The Role of Research in Undergraduate Chemical Education

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There are three aspects of this topic that we want to discuss in this paper:

1. **What role, if any, should research play in undergraduate chemical education?**
2. **What are some good ways to do it?**
3. **How does a faculty member get such a program going?**

First, who are we? John Stevens is Professor of Chemistry at UNC-Asheville. He is an active researcher in the field of Mössbauer Spectroscopy and Director of the Mössbauer Effect Data Center based in Asheville. He was one of the first members of the Council on Undergraduate Research (CUR) when it became a membership organization, and served as its National Executive Officer from 1991-7. He is also the founder of the National Conference on Undergraduate Research (NCUR). Dave Reingold is Professor of Chemistry at Juniata College in Pennsylvania. Prior to that he was on the faculty at Haverford College, Middlebury College, and Lewis & Clark College. He is active in the synthesis of theoretically interesting organic molecules. He, too, was one of the first members of CUR, and currently serves as chair of its Chemistry Division. Clearly we both come from primarily undergraduate institutions (PUIs) and our comments come from that perspective, although many of them are applicable in any setting.

1. What role, if any, should research play in undergraduate chemical education? The first topic we intend to give relatively little time to, since we anticipate there are few readers of this paper who do not already agree that research is an important aspect of the undergraduate experience. Most chemistry faculty were themselves turned on to chemistry by the investigative aspects of the science, and agree that whatever they can do to convey to their students the excitement they feel about learning new chemistry will increase the level of excitement on the part of the students as well. Further, most will agree that there is no substitute for experience, and the best way to demonstrate to students the excitement of discovery is to have them experience it first hand. Thus many of us have incorporated discovery-type activities into our courses, and there are many success stories associated with them. Nevertheless, for the purposes of this paper, we wish to make a distinction between discovery-oriented labs and classroom activities and

"research," the key difference being whether the professor knows the answer to the question being asked. It has been argued that this is an irrelevant distinction, since to the student, new knowledge is new knowledge; but we disagree: there is something about being able to tell students that they now know something that *no one else knows* that brings a qualitative difference to the research experience. We also think there is inevitably a different qualitative interaction between student and professor when the professor knows the answer, even if he or she is pretending otherwise.

We wish to argue that all undergraduates in chemistry (and why stop there?) should have the opportunity to engage in a research project it they so desire. This means that a chemistry curriculum is, in our opinion, incomplete without such an opportunity, and we would argue that departments that do not offer research experiences should not be certified by the ACS. This immediately leads to another question: if research is so important, should it be required of all chemistry majors? Arguments in favor of a research requirement include the following:

- research is the best way to integrate the "book knowledge" acquired in previous courses
- research involves an intimate encounter with ambiguity that is healthy for all students
- research requires an organization and dedication not found in other coursework
- research requires the development of so-called "life" skills relating to communication and cooperation

On the other hand, there are some very real challenges to developing a responsive undergraduate research program in chemistry, including:

- research is extremely costly, both in terms of supplies and faculty time (which is more often than not uncompensated)
- students who are not motivated will go through the motions without deriving much of the benefit

It is hardly surprising, then, that the types of undergraduate research programs currently in place differ widely. There are some institutions that require research of all students in all fields (College of Wooster may have been the pioneer in this, and there are others, such as Hamilton College). Some institutions require research in certain departments but not others; some do not require research of anyone. Finally, there are some institutions where research is not an available option.

We do not wish to take a stand on the question of required research, but some observations are called for. First, it is our perception that among the objections to required research, the costs associated with research, especially the time commitment, are overriding. If some way can be found to count research supervision as part of a faculty member's teaching load, we believe there would be a lot more research occurring. Some institutions are now experimenting with such methods, a common one being credit banks in which credits accumulate at some predetermined rate for supervising research, and when a certain level is reached, can be cashed in for course release. This is a step in the right direction, but all of us who have supervised undergraduate research know that one or two students, supervised properly, occupy as much time as a course, and no formula is likely to be that generous. Thus there is still progress to be made in this area.

Our second observation is a repeat of what we said earlier: there are acceptable arguments for the range of requirements for research experiences, but we see no excuse for institutions that do not provide a research option. These institutions are failing their students and should not be accredited.

A final comment is to note the commitment of the American Chemical Society (ACS) to undergraduate research. This has been a relatively recent development of the last decade. Currently, ACS makes a strong statement concerning the expectations for a department in the awarding of ACS certified degrees and the recent addition of sessions at the National Meetings for undergraduate research. The most recent "Guidelines and Evaluation Procedures" for undergraduate training state:

> "Research. Undergraduate research can integrate the components of the core curriculum into a unified picture and help undergraduates acquire a spirit of inquiry, independence, sound judgement, and persistence. By doing research, undergraduates develop the ability to use the chemical literature and report effectively in spoken and written presentations. Also, supervision of research helps the faculty maintain enthusiasm, professional competence, and scholarly productivity. The Committee strongly endorses undergraduate research as one of the potentially most rewarding aspects of the undergraduate experience…." (Fall 1999)

Further indication of the strong support and recognition of undergraduate research on the part of ACS is the recent increase in participation of undergraduates at the ACS National Meetings; there are almost 700 papers in the program for the 219th National ACS Meeting at San Francisco (March 2000). Some ACS Divisions now have awards to support undergraduate attendance at Division meetings as well.

2. What are some good ways to do it? There are numerous ways in which undergraduate research can be supported. It really depends on the individual faculty member and his or her institution. Listed in this section are a number of suggestions as to how to develop and provide for a vibrant atmosphere for undergraduate research. The first suggestions are ones that are in place at many institutions with successful undergraduate research programs; the latter suggestions relate to means of supporting undergraduate research that are less in vogue at this time, and in some cases are suggestions for which experience is lacking.

Student Funding. Funding can be provided for student employment opportunities for summer research and for student grants both during the summer and throughout the academic year to support the supply costs associated with doing research. This later funding might come from the individual faculty member, the department, and/or the institution. Other types of student funding could include student scholarships with a research requirement.

Courses. Many departments offer undergraduate research courses, which provide a way for students to formalize their commitment to undergraduate research. At many institutions, courses provide institutional funding since they are considered part of a department and/or faculty

member's load. In a few instances these courses are methodological, but in most cases they are strictly for providing academic credit for students carrying out an undergraduate research program. This is one way to get some faculty credit for supervising undergraduate research; many departments rotate this course among the faculty, giving each mentor at least some credit every several years. There are some instances where departments require research as a part of their ACS Certified degree.

Campus Symposia. Campus-wide symposia during the academic year provide students with opportunities to report their research results either orally and/or through poster presentations to the campus community. If this is not practical at the campus-wide level, departmental symposia are always possible.

Journal of Undergraduate Research. To encourage students and faculty to present their research results in peer reviewed journals in their discipline, an institutional undergraduate research journal provides the first important step. These kinds of journals familiarize students with the peer review process. Such journals can take the form of student publications in which students are the authors, production managers, and editors. Faculty are asked to review the submitted research papers but it is the students themselves who decide whether a particular paper merits publication. Student-based journals also provide research students an opportunity to sharpen their communication skills and "socialize" the student via a firsthand understanding of how the peer review system works in the academic community. There are undergraduate research journals at an increasing number of institutions, including the University of Utah, University of North Carolina at Asheville, Wittenberg College, Furman University, North Carolina Central University, and the University of California at Berkeley.

Regional and National Conferences. Students can be encouraged through financial support to present their research results at various state, regional, and national conferences. The annual highlight at a number of institutions is when a group of students leave campus to present their results at the National Conferences on Undergraduate Research (NCUR) and/or a regional/national meeting of ACS.

Institutionalize Undergraduate Research. This can simply take the form of a campus committee charged to develop and sustain undergraduate research for the institution. More developed programs might have an office of undergraduate research, the goals of which are to further enhance and develop opportunities for undergraduate research. Many institutions have profited from sending teams to the CUR Institutes on "How to Institutionalize Undergraduate Research."

Research Scholars. At the University of North Carolina at Asheville there is the special notation of "Research Scholar" at graduation for those students who meet a prescribed set of requirements. These are treated similar to Latin honors. One of the steps in the process of approving the "Research Scholar" notation is the review of the students' requirements by the campus Honors Committee.

Get Freshmen and Sophomores Involved with Research. Typically, students will not become involved with research until their junior year, and in many cases not until their senior year.

Encouraging students' involvement as freshmen and sophomores can be done through the curriculum. An increasing number of departments are developing freshman labs, referred to as "investigative" labs, with a heavy emphasis on developing and carrying out a series of projects that are more research in nature than those in traditional labs. Another way is to involve first- and second-year students directly in the research programs of the faculty. A good analogy is learning to play basketball -- instead of spending years in the classroom, the student simply goes onto the court and learns through practice and experience.

Intensive Junior-Senior Year Program of Research. The concept here is to divide the student's academic program into one-half time of formalized course work and one-half time of research. This would necessitate replacing certain required courses in the curriculum with a guided research experience. We know of at least one school where a similar program operates: at Dartmouth College, every year a few select seniors ("Senior Fellows") are exempted from all unmet college requirements and are allowed to pursue an independent project full time.

3. How does a faculty member get such a program going? Below is advice for faculty getting started in research. For a fuller treatment of the subject, we recommend two booklets (1) "How to Get Started in Research," by Tom Goodwin and Bert Holmes [1] and "How to Involve Undergraduates in Research" A Field Guide for Faculty." By Dwight Neuenschwander and Tracey Schwab [2].

Select Appropriate Research. The first step in establishing an undergraduate research program is to select the most suitable research area. The necessary questions needing to be asked are as follows:

- Is external funding available both to initiate and sustain the research program?
- Can undergraduates easily become involved in the research and be able to make significant contributions to the overall research program?
- Are the necessary facilities available to have an active and productive research program?
- Is the kind of research being proposed stimulating -- is it likely to engage students' natural curiosity? Will both faculty and students have fun doing this research?

Startup Funds and Startup Time. It has now become commonplace at many good liberal arts institutions for start-up funding to be provided to assist in establishing a research program; these funds then provide the basis for a faculty member to seek external funding for sustaining the research. Even if institutions do not offer start-up funding, there is the need for new faculty members to have released time to establish their teaching and research programs involving undergraduates. Startup funding is typically a negotiable item before accepting employment and is less likely to materialize once the conditions of employment have been established.

First year, start early. New faculty should be hired in July, that is, they should be paid on a fiscal year cycle rather than a September-August cycle. DR's first job was at Haverford, where all the contracts were July-June. He was able to come to campus, get set up, prepare for courses, write proposals, etc, without the 1-2 week time pressure most new faculty face. This should not

cost the institution anything, it simply shifts the salary time frame earlier. If all contracts were to be so shifted there would be a huge capital drain the first year, when there would be double pay for all continuing faculty during July and August; but if the program were phased in there should be no significant effect. This would make it much easier for new faculty to be able to afford to come soon and get ready; further, one could expect it of new faculty.

Get the Funding. Faculty members must begin seeking external funding almost immediately upon employment, or even sooner. Fortunately, in the area of chemistry there are many opportunities through several foundations and agencies. The most common funding programs for new faculty are those of the ACS-Petroleum Research Fund, the Research Corporation, and the Camille and Henry Dreyfus Foundation. All have programs that require concise proposals that make the case for establishing an initial research program. Once a program is established, and a publication record has been developed, there are larger funding programs available through NSF and NIH, in additional to a variety of programs through most of the agencies, departments, and foundations involved with science.

Connect Research into the Teaching of courses/labs. Working in an environment of limited resources at primarily undergraduate institutions, it is important that faculty develop teaching laboratories and research laboratories that blend as much as possible. The acquisition of major chemical scientific equipment either for teaching or research purposes should in most cases be actively used in both programs -- this should be a "win-win" situation.

The Mentoring Dimension. An important characteristic of undergraduate research (vs. graduate research) is the existence of a mentoring environment. This means one-on-one time with students in the laboratory on at least a weekly basis. This should be a comfortable, relaxed atmosphere in which the faculty mentor is constantly pushing the students into new territories of learning and discovery. As the mentoring takes form, it should progress into the realm of collaboration where the students take on more and more of the role of teacher, to the point where the faculty member and the students are equals in the research effort.

Associate with Others Doing Research. It is important to seek out associations with other faculty who are committed to developing research programs that enhance their teaching and provide direct research experience for undergraduates. These associations can be at the faculty member's own campus (in the same department or elsewhere within the institution) or through associations formed at the professional meetings of the ACS, regional and national. There are other national organizations which focus direct attention on promoting and developing undergraduate research, the most noteworthy being the Council on Undergraduate Research (CUR), the National Conferences on Undergraduate Research (NCUR), and Sigma Xi. A recent article in the **Journal of Chemical Education** discusses CUR and NCUR. CUR is a membership organization primarily made up of science faculty at PUIs who are developing and maintaining undergraduate research programs; NCUR is an annual conference providing undergraduate students across the disciplines an opportunity to present their research results before a national audience.

It takes lots of time. Output is oftentimes described as proportional to the time expended "times" the efficiency of the operation. In these terms, the success of a good research program

involving undergraduates is the result of the product of the quality of the research program "times" the amount of time put into it by the faculty member (and students). In short, undergraduate research programs take a tremendous amount of time to develop and sustain and are therefore the domain only of the committed. There are simply no short cuts here. For the faculty member, the rewards are immeasurable both in terms of the personal satisfaction that comes from knowing you are making a difference in the development of a young scientist, and in the contributions you are making to the scientific discipline.

Some closing comments.

In the process of developing and sustaining an undergraduate research program it is very important that the research takes place at the home institution of the student. Having a student travel to another institution where there is no established collaboration, has a compromising effect on the student's experience. The ongoing professional development of the individual faculty member is also dependent on a home institution-based research program. In short, being dependent on research efforts at another institution is not in the best interest of the faculty member or the student.

While the interest in undergraduate research has increased dramatically over the past ten years (See the recent "Directory of Research in Chemistry at Primarily Undergraduate Institutions" [3]), the "proposal pressure" is lagging at many of the foundations and agencies that support undergraduate research. Needless to say, this is very disappointing and, at first glance, does not "compute." Although some of the decrease in proposal pressure can be attributed to new, alternate sources of support, both internal and external (Hughes funding, corporate summer programs, etc.), there is empirical evidence that while the number of students involved in undergraduate research has increased, the quality and quantity of the research has not [4]. Thus it appears that the focus has been on providing an undergraduate research "experience," and not on making a research contribution. Meaning: there has not been enough of an effort to produce the quality of research possible by undergraduates, thereby actually providing students with a second-rate experience. The undergraduate community is capable of doing a much better job of producing quality research than the evidence currently suggests, and a greater effort must now be made to "raise the bar." The good news here is the untapped potential of what we call "undergraduate research."

References

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