An Introductory Project-Based Laboratory Curriculum Emphasizing Thermodynamics, Equilibria, and Kinetics

Project Overview. The purpose of this proposal is to facilitate a change in the introductory chemistry laboratory curriculum at DePauw University by developing a cooperative, problem-based laboratory experience that makes more explicit the link between class and lab. Funds in the amount of $20,978.66 are requested for the purchase of eight suites of computer-interfaced instrumentation to be used in a new 200-level course entitled "Thermodynamics, Equilibria, and Kinetics".

Institutional Overview. DePauw University is a private, selective, co-educational, undergraduate liberal arts university serving approximately 2200 students with 220 full-time faculty members. DePauw's students are diverse, hailing from almost every region of the United States and 17 foreign countries, and of high academic achievement, with a median SAT of 1230, a median high school class rank in the 91st percentile, and an unweighted high school GPA of 3.73 for this year's entering class. More than 20% of recent entering classes are first-generation college students.

DePauw has several distinctive programs that provide enriching opportunities for its students. Through its participation in the Posse Program, DePauw promotes social diversity and multiculturalism by helping students from New York City and Chicago attend college. With the Horizons Program, DePauw has increased the number of Indiana high school students attending college. DePauw's Bonner Scholar Program promotes community service. Finally, through its Fellows Programs, DePauw promotes the early engagement of students in the fields of media, management, and science research.

In 1997, Time Magazine and The Princeton Review recognized DePauw University for its Horizon Program, naming DePauw runner-up for "College of the Year." US News & World Report ranked DePauw as the 40th best national liberal arts college in 2001, and as the second-best value amongst all national liberal arts colleges.

Departmental Overview. The Department of Chemistry at DePauw University has a tradition of excellence in chemical education, ranking 10th among 511 comparable colleges and universities as an undergraduate source of students receiving a Ph.D. degree in chemistry[1]. The department currently consists of 6 full-time tenured or tenure-track faculty members and one full-time term faculty member, with backgrounds, training, and interests covering the major areas of chemistry. A search for a seventh full-time tenure-track faculty member is currently in progress.

---

[1] "Baccalaureate Origins of Doctoral Recipients", 8th Ed., Office of Planning and Institutional Research, Franklin and Marshall College, Lancaster, PA, January 1998.

During the 20 years from 1983 – 2002 an average of 13 students graduated yearly with a major in chemistry (ranging from a low of 9 to a high of 19). Of these students, approximately 25% pursued graduate work in chemistry or related disciplines at institutions such as Harvard, Illinois, Indiana, Purdue, Michigan, Notre Dame, Northwestern, Ohio State, and Wisconsin. Another 25% of chemistry majors have pursued studies in medical school or other health-related professions at institutions such as Harvard, Indiana, Ohio State, Cincinnati, John Hopkins, and Washington University. Approximately 25% of chemistry majors have taken jobs in the chemistry industry, working at firms such as ATEC Environmental, Eli Lilly and Company, Sieco, Inc., Pfizer Pharmaceuticals, and Great Lakes Chemical. Finally, the remaining 25% of chemistry majors pursued other careers and educational opportunities, including teaching and law school.

During the 2001-2002 academic year the Department of Chemistry expanded its program by introducing a new major in biochemistry. This program already is proving popular with our students, with 15 juniors currently in the first class of declared majors. When combined with the six declared junior chemistry majors, the total number of departmental majors for the class of 2004 is the largest in almost 40 years. Early indications suggest that we will continue to experience growth in this area.

Curricular Reform at DePauw. To place this proposal in context, it is necessary to briefly review recent changes to the department's curriculum, the general structure of which had been in place since 1968. During the Department's 1999 Self-Study, which was validated by the assessment of an external review committee, curricular reform emerged as an important goal. Several factors catalyzed our interest in curricular reform, including: a desire to counter the vertical nature of the traditional chemistry curriculum with its extensive, linear prerequisite structure; the necessity of meeting a new requirement from the American Chemical Society's Committee on Professional Training that all chemistry majors receive instruction in biochemistry; a desire to provide a better context for learning chemistry; and a need to adapt to perceived changes in the math and laboratory skills that our students bring with them from high school.

An important and key feature of our new curriculum is the elimination of the usual sequence of courses for first-year and sophomore students (one year each of General Chemistry and Organic Chemistry). In its place, we now offer four semester-long courses providing students with introductions to Organic Chemistry, Inorganic Chemistry, Biochemistry, and Physical and Analytical Chemistry.[2] Advantages of the new introductory core include the following:

[2] The specific course titles are, respectively, "Structure and Properties of Organic Molecules", "Structure and Properties of Inorganic Compounds", "Structure and Function of Biomolecules", and "Thermodynamics, Equilibria, and Kinetics"; an additional required course covering stoichiometry also is offered.

- provides greater flexibility in how students navigate the introductory core – students may begin with either the course in organic chemistry or inorganic chemistry, and courses in biochemistry, and physical and analytical chemistry can be taken in the second, third, or fourth semester depending on a student's needs or interests;
- introduces biochemistry as a required course for all chemistry majors;
- focuses each course within the context of a specific sub-discipline of chemistry;
- allows students, if they so choose, to postpone the more mathematically challenging material to the fourth semester.

Although several institutions have abandoned General Chemistry (most notably the "organic-first" curricula at The University of Michigan[3] and Juniata College[4]), we know of no other institution with an introductory core similar to ours.

In addition to the introductory core, students majoring in chemistry must complete advanced coursework in three areas, each of which includes a significant laboratory experience emphasizing individual or group projects. These areas are Chemical Reactivity, Theoretical and Computational Chemistry, and Chemical Analysis. Chemistry majors also may take advanced coursework in biochemistry as an elective.

All members of the Department of Chemistry are involved in implementing our new curriculum through a cyclical process of designing, teaching, assessing, and revising courses in their areas of expertise. Faculty members used the summer of 2001 to prepare materials for several of these new courses and taught them for the first time during the 2001-2002 academic year. Assessment of and revisions to these courses are ongoing.

The Importance of Laboratory in Our Curricular Reform. One motivation for our curricular reform is a perceived decline in the laboratory skills and attitudes toward experimental work that our students bring with them from high school. Although many students enter DePauw with strong backgrounds in laboratory work, we increasingly find that a significant percentage of our students come from high schools where such work is undervalued. Specifically, many high school chemistry labs meet only sporadically throughout the semester, often for only 45 – 90 minutes, and frequently do not provide students with opportunities to become engaged in doing experimental work. Instruction in basic laboratory techniques, data handling and data analysis often is inadequate. Of even greater concern is a decreasing awareness of the importance of experimentation in developing and testing scientific theories.

---

[3] Ege, S. E.; Coppola, B. P.; Lawton, R. G., *J. Chem. Educ.* **1997**, *74*, 74-83.
[4] Reingold, I. D. *J. Chem. Educ.* **2001**, *78*, 869-871.

It is not surprising, therefore, that many entering students are uncomfortable in the laboratory, viewing lab work as a chore to be completed, rather than a significant environment for learning.

Despite the best efforts of faculty members, many of our students continue to miss the important connections between the classroom and the lab. When this connection is not made early, it becomes that much more difficult to establish in subsequent years. This is unfortunate because students who do not appreciate the importance of laboratory work, those who view laboratory work as a chore, are less likely to participate in undergraduate research projects and less likely to pursue industrial or academic research careers. This is certainly the case at DePauw, where we have seen disappointing trends in our students' interest in pursuing research projects (58% of majors graduating between 1989 and 1993 participated in undergraduate research vs. 44% of majors graduating between 1994 and 1998) and in our students' interest in attending graduate school (34% of majors graduating between 1989 and 1993 attended graduate school vs. 19% of majors graduating between 1994 and 1998).

Given this decreasing appreciation for the relevance of lab work, there is a clear need to develop laboratory courses that provide instruction in both basic laboratory techniques and the process by which chemists develop new knowledge. An important part of our curricular redesign, therefore, is a commitment to making more explicit the connections between class and lab in all our courses and to making the laboratory a more meaningful place for learning by emphasizing cooperative problem-based learning. There is a growing body of literature suggesting that shifting the laboratory curriculum from a reliance on "cookbook" experiments to a more student-centered, problem-based laboratory can help create a more effective learning environment.[5] The effectiveness of cooperative learning in chemistry is well documented,[6] with benefits including improvements in reasoning and critical thinking skills, the ability to use prior experiences to solve new problems, and a more positive attitude toward the subject.

Detailed Description of Proposed Project. The central feature of this project is to make the link between class and lab more explicit by using a portion of most class periods for a group discussion on how to experimentally measure or test a concept introduced during class. Throughout this process, students will be encouraged to consider relevant issues such as experimental design, calibration, and the need to control variables. Students also will be asked to consider what the experiment's data will look like, and how it should be processed and analyzed. A trial experiment will be carried out in class using the same equipment and instrumentation available in lab, providing data that students can analyze

---

[5] (a) "From Analysis to Action: Report of A Convocation", National Academy Press: Washington, D.C., 1996. (b) *Student-Active Science: Models of Innovation in College Science Teaching*, McNeal, A. P.; D'Avanzo, C. D., Eds.; Saunders: Fort Worth, 1997.

[6] Wenzel, T. J. *Anal. Chem.* **2000**, *72*, 293A-296A.

immediately during class, or as an out-of-class assignment. Because they will already have participated in designing relevant experiments and considering appropriate data analysis strategies during class time, students can be challenged to design and carry out more investigative experiments during laboratory sessions. Finally, the link between class and lab will be brought full circle when students bring their data to class where it can stimulate further discussion. This project is a natural extension of the "discovery"[7] and "guided-inquiry"[8] approaches successfully implemented elsewhere.

To implement this project in the lab we plan to purchase eight suites of computer-interfaced instrumentation. With enrollments limited to 24 students per section, each instrumentation suite will serve a team of three students. Each suite will consist of: a Labworks II-100 data acquisition system with probes for measuring pH, temperature, and conductivity; an Ocean Optics Chem 2000 USB-Vis plug-and-play visible diode-array spectrometer; and a Dell laptop computer with wireless network access. Because the instrumentation suites are compact, they are easily moved between the laboratory and the classroom. Data collected in class or lab can be saved to a network account where it can be accessed almost anywhere on campus, including other academic buildings and the residence halls.

The principal focus for this project is our new introductory course in physical chemistry and analytical chemistry – Chem 260:Thermodynamics, Equilibria, and Kinetics. This course is required of all students majoring in chemistry and biochemistry, and for most students planning future studies in the health sciences. We anticipate, therefore, an annual enrollment of 48 to 72 students in 2 to 3 sections.

Although the topics covered in Chem 260 are those at the core of a traditional second-semester course in General Chemistry, we plan to approach them in a more rigorous way and to place them in a chemical context that has greater meaning for our students. Compared to a traditional second-semester course in General Chemistry, students in Chem 260 will, on average, have completed more than a single laboratory course in chemistry. Furthermore, students in Chem 260 will, on average, have completed more coursework in physics and Calculus than students in a more traditional curriculum. Given this different student profile, we believe that our students will be better prepared for and more receptive to an integrated laboratory experience that emphasizes the connections between class and lab.

An example of how this project will help us better integrate class and lab occurs early in the semester when the Fe^{3+}-catalyzed decomposition of H_2O_2 is used to introduce enthalpy. After observing a demonstration of the reaction in class, students will note that the reaction is exothermic and will speculate on the role that Fe^{3+} plays in the decomposition of H_2O_2. Because kinetics is not

---

[7] Ricci, R. W.; Ditzler, M. A. *J. Chem. Educ.* **1991**, *68*, 228-231.
[8] Farrell, J. J.; Moog, R. S.; Spencer, J. N. *J. Chem. Educ.* **1999**, *76*, 570-574.

discussed until later in the semester, the catalytic role of Fe^{3+} may or may not occur to the students. The discussion that follows will center on how to experimentally determine the amount of heat released during the reaction. As the concept of calorimetry emerges from this discussion, an experimental apparatus will be constructed and an experiment carried out with the data collected and displayed in real-time. The class will then discuss possible errors, including the loss of heat to the calorimeter, and how to correct for these sources of error. All data collected during class will be available through the course's network account, so that students can reexamine it outside of class.

The link between class and lab is reinforced in the laboratory when students will be asked to design and carry out experiments to determine how the reaction's enthalpy depends on the amounts of H_2O_2 and Fe^{3+} used in the reaction. Finally, to complete the cycle, data collected by students will be brought into the classroom where it will stimulate a discussion of the catalytic role of Fe^{3+}. A similar cycle will be used throughout the semester as students consider, for example, how to experimentally determine the equilibrium constant for an acid-base indicator or the rate law for the bleaching of an organic dye. Data collected in lab will stimulate discussions in class on topics such as the effect of ionic strength on an equilibrium constant's value or how to determine a plausible mechanism for a chemical reaction.

Available Resources and Expertise. Three important internal resources are available to help ensure the success of this project. First, the department's physical space is undergoing extensive renovations as part of a comprehensive $35,000,000 expansion and renovation of the Julian Science and Mathematics Center. The classroom and laboratory for this course have been designed to facilitate group work and will be connected to the University's campus-wide computer network through a wireless hub. Second, DePauw University's strong Faculty Development Program will ensure that faculty members teaching this course will have the time to implement and assess the project through a combination of summer stipends and/or released time during the academic year. Finally, with support from a recent $20,000,000 grant from the Lilly Endowment, DePauw is building a national model for the integration of information technology within a liberal arts curriculum. As part of this program, DePauw University is committed to the comprehensive preparation of its students in the use of information technology, to improving accessibility to the University's network throughout campus, and to maintaining the necessary hardware and software resources.

Faculty members in the Department of Chemistry, including the PI, have significant experience with developing and implementing courses emphasizing innovative learning strategies. Students in our introductory course in biochemistry, for instance, use specially designed 3-dimensional physical models in class and lab to explore the relationship between a biomolecule's structure and its function. These models, along with a computer visualization program, help students understand the nature of protein structures, from secondary features (alpha-helices and beta-strands) to the overall folding of complex proteins. Students in our upper-level physical chemistry, analytical chemistry, and biochemistry laboratory courses work in small teams to carry out multi-week or semester-long projects. When available resources are insufficient, faculty members have actively sought external funding for necessary equipment and materials. Recent external grants have played an important part in transforming the curricula in analytical chemistry[9] and biochemistry .[10]

Assessment of Proposed Project. Assessment of this project will be included in the Department's ongoing comprehensive assessment of its new curriculum, a study coordinated by Dr. Bridget Gourley (Associate Professor of Chemistry), who has released time this academic year and the following academic year for this purpose. In addition to a careful reading of end-of-the-semester course evaluations for evidence of changes in our students' attitude toward laboratory, we also are developing post-semester surveys to assess our students' attitude toward and perception of our curriculum. Our expectation is that these new class and laboratory experiences will change our students' perspective about the value and utility of laboratory work.

The performance of students in our advanced labs will be examined to determine the extent to which students are better prepared for increasingly more independent laboratory work. Of particular interest is the sophistication of the independent projects they choose, the quality of their experimental designs, and their performance on these projects. In addition, faculty members will be interviewed about their perception of the relative preparedness of students for independent laboratory work.

Finally, one clear measure of the success of our curricular reform, of which this project is a significant part, will be an increase in the percentage of chemistry and biochemistry majors choosing to participate in research during the academic year or the summer, and the percentage of chemistry and biochemistry majors pursuing graduate work.

Dissemination of Proposed Project. Results of this project will be shared with the broader community through presentations at regional and national professional meetings, and through articles submitted to chemical education and science education journals. We expect to be particularly vigorous in this effort because this project is part of a much broader and novel curricular change that we believe to be of

---

[9] "Teaching Students to Think as Analytical Chemists by Developing a Laboratory Course in Method Development", NSF-CCLI-A&I Grant #0125835 awarded in 2001.

[10] "Molecular Structure and Function in an Undergraduate Curriculum", NSF-CCLI-EMD Grant #9952693 awarded in 1999; "Molecular Structure and Function in an Undergraduate Curriculum" NSF-CCLI-EMD Grant #008869 awarded in 2000; "Investigating Biochemical Structure/Function Relationships in an Undergraduate Curriculum", NSF-CCLI-A&I Grant #9950343 awarded in 1999.

considerable interest to the chemical education community. Indeed, one such presentation was made at the June 2002 meeting of the Council of Undergraduate Research.[11]

Dissemination of the project will also include sharing information and ideas with other regional colleges and universities. For example, we plan to take advantage of DePauw University's association with the Midwest Instructional Technology Center (MITC) to propose the formation of an interest group of chemistry faculty from the 26 schools in the Great Lakes Colleges Association (GLCA) and the Associated Colleges of the Midwest (ACM) to discuss the use of information technology in chemical education.

Finally, dissemination of the project will involve increasing the awareness of middle school and high school teachers about the use of relatively low-cost, computer-interfaced instrumentation. For example, middle-school teachers will see the results of projects completed by their students during the DePauw Institute for Girls in Science, our annual summer science camp for 8th grade girls. Students in our Chemistry Club, selected in 2001 as one of 20 outstanding American Chemical Society student affiliate chapters, regularly conduct outreach programs at local schools; where appropriate, such activities will include equipment obtained through this grant. Finally, we will take advantage of the Advisory Council for Science Education, created by DePauw University's Education Department in 1999, which promotes science education in five local high schools and their associated middle schools. The existing network can be utilized, for example, to develop workshops for high school or middle school faculty members that take advantage of the instrumentation suites requested in this proposal. Faculty members completing a workshop could then borrow instrumentation suites through a loan program.

Timeline for Implementing the Project. Upon notification of an award, we will purchase the requested equipment during the Spring 2003 semester. During the summer of 2003, the instrumentation suites will be set-up and tested, and class and lab materials for Chem 260: Thermodynamics, Equilibria, and Kinetics will be developed. DePauw University will support these activities through summer stipends for the PI and one student. The course will be taught during the Fall 2003 and Spring 2004 semesters, and will involve both the PI and one or more additional faculty members. To assist other faculty in incorporating the instrumentation suites into their teaching, DePauw University will provide the PI with released time equivalent to one course during the 03/04 academic year. Finally, an initial assessment of the course will take place during the summer of 2004, with appropriate revisions made to course materials. DePauw University will provide the PI with a summer stipend to complete this work.

[11] Presentation by Bridget Gourley and Hilary Eppley at a workshop on "Innovative Chemistry Curricula that Support Undergraduate Research", Council of Undergraduate Research Ninth National Conference, June 2002.

Resume of David Harvey (Principle Investigator)

Professional Preparation

Knox College	Chemistry	AB	1978
University of North Carolina-Chapel Hill	Chemistry	Ph.D.	1982

Academic/Professional Appointments

1986 - present	Department of Chemistry, DePauw University (promoted to Full Professor in 2000)
1985 - 1986	Laboratory Manager and Director, Stockton Environmental Lab
1982 - 1986	Department of Chemistry, Stockton State College (tenure-track)

Selected Publications in Area of Chemical Education (* indicates a student co-author)

- Harvey, D. T. "External Standards vs. Standard Additions: Selecting and Validating a Method of Standardizations", *J. Chem. Educ.*, **2002**, *79*, 613-615.

- Harvey, D. T. "Two Experiments Illustrating the Importance of Sampling in Quantitative Analysis", *J. Chem. Educ.*, **2002**, *79*, 360-363.

- Harvey, D. T. *Modern Analytical Chemistry*, 1st Ed., McGraw-Hill: Dubuque, IA, 2000.

- Harvey, D. T. "Statistical Analysis of Acid/Base Indicators - A First Experiment for the Quantitative Analysis Laboratory:, *J. Chem. Educ.* **1991**, *68*, 329-331.

- Harvey, D. T., Byerly, S.*, Bowman, A.*, Tomlin, J.* "Optimization of HPLC and GC Separations Using Response Surfaces: Three Experiments for the Instrumental Analysis Laboratory", *J. Chem. Educ.* **1991**, *68*, 162-168.

- Harvey, D. T., Bowman, A.* "Factor Analysis of Multicomponent Samples", *J. Chem. Educ.* **1990**, *67*, 470-472.

Significant Grants in Area of Chemical Education

- 1985 New Jersey Technology/Engineering Education Grant; "Integrating Modern Instrumentation into the Chemistry Curriculum", $37,000 (co-PI).

- 1986 NSF-CSIP Grant; "Integrating FT-IR into the Chemistry Curriculum", $29,500 (co-PI).

- 1987 NSF-CSIP Grant; "Modernizing the Instrumental Analysis Laboratory", $21,995.

- 1995 NSF-ILI Grant; "Separations and Structures Throughout the Chemistry Curriculum", $27,816 (co-PI).

- 2001 NSF-CCLI Adaptation and Implementation Grant; "Teaching Students to Think as Analytical Chemists by Developing a Laboratory Course in Method Development", $97,680.

Proposed Budget

Item	Description	Unit Cost	No. Units	Total Cost	DePauw Match[a]	Dreyfus Request
1	LabworksII-100 Interface	$417	8	$3,336		
	AC-controller	$70	8	$560		
	Conductivity probe	$90	8	$720		
	pH probe	$78	8	$624		
	Temperature probe	$30	8	$240		
	Total Cost for Item 1			$5,480	$1,826.67	$3,653.33
2	Ocean Optics Chem2000-USB-Vis spectrometer	$2,999	8	$23,992		
	Discount for trade-in of old spectrometers	$1,500	8	($12,000)		
	Total Cost for Item 2			$11,992	$3,997.33	$7,994.67
3	Dell Latitude Laptop with internal wireless capabilities	$1,687	8	$13,496	$4,498.67	$8,997.33
4	Estimated Shipping for items 1 – 3			$500	$166.67	$333.33
5	Site preparation (wireless access hubs for class and lab)	$750	2	$1,500	$1,500	
6	Summer stipends for PI	$2,500	2	$5,000	$5,000	
7	Summer stipend for student	$3,500	1	$3,500	$3,500	
8	Academic year release time for PI (one course)	$8,500	1	$8,500	$8,500	
	Total Cost of Project			$49,968	$28,989.34 (58.0%)	$20,978.66 (42.0%)

[a] This match represents one-third of all equipment-related expenses and 100% of all expenses associated with site preparation and faculty development.

Equipment Description. The computer interface chosen for this project is the LabworksII-100 from SCI Technologies. It was selected over other interfaces because of its low price and its student-friendly software. The AC-controller allows the LabworksII-100 to control power to other devices, making it possible to create, for example, a constant-temperature bath using a stirring hotplate and a temperature probe. The conductivity, pH, and temperature probe will be useful for a variety of experimental systems, such as calorimetry and titrimetry, common to introductory courses in physical chemistry and analytical chemistry. The Ocean Optics spectrometer is a low-cost, self-contained plug-and-play diode array spectrometer with a usable wavelength range of 400-850 nm, which will be particularly useful for kinetics experiments and for the study of equilibria involving acid-base indicators. Both the Ocean Optics spectrometer and the LabworksII-100 interface are compatible with standard PC laptops, such as the Dell Latitude chosen for this project.