Research with First- and Second-Year Undergraduates: A New Model for Undergraduate Inquiry at Research Universities

Aaron R. Hutchison and David A. Atwood*
Department of Chemistry, University of Kentucky, Lexington, KY 40506-001; **Datwood@pop.uky.edu*

In recent years, there has been an increasing interest in getting undergraduate students involved in research. There are two good reasons for this. First and foremost, this is because undergraduate research is an important step toward accomplishing the main goal of the university, namely, educating its students. It is undeniable that hands-on research is a predominant theme in chemistry today; no one can get an advanced degree in the field without spending a serious amount of time in the lab. Furthermore, the "follow-the-recipe" style of traditional teaching labs is a far cry from the largely independent research most students will engage in after graduation. Also, and perhaps less recognized, the undergraduate population is a mostly untapped, energetic, and creative resource to the professor, offering him or her many extra and willing hands to assist with research projects.

Our group at the University of Kentucky has relied heavily on undergraduate research for many years. This has reached the point where there are often as many undergraduates as graduate students working in the laboratory. Because we have also made a concerted effort to recruit undergraduates very early in their careers, most of our recruits are first- and second-year students. Although this is counter to the conventional wisdom that only an upper-level student is ready to do serious research, it has been an extremely successful system for us.

The Model

There is growing consensus among chemical educators on the need to expose undergraduate students to research early, as demonstrated by several previous articles in this *Journal* (*1*). We feel that our model, however, has been especially successful at quickly integrating students into the joys of productive research. We usually pair an undergraduate with a graduate student. This upper-level researcher has already done some groundwork on a project, preparing it for the incoming student. The graduate student then oversees the project, teaching the newcomer the necessary skills for the work they are doing and giving assistance as needed. The graduate mentor gets joint credit for the project, acting as a coauthor with the undergraduate when the work is published. This gives the graduate mentor a major stake in the project and has the extra benefit of giving our graduate students significantly more publications than would ordinarily be obtained in the same length of time. Furthermore, the undergraduates quickly become proficient in the area they are working in and by the end of the project, they are many times quite comfortable discussing options with and even offering suggestions to their mentor. Eventually the undergraduates will have the option of working independently on projects of their choosing.

Some Results from the Model

We have produced several excellent examples of this model in action. One such example is John Twyman, a first-year chemical engineering student who chose to join our group after taking a general chemistry course with one of us (DA). He worked on a ligand design process with a graduate student (AH). On average, Twyman worked around 12 hours a week for two semesters and a summer. He quickly learned solid laboratory technique and by his second semester in the lab, he was routinely setting up and running reactions with minimal guidance from the graduate student. At the end of his time in the lab, he was able to present his work as a poster (The Determination of the Dissociation Constants of Trithiocyanuric Acid, abstract number 463) at the 32nd ACS central regional meeting in Covington, KY, and he was listed as a coauthor on a talk (The Search for an Ideal Mercury Remediation Ligand, Phase 1, abstract number 393) at the same meeting. He will also be a coauthor on an upcoming publication.

Perhaps an even better example is offered by Brock Howerton, who joined our lab at the beginning of his sophomore year and at this writing is well into his second year of research on environmental remediation with graduate student Matthew Matlock. Like Twyman, he quickly mastered the techniques required for his work and now performs most of the synthetic work for the project independently, freeing Matlock to spend more time planning future routes for their project. Howerton is a coauthor on a patent (*2*) and three peer-reviewed publications (*3*) and gave a talk (Multidentate Ligands for Mercury Remediation from Contaminated Soils, Envr. #17) at the 221st national ACS meeting as part of a symposium on heavy metal remediation (*4*).

A final example is given by Brandon Connely, who also began working for us during his sophomore year. After a brief start-up project involving our group's work on environmental remediation chemistry, he took over his own project concerning the synthesis and biological activity of AlF_4^-. So far, he has presented a poster (History and Recent Investigations of 2,4,6-Trimercaptotriazine (TMT), abstract no. 471) at the 32nd ACS central regional meeting, represented our group with a poster (Investigation of Specific and Efficient Preparations of Tetrafluoraluminate, poster no. 16) at the Fourth Keele Meeting on Aluminum in Stoke-on-Trent, England, presented a talk (Investigation of the Synthesis and Characterization of Tetrafluoroaluminates and Hexfluorosilicates of Organic Base Cations) at the 15th National Conference on Undergraduate Research, and will be the primary author of several papers soon to be submitted.

Benefits of the Model

Not only have our students gained the obvious benefits of peer recognition through their work, they have also gained several more intangible benefits. High among these is the knowledge of how a research lab functions, as opposed to a teaching lab. The students saw firsthand the necessity of choosing a realistic research goal, planning reaction schemes to get to the goal, searching the literature for precedents and procedures, and then modifying these procedures to achieve the desired goal. This process stands in stark contrast to the recipe-like method many times used in teaching labs, where students follow clear, prepared directions without always understanding what they are doing or why. Furthermore, this experience gave the students involved a new appreciation for the importance of lab safety and waste disposal. There is, after all, a significant difference between handling and disposing of a hazardous substance once, with clear guidelines and close supervision, and handling the same substance daily, eventually with little supervision. Their research experience, finally, endowed the students with a clearer understanding of what they were studying in class. Almost daily, they saw the importance of stoichiometry for calculating the amounts of reagents to use in their reactions. They saw many of the basic reactions they studied in sophomore organic chemistry carried out routinely and, as some procedures worked and some didn't, they quickly realized the importance of reaction mechanisms and experimental conditions for getting the desired products. This gave an immediacy to their studies that many hours of lecture could not have provided.

Research should be a significant part of an undergraduate chemistry student's education. Far too often, however, this has been neglected simply for lack of an effective system for doing it. We in the Atwood group feel we have developed an unusually effective method of utilizing undergraduates for practical research. This benefits the undergraduates by giving them a chance to tackle real-world research problems, benefits the graduate students and postdoctoral fellows by giving them practical experience in a supervisory position, and benefits the professor by effectively dealing with many projects simultaneously with a larger number of researchers. Therefore, we would like to recommend this system to others in the field of chemical education and research.

Literature Cited

1. Craig, N. *J. Chem. Educ.* **1999**, *76*, 595–598. Lindsay, H.; McIntosh, M. *J. Chem. Educ.* **2000**, *77*, 1174–1175. Slezak, J. *J. Chem. Educ.* **1999**, *76*, 1054–1055.
2. Matlock, M. M.; Atwood, D. A.; Howerton, B. S. Novel Multidentate Sulfur Containing Ligands; U.S. patent (pending), 2000.
3. Matlock, M. M.; Howerton, B. S.; Atwood, D. A. *J. Hazard. Mater.* **2001**, *84,* 73–82. Matlock, M. M.; Howerton, B. S.; Henke, K. R.; Atwood, D. A. *J. Hazard. Mater.* **2001**, *82*, 55–63. Matlock, M. M.; Howerton, B. S.; Atwood, D. A. *Adv. Environ. Res.*, in press.
4. Howerton, B. S. *Extended Abstracts, American Chemical Society National Meeting, ACS Division of Environmental Chemistry* **2001**, *41* (1), 419–421.