Enhancing Student Understanding of Environmental Systems with Ion Chromatography

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Project Narrative

A. Project Overview

Funds are sought to purchase an automated DX-320 Ion Chromatograph (IC) to facilitate students' understanding of environmental systems with applied, inquiry-based laboratory experiences. Outlined in this proposal are the specific ways that use of the IC will be incorporated into new courses for a new Environmental Geoscience Major as well as existing courses in Geology, Chemistry, and Biology. The instrument will be a valuable resource that will increase the number and types of teaching laboratory and research projects available to students, thus broadening the impact and scope of DePauw's Science Programs.

Institutional Overview. DePauw University is a private, selective, co-educational undergraduate liberal arts university serving approximately 2300 students with 223 full time teaching faculty members. DePauw's students are from diverse backgrounds, hailing from almost every region of he United States and 16 foreign countries, and of high academic achievement, with a median composite SAT of 1210 and a median high school class rank in the 91st percentile for this year's entering class. 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. The Posse cohorts have helped the University reach its overall goals of 14% from under-represented ethnic groups. With its Horizon Scholarship Program, DePauw has increased the number of Indiana high school students who are the first in their families to attend college. DePauw's Bonner Scholar Program recruits students devoted to community service as part of their work outside of class. The Holton Memorial Scholarships, established with a $128 million endowment four years ago, provide added support for students with strong academic credentials who are committed to lives of leadership and service. DePauw has an active Women in Science program that creates a "mutually supportive environment in which women science students can achieve their full potential."[1] Activities sponsored by the group, which include monthly meetings, seminar series, reunions, and outreach, are primarily driven by

student interests, and provide significant opportunities for student leadership and responsibility. Finally, through one of its four honors programs, entitled Science Research Fellows, DePauw promotes the early engagement of students in all areas of science and offers extensive independent research opportunities as early as the summer after the first year of enrollment. In 1997, Time Magazine and The Princeton Review recognized DePauw for its Horizon Program, naming DePauw runner-up for "College of the Year." US News & World Report ranks DePauw as the 39th best national liberal arts college[2].

Departmental Overview DePauw's Department of Geology and Geography has a strong tradition of excellence in traditional Earth Science Education and has served the needs of the University by teaching between 400 and 500 students per year in introductory and advanced courses. Recently, DePauw responded to the national need for well-trained scientists to solve geological and environmental problems by approving a new Environmental Geoscience Major as part of the existing Geology curriculum (see Appendix A). To support this major, the University expanded the size of the Geology faculty by hiring a tenure-track Environmental Geologist, the Project Director of this grant proposal. In addition, DePauw is completing a $35 - 40 million renovation and a 100,000 sq. ft. expansion project for the Percy L. Julian Math and Science Center, which includes new laboratory spaces for environmental geoscience (geochemistry, hydrology) classes and for student research in these fields.

B. Objective and Goals

The broad, pedagogical objective of this project is to enhance student learning of environmental systems by introducing modern, sophisticated instrumentation into discovery-based exercises at all levels of the curriculum. NSF-supported projects at Coe College[3] and Calvin College[4,5] have demonstrated the effectiveness of ion chromatography as a tool to enhance learning in chemistry and biology classes. In addition, researchers at Bates College[6,7], SUNY at Cortland[8], and Amherst[9] have also used NSF funds to implement inquiry-based laboratories involving ion chromatography into upper-level geochemistry and hydrology courses.

curriculum supports and expands these efforts, especially with the ion chromatography component.

Goal 2) To train environmental geoscience majors in the use of standard analytical instrumentation. Solving complex, environmental problems requires scientists who understand earth processes. However, a recent report from the American Geological Institute indicates a decrease in the number of students enrolled in geology programs[15]. In addition, the report shows that many current professional Earth Scientists are nearing the age of retirement. Well-trained scientists are needed to sustain progress in science and technology[16]. Therefore, it is essential that analytical skills be taught in undergraduate science classes, especially geology. Students' knowledge of standard methods of sampling and analysis will make then more attractive to employers and graduate schools.

Goal 3) To develop critical thinking skills about instrumentation and data analysis at all levels of the curriculum. Quantitative reasoning ability is essential for a good scientist. Unfortunately, some students consider instruments such as ion chromatographs to be "black boxes." By collecting and analyzing samples themselves, students will better understand how data is generated, what the quality of data is, and what it means. This approach can also introduce students to scientific ethics while developing their critical thinking skills.

Goal 4) To increase the diversity of research projects available to students. The sciences at DePauw are instrumentally well equipped (see *Existing Equipment* section below), with some noticeable gaps. An IC will nicely complement the existing instrumentation and broaden the scope and depth of research opportunities available to students.

Goal 5) To support teaching and student research projects in other science departments. DePauw is a relatively small school, and to remain efficient, instrumental resources in one department must be shared with students and faculty members in other departments. In addition, students and faculty members in several departments will both benefit from the many opportunities for interdisciplinary research using shared instrumentation.

C. Project Description

As noted by Robert Gavin, "good science courses … teach about observation, experiment design, and interpretation of data[10]." The goals of this project, which emphasize the approach suggested by Gavin, will be met by introducing ion chromatography into the curriculum in three areas. The majority of the project (***goals 1-4***) will be focused on redesigning and developing new courses for the new Environmental Geoscience Major. The Ion Chromatograph will be housed in the new Environmental Geology laboratory and primarily used by students in Environmental Geology, Geochemistry, Hydrology, and Independent Study classes. In addition, the IC will support other science classes (Ecology, Analytical Chemistry, Mineralogy, the Science Research Fellows Seminar) and student research projects, thus meeting ***goal 5***. The description of this project is broken into the three areas specifically targeted: 1) the Environmental Geoscience curriculum; 2) the Geology Curriculum; and 3) other courses in the Science Curriculum.

Impact Area 1: The Environmental Geology Curriculum. The required courses for the Environmental Geoscience Major are listed in Appendix A. Students are required to take a number of environmentally-oriented courses in the Department of Geology and Geography and choose two other areas of concentration, depending on their interests. The combination of courses in geology and in two environmentally-related fields of study provides both the depth and breadth of training that is required for environmental scientists (***goal 2***). Included in the required courses are three classes primarily targeted by this project: Environmental Geology, Geochemistry, and Hydrology. Descriptions of the activities that will be adapted and implemented and a discussion of how those activities relate to the project goals are included for each of these classes.

In addition to the students served in the classes listed, exceptional students may conduct independent research projects for course credit. The number of opportunities and depth of the research that can be conducted will increase if the department acquires an ion chromatograph.

As this specifically relates to ***goal 3***, a description of *potential* student research projects is provided even though each specific thesis topic will be generated by the student.

Environmental Geology

This new introductory, laboratory class is open to all students and fulfills part of the general education science requirement at DePauw. As described in the schedule of classes, Environmental Geology "focuses on the environmental impact of the extraction and use of natural resources, and interactions between the lithosphere, hydrosphere, atmosphere, and biosphere as they pertain to environmental issues."[17] Traditionally Geology lab classes have been very popular; it is not uncommon for as many as four times the number of students to request the class as there are openings, despite the fact that the department offers several sections of introductory classes a year. Based on students' interest in environmental studies, it is expected that the demand for Environmental Geology will be high as well. Therefore, this course will serve ***goal 1*** by introducing environmental concepts and methods of analysis to students who will not go on to major in science.

The students will be introduced to ion chromatography through multi-week, discovery-based laboratory experiments, adapted from the approach Dr. Sinniah at Calvin College implemented for his Introductory Chemistry Course[4,5]. The goals of this project are to teach students about the chemistry of water, how data are collected, and why water quality issues are important. The project will use some of the same features as the one developed for chemistry, including an introduction to the technique and the use of natural samples, but will be changed to suit the nature of a geology course. Rather than collected local samples, which will tend to show similar geochemical signatures based on the fairly homogeneous nature of local rocks, students will be asked to collect samples when they travel over the mid-semester break.

The project will be conducted over a five-week period after approximately six weeks of the course. The first week of the project will be spent discussing how ion chromatography works and developing a method for the analysis of their samples. Data will be collected during the second week of the project and shared with the class after the third week. At this time, the

students will notice that the water samples have different chemical signatures. Using the whole data set, they will apply statistical tests to sort and group the data. In week four of the project the students in the class will be asked to discuss possible explanations for the differences between the data and decide how they want to classify their data. A formal lab report, including an introduction to the problem, methods, results, discussion/interpretation, and conclusions, will be due at the start of class in the fifth week. In class that week, each person will discuss the source of the contributed water sample, how it differed from the other samples, and what influenced its chemical composition.

GEOL 306 Geochemistry

This advanced geology course emphasizes the chemical reactions between water-air-rock/mineral, and how these interactions influence and, in a dynamic system, change the distribution of the elements on earth. Geochemistry is by its very nature an interdisciplinary course in which students must learn chemical methods of analysis and geologic controls on natural waters. Ion chromatography is an ideal tool to analyze aqueous samples and has been successfully incorporated into many geochemical classes with NSF support[3,8,9,13]. Implementing the IC into a class project will teach students how geochemists collect and analyze water samples to determine their chemical constituents (***goal 2***) and how to interpret the geochemical significance of the samples (***goal 3***).

The proposed project to be implemented for DePauw's Geochemistry class was developed by Dr. Carl Kirby as a student senior thesis research project at Bucknell University. The student researcher monitored the change in stream chemistry as it flowed from a siliciclastic environment into a carbonate environment[18]. This project will be adapted from an independent project to one that is appropriate for a class with 6-12 students.

During the semester-long, field-based project, students will collect samples several times during the semester and at regular intervals along West Little Sugar Creek near Terra Haute, IN, as it flows from its headwaters, through farmland, past a coal refuse pile, through more farmland, and into an urban environment. The stream is approximately a one-hour drive from campus, and

samples can be collected during the regularly scheduled laboratory time period. Samples will be analyzed for pH, alkalinity, dissolved oxygen, major cations and anions, and some trace metals (iron, aluminum, copper, and zinc). Students will be taught both standard sampling techniques in the field and standard analytical techniques in the laboratory. After initial teaching trips, the work will be divided such that teams of students will be responsible for collecting, analyzing, and contributing their data to the total data set that the whole class will use. The samples and data sets will be used to teach several standard geochemical principles, including charge balance, elemental load, speciation, complex-formation, dilution effects, and temperature effects. In their final report, the students will be asked to plot the data and analyze the trends based on discharge, land use, and geology.

One advantage of this type of project is that students learn not only the techniques used in geochemistry, but also the approach. They will benefit by working together on an open-ended problem that will be different every year. Including this project into a class has the advantage that the students have peer-support, which makes for a more enjoyable experience. A subsequent benefit of this research is that it will provide valuable, long-term data on local fluvial systems. The results will be made available to the scientific community through student presentations at meetings, web sites, and publication in peer-reviewed journals. Students will gain the satisfaction of contributing to ongoing, long-term research.

GEOL 316 Applied Hydrology

Applied hydrology investigates the mechanisms by which water moves underground, which is a crucial component to many environmental problems. However, for many undergraduate students, hydrogeologic concepts are abstract and confusing. Student learning of these principles is enhanced with hands on projects like those developed at the Water Resource Center at the University of Wisconsin[19,20,21,22,23]. DePauw has recently installed a well field in an unconfined aquifer to help students understand the concepts of the saturated zone and movement of the water table. The addition of an ion chromatograph component to existing labs will increase the use of the well fields (**goal 4**) through the incorporation of sophisticated tracer

experiments, which are commonly used by professional hydrologists. Students will be able to see how quickly water moves in the subsurface compared with flow rates in local rivers and streams.

GEOL 492 Readings and Research

Exceptional students are invited to do independent research projects that are developed by each student in consultation with an advisor. The benefits of independent research are well documented[10,11,12], which is why it is encouraged at DePauw. Offering students this course in the Environmental Geoscience Curriculum will train students how to conduct environmental research (***goal 2***) and further develop their critical thinking abilities (***goal 3***). By acquiring an ion chromatograph, the department will be able to increase the number and type of projects that are available (***goal 4***). For example, students may be interested in determining the impact of acid mine drainage tailings piles on the ecosystem and water quality of streams in Southern Indiana. For another project, a student might wish to examine the urban runoff in Greencastle as a function of precipitation rates and volumes. Students may also choose to develop a laboratory project that would require chemical analyses of water. For example, all kinetic experiments require the monitoring the production or consumption of a chemical constituent as the rate variable. All of these projects will provide important information to the scientific community and/or local regulatory boards. In addition, these types of research experiences will help prepare students for what they will encounter in graduate school or as an environmental professional.

Impact Area 2: The Geology Curriculum. In addition to an Environmental Geoscience Major, the Geology and Geography department offers a major in Geology. The above courses, which are part of the core requirements for the Environmental Geology Major, are also available to students wishing to major in traditional Geology. Therefore, these students will be exposed to environmental sampling and analyses. In addition, the department is interested in integrating ion chromatography into other geology classes, including the independent research courses, which

address ***goals 2, 3, and 4***. The following narratives, written by other members of the Geology Department, include specific plans to integrate the IC into existing courses.

GEOL 301 Mineralogy (J. Mills)

An ion chromatograph analytical facility in the Department of Geology and Geography would significantly enrich the laboratory exercises in the department's 300-level Mineralogy course. Currently, the only mineral analysis facility in the department is a General Electric 700D x-ray diffraction machine. The x-ray machine is used routinely in Mineralogy for laboratory exercises. The addition of an ion chromatograph to the department would considerably strengthen the laboratory component of the course (**goals 2 and 3**). For example, chemical analysis of mineral species associated with acid mine drainage areas in central and southern Indiana to determine the effect of trace metals on minerals' crystallographic structure could be easily added as either a laboratory exercise or a semester-long research project.

Science Research Fellows (J. Mills)

An IC would also contribute to semester-long student research projects in the Science Research Fellows Honor Program. Science Honors students are required to complete two semester-long research projects during their first year. For the geology project, the students have been working in recent years on a multi-year study of the local well field for the town of Greencastle, IN and associated unconfined aquifer. Studies of the well field and aquifer thus far have been limited to determination of physical hydrogeologic data. The addition of an ion chromatograph in the department would enable students working on this project to collect short- and long-term data on the aquifer geochemical properties (***goal 4***).

GEOL 492 Readings and Research (F. Soster)

Because the proposed Ion Chromatograph can be used to analyze cations and anions in aqueous solutions, I would anticipate having students use it in their research projects with me on the geochemistry of modern lake sediments. I envision summer research projects where students would learn to use the instrument and then collect cores from Indiana lakes to look at the historical trends in various elements associated with pollutant materials in the environment (***goal***

2). Coupling data acquired from ion chromatography with radionuclide data acquired from our existing alpha and gamma spectrometers will allow students to examine the historical trends in anthropogenic inputs to Indiana lakes (***goals 3 and 4***).

Impact Area 3: Other Courses in the Science Curriculum. To specifically address ***goal 5***, the Project Director approached members of the Chemistry and Biology departments to discuss uses of an ion chromatograph to support their classes and student research projects. Included below are discussions of how the instruments would be used by other departments.

The Chemistry Department (D. Harvey)

Students in Chem 450 (Method Development), an advanced lab in analytical chemistry required of all chemistry majors, work on semester-long projects in which small teams of students design, optimize, and validate an analytical method for one or more analytes in a complex, real matrix. At present the lab is built around atomic absorption spectrometry, HPLC, GC-MS (all fully automated), and microwave digestion. The availability of the automated ion-chromatograph requested in this proposal will substantially increase the range of analytes, particularly anions, that students can study. For example, students will use this instrument to develop methods for determining relevant anions and cations in complex matrices, such as simulated industrial waste streams and simulated gastric juice.

The Biology Department (J. Benedix)

There are multiple scenarios in which the Biology Department at DePauw University would find an ion chromatograph useful as a piece of research equipment. The department is currently developing an Environmental Biology major that would complement the current Environmental Geosciences major in the Geology Department. As part of this major students would participate in research that would very likely include water quality assessment, as we are planning to use the multiple streams and ponds on University-owned properties as study sites. We plan to monitor these streams and ponds, taking long-term data on both their biotic and abiotic characteristics. Thus the ability to accurately measure ion and transition metal

concentrations will be crucial. In addition, Biology Department faculty and students could use the ion chromatograph for laboratory work. For example, it could be used to monitor water quality in tanks where study animals (e.g. tadpoles, fish, crustaceans) are being maintained or in experimental set-ups designed to measure the influence of changing environmental conditions on study organisms. It could also be used to measure ion exchange by aquatic organisms. All of these applications of the IC could occur as part of independent research projects by faculty and students as well as for research conducted in the laboratory portions of a biology courses.

Timeline of the proposed project The materials discussed in this proposal will be developed for new and existing courses during the next three years. During the first year, the instrument will be acquired, installed, and tested during the summer and fall of 2003. It will first be used with Applied Hydrology, which will be taught in the spring of 2004. Over the next summer, Environmental Geoscience majors who were trained on the instrument during the hydrology course will be encouraged to conduct independent research. Experiments using the instrument will be added into Environmental Geology the next fall and into Geochemistry in the following spring (2005). Supervised student research projects will be ongoing during the second and third year of the project. During the final year of the project, materials and exercises will be modified and redesigned based on the results of the assessment plan. At this time, the results of the project will be complied and presented to the greater scientific and educational community.

Equipment requested The Council on Undergraduate Research recognizes that "modern scientific inquiry is dependent on an adequate collection of research-grade instrumentation. Not only must specialized equipment for individual projects be obtained, but also the routine instrumentation must be of research quality."[24] Based on the rationale promoted by CUR, the instrument requested for this project is a DX-320 ion chromatography equipped with an automated sampler. An ion chromatograph was selected because it is a standard instrument used in water quality analysis and because it will mesh well with existing equipment and expand the possible research projects available to students. The DX-320 was chosen because it can be used

to analyze anions, cations, and metals in a variety of matrices and thus will meet the needs of a variety of projects. In addition, this model contains high quality components that yield high precision results. Yet, the instrument is compact, rugged, and easy to use. The instrument is fully automated for routine sample analysis but contains manual overrides that can be used to teach students the methods of ion chromatography. The final factor that contributed to this choice of instrument is that Dionex, the manufacturer of the instrument, provides free training for users of their products. While this is not necessary for the Project Director, it may be useful for students and other faculty members who use the machine.

Existing equipment The Department of Geology and Geography is equipped with two new Environmental Geology Laboratories, one for class use and one for student research use, and is well suited to support this project. The labs have standard features (hood, gas lines, DI line, refrigerator, etc.) and instruments and equipment (pH meters, conductivity meters, spectrometers, glassware, constant temperature bath, hot plate, chemicals). The Chemistry and Biology departments also have instruments, equipment, and lab space to support the teaching and student research projects discussed.

Implementation and maintenance All costs associated with site preparation and instrument maintenance are provided for in the department's and university's annual budgets. (Please see Letter of Support from the Vice President of Academic Affairs).

D. Experience and Capability of the Project Director

The Project Director for this proposal has been involved in environmental research for over nine years and is extremely experienced with ion chromatography. She has had formal graduate training in geochemical analysis and has used several ion chromatographs in a variety of applications at four different institutions. In addition, the Project Director is a dedicated teacher. She spent considerable time developing new laboratory exercises as graduate teaching assistant. As a research assistant, she mentored undergraduate students and helped them develop research projects and theses. Although new to DePauw, the Project Director has taken active

steps to excel in her new environment, including participation in a NSF-funded workshop for Early Career Faculty in the Geosciences[25]. She is committed to excellence in undergraduate education and is a member of the National Association of Geoscience Teachers and the Council on Undergraduate Research.

E. Evaluation

The effectiveness of the IC and the projects discussed in this proposal on the pedagogical objective of this proposal (i.e. increasing student understanding of environmental systems) will be determined using quantitative and qualitative assessment techniques. The Project Director is working with Dr. Karin Ahlm, an in-house expert of student learning assessment, and the Office of Institutional Research to develop entrance and exit surveys to determine the effectiveness of the proposed projects in the courses she teaches. Techniques and methods described by Angelo and Cross (1993)[26] will be used to determine the students' prior knowledge and misconceptions of water quality data and analysis before using the instrument. At the end of the course, students will be surveyed and interviewed to determine how the instrument and the projects impacted their understanding of water chemistry and geochemical processes.

During the next semester, before the instrument can be acquired, the Project Director will teach Geochemistry. This is an excellent opportunity to determine student understanding of water chemistry without the benefits of the applied, discovery-based research project. A course goal for Geochemistry is to integrate knowledge of chemical processes with geologic processes and to evaluate how they control water chemistry. The Project Director will incorporate assessment techniques from Angelo and Cross (1993)[26] and the EHR/NSF Evaluation Handbook (1992)[27] into the class during the next semester to establish how well students accomplish the goal without the an IC. It is hypothesized that course the goal will be enhanced by successful implementation (***goals 2, 3,*** *and* ***4***) of this project. The data collected over the next semester will provide a baseline of student learning to which assessment in subsequent semesters can be compared. It would, of course, be inappropriate to withhold the instrument and projects from

These types of projects are ideally suited for implementation at DePauw because of the small student-faculty ratio in all classes, especially at the junior and senior levels, the availability and ease of access to a number of different field sites (rural, industrial, agricultural, karst, coal drainage, etc), and the similarities between the demographics at DePauw and the other institutions which have piloted similar efforts.

Studies of pedagogical effectiveness have shown that sophisticated instrumentation is useful for enhancing student learning of complex material[10,11,12]. This is appropriate not only for the advanced classes targeted by the projects listed above, but also for introductory level classes. Recently, NSF has funded a project at University of North Carolina at Asheville (UNCA)[13] and at Calvin College[3] that uses ion chromatography at all levels of the chemistry curriculum. Specifically, they call for the use of IC in multi-week, discovery-based projects in an introductory (first-year) chemistry laboratory course. The project in this proposal will adapt the methods and instructional material developments in chemistry at UNCA and Calvin College for use at DePauw in introductory level classes in environmental and geological sciences.

This proposal outlines the implementation and adaptation of ion chromatography and discovery-based laboratory exercises into the environmental geoscience curriculum. Five goals define this project.

Goal 1) To improve non-science majors' understanding of environmental systems and to increase the science literacy of all students. DePauw is a liberal arts university and includes lab science courses as part of its general education graduation requirements. Many students enrolled in introductory level geology classes consider themselves "non-scientists" at best and "science phobic" at worst. The vast majority of these students do not major in a scientific discipline. Therefore, it is especially important for this group of students to be taught the value of science and good scientific procedures. As promoted by the Nation Research Council[14], the Geology and Geography Department has successfully taught the scientific method through a series of discovery-based laboratories, field trips, and active learning exercises. The new environmental

students in order to determine a baseline for the other courses. However, the baseline developed in the Geochemistry class can be adapted and used in other courses affected by this project.

The Project Directoror will also solicit verbal and written feedback from students relating to their understanding of the operation of the machine (***goal 2***) and significance and/or meaning of the data that were collected (***goal 3***) by users of the instrument. She will use these responses to revise exercises and training sessions for the instrument. In addition, the Project Director will collaborate with Professors of other courses to develop assessment techniques for their classes and projects to be assured that this instrument is enhancing students learning in other areas of the Sciences (***goal 5***).

Finally, the Project Director will monitor the experience of graduates from her classes as they enter graduate school or industry. The success of the individual beyond DePauw is the ultimate measure of the effectiveness of their learning in the Environmental Geoscience program.

F. Dissemination of Results

The materials and exercises developed during this project will be made available for global distribution through the Department of Geology and Geography Web Site[28]. As the pedagogy is developed and refined, the projects and results will be reported in appropriate scholarly journals such as the *Journal of Geoscience Education*. In addition, all students will present the findings of their research, either in class presentations or during DePauw's annual Science Poster Session. Exceptional students will be encouraged to present their results at regional or national meetings of the Geological Society of America or the Council on Undergraduate Research. When appropriate, the Project Director will publish the cumulative results of student project for the benefit of the greater scientific community in peer-reviewed journals (i.e. *Chemical Geology*, *Environmental Science & Technology*, *Applied Geochemistry, Hydrology Journals*).