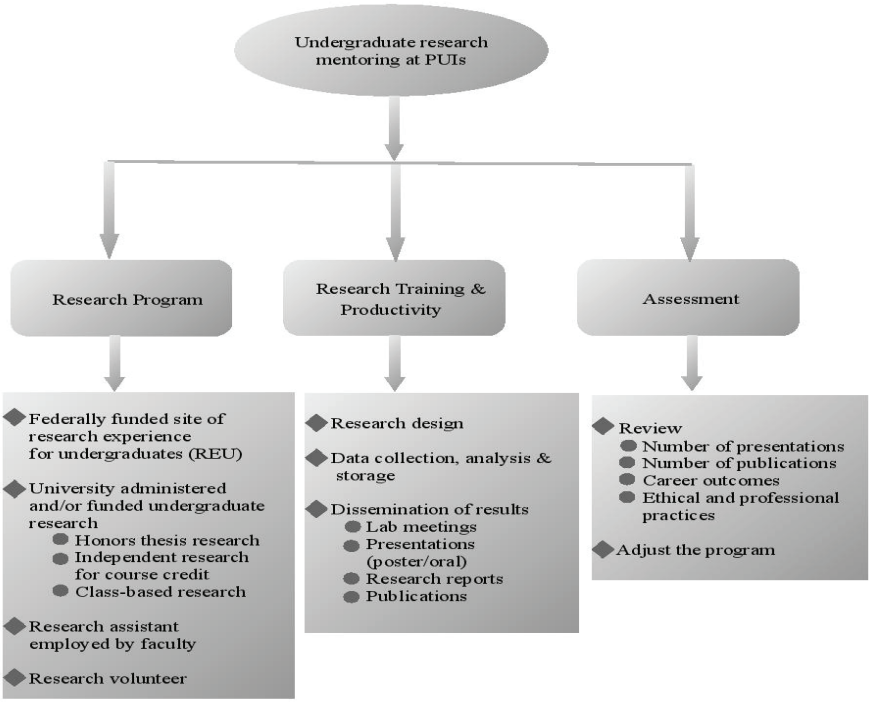

FIGURE 1. Undergraduate research programs at primarily undergraduate institutions (PUIs).

of the distinct goals of these students versus students with an interest in research for its own sake, different criteria may apply. Projects with a relatively narrow scope and undemanding techniques may be more appropriate. In this way, students secure exposure to experimental methods and critical thinking, while mentors acquire a familiarity with the professional and personal attributes of students that allow them to write stronger letters. As undergraduates generally have a more limited exposure to the research field than to the medical field, this exposure to the experimental process may spark a student's interest in a career path previously unknown to them.

Some research programs limit the credit hours a student may earn through independent research to one to six credits. In keeping with the view that students should be compensated for their research after an introductory semester, such limitations on course credit may be counterproductive. Studies have shown that UREs have a strong influence on learning and career paths only after students engage in laboratory research for longer durations (8, 12). In short UREs, students may have sufficient time to learn laboratory techniques, but not to formulate hypotheses, design experiments, and interpret results. Therefore, it is not surprising that short UREs provide little or no benefit to students (7). We advocate for undergraduates to begin research as freshmen or sophomores and continue through graduation, so that they may progress from junior researchers who have mastered laboratory techniques to "knowledge-producers" who are adept at interpreting results and testing hypotheses (8, 12).

Many universities that have URPs sponsor UREs during summer breaks. We believe that, in addition to the timespan, cumulative time is important in attaining the goals of a URE. Consequently, we advocate the sponsorship of UREs that span both the academic year and summer break. The summer break provides a distraction-free time for students to concentrate on research but, on its own, may not provide sufficient longevity to build critical thinking skills and is not sufficient to carry most projects to their fruition.

Managing research activity

Starting your lab's undergraduate research program. When faculty join a PUI, their initial source of undergraduates will likely be their own courses. For this reason, it is strategic for faculty to teach an introductory course early in their career, as students in upper-level courses will not have sufficient time to obtain the full benefits of UREs. In lieu of an introductory course, a guest lecture in an introductory course or a departmental seminar may suffice. Students gain more from long-term UREs and become more productive with time, which is beneficial for faculty. Many areas of research require techniques that students may not have time to master if they start only in their later years. Even though juniors and seniors have taken more relevant coursework, this advantage is far outweighed by the disadvantage of their limited time to learn techniques. Therefore, it is best for faculty to recruit students in their first or second year. Once faculty have a few students, word of mouth will likely be sufficient to provide a pool of undergraduates.

In choosing students for UREs, one must assess multiple factors. Selecting students based on their GPA and a brief interview is common, but success in these two measures is not a proven predictor of research success, and reliance on them may exclude individuals from disadvantaged backgrounds (1). The importance of motivation should not be discounted. In some students, motivation may outweigh grades in predicting research success. While students' motivation may be difficult to measure, a student independently seeking out a faculty member and making persistent efforts to join a lab is a strong indication. In addition, providing research experiences to highly motivated students with less than exemplary grades provides a greater benefit to these students. The boost in their grade point average due to the enhancement of their critical thinking skills is likely to enhance their career choices (7, 12).

Training and productivity. At research-intensive universities, most undergraduates are trained by graduate and postdoctoral students (11). PUIs generally have fewer graduate and postdoctoral students, and hence faculty directly train more undergraduates. Studies have shown that UREs are most successful when students have more direct interactions with faculty (11). A student is therefore likely to benefit more from a URE at a PUI than at a research-intensive university, and the continuation and growth of UREs at PUIs is important for maintaining a diverse pool of talented students.

In an established lab, there will be overlap between novice and experienced undergraduates. Interactions between these students can be fostered in structured settings, such as weekly lab meetings or meetings arranged through the mentor; they can also occur spontaneously in the laboratory. Having an area in or near the lab where students can congregate during experimental incubations and between classes is conducive to impromptu research discussions. However, these transient interactions will not provide sufficient guidance to new students. Therefore, mentors should allocate sufficient time to train undergraduates in lab procedures, research techniques, time management skills, and recordkeeping. It is useful to provide undergraduates with a "Lab Philosophy" that outlines requirements for a lab to operate efficiently, including discussions on communication, cooperation, and consideration between lab members; conflict resolution; lab duties; recordkeeping, i.e., notebook, reagent databases, data backups, etc.; and protocol for leaving the lab. This protocol includes storage of all propagatable reagents, providing the mentor with completed notebooks including all data, and cleaning out the workspace. There are several lab philosophy templates available, including one on Brigham and Women's Hospital

website (www.brighamandwomens.org/research/oprc/documents/Lab_Philosophy.pdf).

Undergraduates need a more structured research plan than graduate and postdoctoral students. To provide this structure, mentors must closely supervise their research. To ensure that a detailed and accurate notebook is kept, its content should be checked on a regular basis during a student's first semester in the lab. An inexperienced student's notebook often lacks critical details of procedures required to accurately repeat an experiment. This will cause needless delays upon replication of the study, or when another student continues a similar line of research. In addition, undergraduate notebooks frequently lack a cohesive structure specifying the purpose of an experiment, the significance of the results, and future experimentation suggested by the current results. Moreover, when multiple students are involved in data collection, uniformity of the data must be maintained.

It is useful for faculty to have weekly one-on-one meetings with undergraduates. Prior to these meetings, students should e-mail the mentor a list of the work done in the previous week, including the significance of their findings. In addition, students should provide their plans, including the underlying rationale, for the following week. In this way, students begin to learn the skills of data organization and interpretation, and how to write a research report. Moreover, this helps students gauge their progress, and the mentor can more easily monitor the students' time management skills and productivity. A somewhat similar information exchange, but in a more abstract form, was suggested by Campbell and Lom (3). Close supervision is important for students to get the most out of their research experience, and faculty members should not take on more students than they can reasonably advise.

Faculty motivation is important in determining the success of a URE. Faculty must be motivated to take the time necessary to train and mentor undergraduates. While the requirements for tenure and promotion may provide this motivation, as publications are a component of these achievements, faculty must remain motivated to train the next generation of scientists once their own milestones have been reached. In some cases, universities also offer salary incentives for publications and funded grant proposals. We believe, however, that the best mentorship is carried out by faculty who are self-motivated and do not require outside incentives.

UREs present a multilayered approach to promote critical thinking. This process requires providing a stimulating research environment for students so that they can gain the ability to interpret the scientific literature, formulate hypotheses, design and carry out experiments, interpret results and plan further research objectives, and, finally, organize and present research findings in both oral and written formats. The ability to carry out these processes will endow undergraduates with the tools they need to succeed in their coursework, and it also lays a foundation upon which their future scientific career can be built.

Experimental design, data collection and analysis, and dissemination of results. Independent research involves identifying a research question, formulating hypotheses, experimental design, data collection and analyses, and dissemination of results. A critical limitation for undergraduates is that they often do not work on a project from its beginning (formulating hypotheses and planning controlled experiments) to its end (manuscript preparation), two activities that we consider to be the most important parts of a research project. The first involves reading literature to identify a research question and formulate a hypothesis; this is generally conceptualized and preconfigured by the mentor. In other words, research projects are generally assigned to students. Students often do not get the opportunity to develop their own research hypotheses, as most undergraduates are plugged into interim steps of an existing project.

The next steps are data collection, data analysis, and the preparation of graphics for presentations at lab meetings or professional conferences. We recommend that the majority of students involved in undergraduate research be given the opportunity to present a poster, and that advanced students be encouraged to give an oral presentation at a conference. The process of preparing, presenting, and defending their data and conclusions, as well as being rewarded or recognized for their presentation, motivates students for future research. Some mentors are stringent concerning the amount of data required for a presentation. However, the presentation of even preliminary results at a local, state, or regional conference is appropriate for an unseasoned undergraduate. Students who take research for credit must write a report and present their research findings at a lab meeting, departmental seminar, or conference.

The last and critical step in the research process is publication in a professional journal. Mentoring undergraduates through independent research is time-consuming and should be duly recognized at the time of faculty review. In the absence of such criteria, there is a general tendency among mentors to write manuscripts, as publications are required for faculty merit review. Although this practice is not wrong, as the mentor owns the research project, mentors should take the time to train undergraduates to organize their data and prepare a draft manuscript. On a project that several students have worked on over several years, the student who obtains the majority of the data should write a draft and be first author. The mentor should be the last and corresponding author, and other students who contributed significantly to the project should be co-authors. Students must be included as authors if they contributed substantially to the project, even if they are no longer in the lab or at the university, as this is a standard rule of authorship. Even if not required by the journal, it is useful to make a list of author contributions. In this way, an equitable and more transparent authorship order can be determined. Mentoring undergraduates in the writing process may be challenging and time-consuming, but it is more rewarding for students to have ownership of their scholarly work. Authorship on

a paper cements a student's contribution to scholarly work and demonstrates attributes indicative of future success in graduate school and/or the professional world (2).

URP evaluation and assessment

URPs must be assessed to determine their strengths and where they may need to change to better meet the needs of students and mentors. The success of URPs can be assessed in many ways, including the research output of the undergraduate as measured by presentations at conferences and publications in journals.

Another mechanism involves student and mentor surveys administered by the department or the URP. Self-evaluation surveys can be administered to students when they begin research and re-administered at its completion. The National Science Foundation (NSF) has supported the development and testing of an excellent survey entitled "Undergraduate Research Student Self-Assessment (URSSA)," the survey recommended to evaluate NSF's REU Program. It is modifiable and available for download by choosing the "URSSA MASTER" instrument through the Student Assessment of their Learning Gains (SALG) website (www.salgsite.org/).

A third mechanism to assess URPs is tracking student careers. This is the ultimate indicator of the efficacy of a URP. Initially, students provide their career plans immediately upon graduation, whether it is graduate school, medical school or other health professions, or entering the work force, etc. They are also contacted five and ten years post-graduation to track their career advancement. These types of surveys are currently done in many academic departments, and comparisons of career trajectories of students who participated in UREs with those that have not can be made. Although a direct conclusion that a URE promoted career success cannot be drawn until sufficient data are collected, a trend indicating that a higher percentage of students who participated in UREs remained and succeeded in science, technology, engineering, and mathematics (STEM) fields is highly suggestive of the success of a URP.

The importance of direct measures of accomplishments, including presentations or publications and career paths, relative to student surveys must be kept in mind during the review process (9). In addition, faculty and students should provide feedback about professionalism throughout the mentoring process. Both parties should be mindful of their strengths and weaknesses and be ready to adjust to the standards set for the mentoring process.

CONCLUSION

Undergraduates should not spend more than one semester as volunteers in a laboratory, but should receive course credit or be paid for their research in the long-term. The best outcomes result from training periods spanning the majority of students' time at university. In this way, undergraduates can reap the benefits of their dedication and develop into "knowledge-producers," and faculty can lead productive research programs. Undergraduates should interpret their experimental results, propose their next experiments, and meet with their mentors on a weekly basis. Although undergraduates often do not research a project from start to finish, they should be mentored in writing and presentation skills and receive their earned authorship. Assessment of the efficacy of URPs should be done on a regular basis to ensure that the programs are meeting student and faculty needs. As students are likely to benefit more from UREs at PUIs than research-intensive universities, the continuation and growth of UREs at PUIs is important for maintaining a talented pool of young scientists.

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