Undergraduate Research: Mission Integration in a Chemistry Laboratory

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The 2011-2012 Mission Academy was comprised of nine faculty members who met for six sessions under the guidance of Dr. David Burns (Director of Faculty Programs, Center for Mission and Identity). Our objective was "to explore the integration of Xavier's Ignatian Mission into the classroom". Before our Mission Academy I was admittedly skeptical that I could find a way to incorporate our mission into classes on an empirical, physical science. Reflecting on our discussions, I was able to see how broadly and thoroughly one requirement for our majors did indeed achieve the goal of integrating Xavier's Ignatian Mission into the Chemistry curriculum: undergraduate research.

Undergraduate Research in the Chemistry Department

The Xavier University Catalog entry for our research course is as follows:

> **CHEM 400 – Research/Seminar**
> **(1) Credit Hours**
> Capstone course for the chemistry and chemical science major. Undergraduate research performed under the direction of a faculty member. Students share the results of their research and interact with outside speakers during weekly seminar sessions. A written thesis is the final product of these activities.

Our Chemistry majors must register for CHEM 400 a minimum of three semesters, while our Chemical Science majors need a minimum of two semesters. This is a genuine capstone experience for our students, as they need to (a) apply the principles they learned in their lecture courses, (b) use the techniques and chemical instrumentation they encountered in their laboratory courses, and (c) employ the skills needed to search the literature that they learned in CHEM 300 (Intro. to Chemical Research).

Overview

During the six sessions in our Mission Academy three main tenets were deemed essential for successful integration of our Ignatian Mission into the classroom: (1) The principle of *Cura Personalis* is paramount. (2) The ability to think critically must be cultivated in our students. (3) The desire for service can be instilled within an academic setting. Consequently, this essay will be organized around those three themes.

Cura Personalis

At the heart of Ignation spirituality is *cura personalis* – care for the entire person – and undergraduate research is an ideal setting for the faculty to fully engage our students. Each Chemistry professor has a small research group, typically three-to-four students. This permits

one-on-one contact at many stages in the student's research experience. When a student first joins my research group we sit in my office to so I can explain the project's scope and impart the relevant principles/models. After a few such sessions we move to the laboratory, where I can teach the students specific synthetic techniques (for example, students in my group need to learn how to manipulate a dual-manifold Schlenk line to handle air-sensitive compounds) and the use of the Chemistry Department's state-of-the-art instrumentation (especially our multi-nuclear NMR spectrometer). It is very gratifying to observe each student progress to the point where they can synthesize and characterize compounds independently, usually a month or so after they join my group. Even after they can work independently, they still begin each research session by briefly sitting in my office to plan that day's activities, and later they bring in their spectra or other data so we can discuss their results. The constant mentoring ensures they mature as scientists and that their time in laboratory is as productive as possible.

It is important to note that the mentoring is not limited to the students' "hands-on" activities in the laboratory. We hold a weekly department seminar, featuring both our student researchers and outside speakers from both industry and academia. Within a few weeks of joining my research group each student must present a seminar to the faculty and their fellow research students; in this initial talk each student outlines the objective of their project, shares previous work done by their group or other researchers, and lays out the plans for their portion of the project. Quite a bit of guidance from the faculty mentor is necessary because the students have not yet become familiar with the concepts or jargon specific to their area of research. Towards the end of their research experience the students construct a poster summarizing their work to present at Xavier's annual Celebration of Student Research and Creative Activity, again with the guidance of their faculty mentor. Finally, as stated in the course description, each student must submit a thesis as a requirement for graduation, a process that normally involves two-to-three drafts that are edited extensively by their mentor.

The mentoring even extends the beyond the project. A research laboratory is a wonderful venue for long personal conversations. A common topic is the student's career goals, principally the immediate concern of whether to go to graduate school or work in the chemical industry right after graduation. If the student opts for the former, the faculty member can help the student navigate the graduate-school search and find the right fit for them; if the latter, the faculty member can suggest employers and sometimes name a specific contact person (often one of the department's alumni). Furthermore, these laboratory conversations allow the faculty to learn more about the students, their families, and their life stories. Often tales of personal or financial struggles emerge, and the students appreciate having a concerned adult listen to them.

Most importantly, the students gain tangible professional benefits from research: For the past several years our department has paid for most of our seniors to attend the National Meeting of the American Chemical Society to present their posters and interact with other students and professional chemists; other students have attended the annual National Conference on Undergraduate Research, which encompasses students from all disciplines. Also, my long-term observation of students (and our conversations) in the laboratory allows me to write detailed, significant recommendation letters when they apply to graduate school or for jobs. Finally, prospective employers are impressed when our students can explain their project in depth, as well as with the practical laboratory skills they have developed. One of my students who earned an M.D./Ph.D. credits experience his collaboration with me for admission to that program. (His story appears at the end of this essay.)

Critical Thinking

Undergraduate research is the academic enterprise most conducive for developing critical thinking skills in our students, for one simple reason: the faculty members don't know the answers! The students and faculty are on a journey together. We have a sense of the destination, but we certainly do not have a map. Research projects do build on previous results and established theories/models; however, each system is different, and thus outcomes of new reactions or methods cannot be predicted.

The first area in which a student is challenged to think critically is performing the reactions. If a reaction fails, the student must consider new reactants (or solvent, or temperature, etc.), careful to change one variable at a time so its effect (or lack thereof) is clear. The second area is in data analysis. Students themselves use modern spectrometers (nuclear magnetic resonance, infrared, or UV-visible) to obtain their own data and learn to interpret the spectra.

It is the data analysis step that prompted me to write earlier that we only have a *sense* of the destination. When examining a spectrum the student certainly must look for peaks that will confirm the existence of their synthetic target. However, it is more important that the student learn to look at the spectrum objectively, and be open to signs of unexpected products. Indeed, the two articles I have published in research journals while at Xavier highlighted such results. (In the first article, our tungsten-based reactant did not bind to our borane, but rather promoted the fusion of two borane units; in the second article, our metal reactant likewise did not bind to this same borane, but rather abstracted a hydride anion, which allowed two borane units to be bridged by the phosphorus-based reactant.) The discernment of a surprising result of an experiment is an unparalleled opportunity to foster critical thinking.

Service

The most significant insight I experienced during our Mission Academy discussions was a new perspective on service. Usually we desire an academic experience to inspire a student to perform deliberate acts of service. However, the subtle lesson I learned is *the act of doing research <u>is</u> service*. Following are brief sketches on how the research experience enables students to serve many groups of people in very different ways.

Service to the Faculty Mentor

A synergistic relationship develops between the faculty and their research students. In the section on *cura personalis* I outlined ways in which we mentor the students. However, a broader view of our undergraduate research program would reveal that the students have much to offer the faculty. The students are our "hands" in the laboratory; our teams of three-to-four students can accomplish much more than if faculty worked alone. Plus, new research students who replace those who are graduating bring fresh energy and enthusiasm to the group. Most importantly to me is the fruitfulness of discussing the project with my students. Countless times I have stumbled upon the remedy to a problem or a new avenue to explore during a few minutes of conversing with a student, while long stretches of thinking alone had yielded nothing.

Service to Other Students

Students have many opportunities to assist each other. Within a research group the veteran members willingly teach laboratory techniques and the use of the instruments to new members,

and group members always encourage each other when reactions fail. At department seminars all research students evaluate each other's talk, providing valuable lessons in peer review.

Service to Other Educators

My group has developed new laboratory exercises for Inorganic and Analytical classes. Four students (Megan Klein '99, Matt Mauck '03, Kelly Curran '04, and Bridget Dixon '09) have each been a co-author on four articles that have appeared in the *Journal of Chemical Education*. A fifth article (with student co-author Tyler Borg '08) will be submitted this summer.

Service to Other Researchers

My group has contributed to the body of chemical knowledge. Two pairs of students (Ken Nicholson '97 and Megan Klein '99; Vincent Schnee '03 and Alex Hamilton '06) have been co-authors on two articles in *Phosphorus, Sulfur, and Silicon*. Additionally, thirteen other students have presented posters at national conferences.

Service to the Planet

Sometimes former students have the good fortune to serve through their professional work. Audrey Martin ('03) earned a Ph.D. in Analytical Chemistry (Michigan State University); she currently works at Lawrence Livermore National Labs (outside Berkeley, CA), where she develops analytical techniques to detect chemical weapons. Therese Dorau ('05) earned an M.S. in Sustainable Systems (University of Michigan), a degree that blends an understanding of technology and business to create solutions to widely-entrenched environmental problems; she now works at ICF International (in Washington, D.C.) as a sustainability consultant for corporate and federal clients.

Student Profile: Matthew Mauck, Class of 2003

Matt graduated with a perfect 4.0 G.P.A. and completed an M.D./Ph.D. program at the Medical College of Wisconsin. His sophomore year he was in my Physical-Analytical Laboratory class. One of the exercises was to measure the volume of carbon dioxide dissolved in a can of soda. Later, Matt visited my office to share an idea. During Christmas break his younger sister was eating a candy called "Pop Rocks", and the package explained how the candy had pockets of carbon dioxide at 600 pounds per square inch. Matt said he immediately thought of our lab experiment, and wanted to work out a modification of the root-beer procedure with Pop Rocks (on his own time, no less). Eventually we published this laboratory exercise in the *Journal of Chemical Education*. Incidentally, Matt told me that when he interviewed for the M.D./Ph.D. program, the committee was more impressed with the Pop Rocks exercise than his two-year research project with my former colleague Ed Fenlon on transition-state analogues of ribozymes that culminated in his thesis.