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Broadening the Existing Intergenerational Structure of Scholarly Development in Chemistry

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Who discovers new knowledge, what are the structures that support its discovery, and what infrastructures enable new discoverers to join in? The answers to these questions vary wildly across different disciplines. New knowledge in the classics, for example, takes place primarily, if not nearly exclusively, at academic institutions. New knowledge in chemistry, on the other hand, is created both in academic departments as well as in the laboratories of companies—Pfizer, Eli Lilly, Dupont, Dow, Abbott, General Electric, Procter and Gamble, 3M, et al.—and increasingly at places known as biotech, materials, or nanotechnology start-up companies. Such corporate settings are a significant source of employment for our discipline's annual output of ca. 2200 PhD students, whom we consider to be the most important products of our scholarly research programs.

In academic settings, the models for doing discovery research vary considerably. At the University of Michigan, there are thirty-five faculty members in the Department of Classics, and twenty-four graduate students in Classical Studies. If you removed the students from the classics department today, it is safe to say that new knowledge in the classics would be discovered tomorrow. In chemistry, although we have about the same number of faculty (thirty-nine), we also have, in residence, 290 graduate students and seventy-five post-doctoral students, and a steady state of about 100 undergraduate research students. If students were removed from chemistry department today, we daresay that new knowledge in chemistry would reduce considerably, if not disappear, tomorrow. Although the goals for how new scholars are educated in these two departments probably overlap greatly, the tactics for how scholarship is developed must clearly be different.

In chemistry, there is a historically robust and finely grained model of scholarly development. This model casts a broad net into the first-year college classroom and, within the same 8-12 year time period that has been used for 150 years, transforms some of these novices into stewards of the chemical profession. First-year undergraduate chemistry courses resound with the rhetorical designs of "discovery laboratories" and "teaching chemistry by doing chemistry," and, accompanied by the widespread availability of undergraduate research experiences, the chemistry discipline provides actively and early the opportunities for its next generation to display its stewardship potential. When undergraduate chemistry research students join research groups, they are residing immediately in an intergenerational community of widely ranging experiences. And while a faculty member (the research advisor) sets the overall direction and scope of the work, and ensures adequate space, money, and scientific resources, the graduate students (at doctoral departments) are often responsible for designing and supervising the day-to-day scientific and scholarly development of the undergraduate students. This is only one link in the chain, though, as a faculty research director interacts with all of the students to varying degrees, and post-doctoral scientists take on certain immediate tasks on a day-by-day basis in the laboratories, and senior graduate students mentor their junior colleagues, and undergraduates are moving through the infrastructure of scholarly development according to their own gifts and experiences. In chemistry, developing disciplinary stewardship for carrying out research is a highly evolved and finely articulated process where the epistemological knowledge is inherited through the intergenerational community described here.

Chemical Sciences at the Interface of Education

If the strategy of forming intergenerational communities has evolved in response to the needs for advancing disciplinary stewardship for carrying out research in science, can this deliberate design be adapted to advance understanding in areas where this system did not arise? Interestingly, in 1988, the National Science Foundation created its Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE) program in mathematics based on this hypothesis. In forty mathematics departments, the VIGRE program has catalyzed the kind of intergenerational team structure that is *de rigueur* in the physical and biological sciences. In our department, we have asked the same question: Can we advance our understanding of other professional aspects of the discipline – in particular teaching and learning – by using the same intergenerational strategy that we understand so well from chemistry research?

Over the last six years, the department has demonstrated that an ordinary idea derived from chemistry research can impact undergraduate education: faculty who wish to pursue instructional development work can do so by forming "research groups" of undergraduate, graduate and post-doctoral-level chemistry students who wish to add future faculty development to their education. By assuming that scholarly development is an intrinsic outcome of a well-applied model, students have educational opportunities in teaching and learning that parallel as closely as possible their work in research. The outcome is an infrastructure for the design, implementation, documentation, and assessment of undergraduate and graduate instructional development done by faculty and students that mirrors a proven and productive model of research development. In 1998, one of us (BPC), as a Carnegie Scholar, used the early development of this concept to tie together ideas from the Scholarship of Teaching and Learning with the ideas from the national Preparing Future Faculty (PFF) program. The department is also representing this mechanism for undergraduate instructional development as part of our contribution to the Carnegie Initiative on the Doctorate. We call our program Chemical Sciences at the Interface of Education (CSIE).

At the beginning of the CSIE pipeline, undergraduate students demonstrate their potential for taking on teaching responsibilities in the Structured Study Group (SSG) sections. Once identified, they are mentored to assume instructional activities. As SSG leaders, they learn about design, implementation, and assessment in our informal weekly seminar. Higher level and more independent projects become available (e.g., Pipeline for Student Success, Michigan Mathematics and Science Scholars, educational research collaborations) for those who wish to take their teaching education further. These undergraduates are co-authors on papers as well as presenters at and organizers of symposia at national meetings. They are becoming important resources for faculty at their graduate institutions and (with *continued mentoring* from Ann Arbor) some have been agents of change within their own PhD programs at other institutions.

Broadening Graduate Education to Improve Undergraduate Instruction

Using funding from the US Department of Education's *Graduate Assistantships in Areas of National Need* (GAANN) program, the Chemistry Department has also used the familiar strategy of a graduate training grant program in order to add future faculty development for those PhD students interested in academic careers. Blending teaching and carrying out research on teaching and learning, graduate students (singly and in teams) have worked with chemistry faculty and collaborators in education to implement and assess instructional projects. These graduate students take courses in educational design and assessment, write proposals for projects, present their results, and organize symposia at national meetings. In an externship program, modeled after work in the national PFF program, graduate students have spent 10-14 days off-campus at another institution during which an exchange of expertise takes place. Contemporary ideas on research and teaching brought by our students are exchanged for the experience and perspective about faculty life at an institution unlike the University of Michigan. In 2003, the first three students who joined the program received their PhD degrees. All three presented full chemical research theses plus two or three chapters on the educational development and research they did as a part of their programs. Graduating at 4.75, 4.75, and 5.25 years, their stay in Ann Arbor was not extended by adding these activities, nor was their laboratory research compromised.

The structure is beginning to prove robust. Moderate to large-scale undergraduate instructional development now takes place through teams of faculty and students (post-doctoral, graduate, and undergraduate). Some of these innovations are driven by faculty interests in modernizing and/or otherwise modifying our courses. In a year, far less time than it would have taken for an individual faculty member working in isolation, a team comprised of three faculty, a post-doctoral, six graduate students, and four undergraduate students have created and evaluated a "one-room schoolhouse" or "studio" version of general chemistry for a experimental group of fifty first-year students. Graduate students have initiated other course proposals according to their interests; for instance, our college has permitted these students to design and implement courses in the small first-year student seminar program.

Understanding and advancing knowledge about teaching and learning has paled compared with how we understand and advance knowledge in the sciences. Particularly spurred on by Federal funding, faculty members carrying out basic scientific research with intergenerational groups of students, within a context scholarly development, has emerged as the single training model for educating the next generation of scientists. Without such an efficient system for identifying and educating new scholars, research, like teaching, might be stuck in continuous cycles of what Stanford's Larry Cuban calls "reforming… again and again" as each generation would not learn from, build on, nor pass on its knowledge as productively as it happens today. Instead, in ways too familiar in teaching and learning, innovations would arise, flourish under their innovators, and then die with them. By rethinking the problem of advancing undergraduate education, and creating a program that takes the advancement of teaching and learning as its goal, we have found that the powerful system of intergenerational scholarly development can be broadened to educate better the next generation of faculty – while simultaneously providing the current faculty with a previously unrecognized source of energy and creativity for carrying out their responsibilities and obligations.