6-2010

Improving Student Attitudes about Science by Integrating Research into the Introductory Chemistry Laboratory: Interdisciplinary Drinking Water Analysis

Dana Richter-Egger
University of Nebraska at Omaha, drichter-egger@unomaha.edu

James P. Hagan
University of Nebraska at Omaha

Fredric C. Laquer
University of Nebraska at Omaha, flaquer@unomaha.edu

Neal Grandgenett
University of Nebraska at Omaha, ngrandgenett@unomaha.edu

Robert Duncan Shuster
University of Nebraska at Omaha, rshuster@unomaha.edu

Recommended Citation

Richter-Egger, Dana; Hagan, James P.; Laquer, Fredric C.; Grandgenett, Neal; and Shuster, Robert Duncan, "Improving Student Attitudes about Science by Integrating Research into the Introductory Chemistry Laboratory: Interdisciplinary Drinking Water Analysis" (2010). *Teacher Education Faculty Publications*. 52.
https://digitalcommons.unomaha.edu/tedfacpub/52

Improving Student Attitudes about Science by Integrating Research into the Introductory Chemistry Laboratory: Interdisciplinary Drinking Water Analysis

Dana L. Richter-Egger,* James P. Hagen, and Frederic C. Laquer
Department of Chemistry, University of Nebraska at Omaha, Omaha, Nebraska 68182
**drichter-egger@unomaha.edu*

Neal F. Grandgenett
College of Education, University of Nebraska at Omaha, Omaha, Nebraska 68182

Robert D. Shuster
Department of Geography/Geology, University of Nebraska at Omaha, Omaha, Nebraska 68182

Students in introductory science courses, including chemistry, often gain little practical understanding of the nature of scientific careers, the application of science to their lives, or the interdisciplinary nature of science *(1)*. This knowledge is important because the majority of these students will never study science beyond these initial courses. Many of these undergraduates also exhibit a "science-phobic" attitude evident in their tendency to gravitate toward reputedly less-threatening courses and away from more rigorously quantitative science courses such as chemistry. Coursework that does not deepen student scientific understanding or challenge these students in their learning of science can perpetuate this fear by allowing students to further avoid rigorous science coursework. The need to confront these student attitudes and their related poor understanding of science is urgent and growing *(2)*.

We address these issues by integrating student research into the general chemistry curriculum: research that is relevant, interesting, and interdisciplinary. We examine an environmental topic, drinking water quality, as the first research project to integrate into the general chemistry laboratory and environmental geology lecture course. This project involves the design, use, and evaluation of early undergraduate, interdisciplinary research in chemistry that highlights its relevance, emphasizes its application to other sciences, and illustrates career opportunities in science. The primary objectives of this approach are to improve (i) student attitudes about science, (ii) student understanding of the nature of experimental science and the scientific method, and (iii) student perceptions of the application of science and the interdisciplinary nature of science. Additional objectives are to (iv) increase the number of chemistry and geology majors, (v) increase student independence, responsibility, and self-motivation, (vi) increase retention of students in introductory chemistry and environmental geology, and (vii) provide preservice education students with a sense of scientific investigation.

Instances of water analysis by undergraduates using ion chromatography *(3)* and capillary electrophoresis *(4, 5)* have been reported in this *Journal*, as has the use of advanced instrumentation to influence student attitudes and understanding *(6–8)*. The project described here expands upon the examples in the literature that illustrate improved scientific understanding *(9–11)* and science attitudes *(12–18)* resulting from collaborative learning *(12–15)* and interdisciplinary undergraduate student research *(13, 19, 20)*. Environmental concerns are especially useful in this context and can provide research topics that are directly relevant to students. Environmental concerns have the added benefit of being well suited to interdisciplinary teamwork, because such issues often draw from a variety of disciplines.

During the student research in this project, the chemistry students collaborate with students from an introductory geology class. The chemistry and geology students work together to study the composition of the area's drinking water, resulting in conclusions and understanding beyond what either group would likely have achieved on their own. We anticipated that the use of advanced chemical instrumentation (relative to items more common to general chemistry labs) would enhance these benefits for the students. This type of collaborative environment and relevant context has been shown to be supportive of a more enriching student experience, resulting in broader and more meaningful scientific understanding *(13, 19, 20)*.

Course and Participant Information

General chemistry, with an enrollment of approximately 550 students annually, is a first-year course for chemistry majors but populated predominantly by life sciences and engineering students. The associated laboratory consists of 14 one-week experiments, accommodates 24 students per section, and heavily utilizes assistant instructors (about 4 out of every 5 sections) rather than professorial faculty. These assistant instructors are full-time faculty with at least a BS degree in chemistry and typically teach 4 or 5 laboratory sections per semester. As many as four to eight different professors or instructors are involved in general chemistry labs during any given semester. The student population of these labs is typically about 50% first-year, 25% second-year, and 25% third-year and fourth-year students. Typically, about 50% of these students report having a life-science major, approximately 20% report having an engineering

10.1021/ed1002064 Published on Web 06/10/2010

major, and about 4% report being a chemistry major (although only about 1% ultimately graduates with chemistry degrees). Education students, who will eventually be certified to teach in an elementary or secondary classroom, represent about 3% of the general chemistry students.

The partnering geology course, environmental geology, is an introductory-level course that does not have an associated laboratory. This course has an average annual enrollment of about 650 students, is often taken by students to fulfill a natural science requirement needed for graduation, and is taught by both full-time faculty and part-time instructors. The course serves as a major recruiting tool to attract students to either geology or to the environmental studies program and typically consists of about 30% first-year, 30% second-year, 25% third-year, and 15% fourth-year students. An important student population in this course is the group of preservice teachers, who account for approximately 15% of the environmental geology students. This project is one of the few times some of these future teachers experience science and the scientific method. The geology course concentrates on the impact humans have on their physical environment and how the environment affects humans, including a significant focus on water, water use, and water quality. However, most geology courses with a unit on water could easily serve as the partner course for similar research.

Project Structure and Organization

The semester begins with the collection of drinking water from various sources in the area. The water is collected by the geology students according to a written sampling protocol (available in the supporting information). Samples of softened, unsoftened, filtered, unfiltered, private well, and city waters are collected in the area. The samples are delivered to the general chemistry students who analyze the samples by ion chromatography (IC) during one 3.5 h laboratory period. The chemical analysis data are then returned to the geology students who study it for geographic, geologic, and other correlations.

The chemistry students use Metrohm IC Basic 792 ion chromatographs to analyze the water samples for the most common ions in drinking water: sodium, ammonium, potassium, calcium, magnesium, fluoride, chloride, nitrate, phosphate, and sulfate (elution order). The students work in pairs and each pair is responsible for the analysis of one water sample, which requires two IC separations: one for cations and one for anions. One student in the pair operates an IC instrument for the cation separation (assisted by the other) and then they exchange roles so that other student operates an instrument for the anion separation. As a result, every general chemistry student operates an ion chromatograph. Six student pairs begin with the water analysis and the other six pairs start with a paper chromatography (PC) separation of the pigments in black ink markers *(21, 22)*. The inclusion of the PC separation, though not related to the actual water analysis, is an integral part of the student experience. It provides an excellent, colorful demonstration of the fundamental, underlying principles of chromatographic separations. By using four different black ink markers, students observe that black inks do not all contain the same pigments and that these pigments will not separate the same way (or sometimes at all) when the eluting solvent is changed (two different solvents are used). Without the PC experiment, students would be more likely to perceive the IC instruments as “black boxes”. About halfway through the lab period, all students finish their respective analysis and then switch to the other analysis: PC to IC and IC to PC.

The Metrohm IC instruments are easy for the students to use, in part because they are not loaded with complex options and yet still provide accurate data at an affordable price. In its most simplified form, the water analysis can be perceived as requiring only two steps: squirting some water into a box and collecting a printout from the printer. During a focus-group analysis conducted with students, one student expressed this potential black box perception quite effectively “With the `ion-o-meters', we squirted something into it and got a picture out of it...I had no clue.” Lab instructor guidance and the PC separation help to combat this potential black-box perception and enhance the inquiry-based context of the activity that is valuable to science learning and its effective instruction *(1, 23, 24)*.

In addition to the IC water analysis and PC separation of black ink pigments, the chemistry students calculate the bicarbonate concentration and hardness of the water samples. To determine the bicarbonate concentration, students calculate the charge balance of the ions detected by the IC instrument and assign the “missing” anion charge to bicarbonate. In doing so, the students are operating on the assumption that bicarbonate is the only undetected ion with a large enough concentration to affect the charge-balance calculation, an assumption they are asked to confirm by inspection of their data. (Bicarbonate is not detected by the instruments because it is a major component of the anion eluent.) Though more challenging and beyond what is discussed in the general chemistry lecture, both calculations (bicarbonate concentration and hardness) are well supported by the lab manual, connected to the laboratory work, and are valuable parts of the students' experience.

The data-collection process is centralized and coordinated with the use of a Web-interfaced computer database designed specifically for this project *(25)*. Geology students record the collection information: date, time, location, and type of water (tap, filtered, softened, private-well, etc.). After the chemical analysis, the chemistry students add their data to the same database. This method of data collection worked well for this project because the data are generated sporadically (both during sample collection and analysis) and can be entered from any location with Internet access. It also reduces transcription errors that would occur if the project were dependent on reading student handwriting. The electronic format of the database also facilitates later data processing.

Each semester, in the weeks following the water analysis, a total of 6–12 students from the general chemistry laboratory volunteer to work together to prepare and deliver an oral presentation for the geology students. Similarly, geology students volunteer to prepare and deliver an oral presentation for the general chemistry students. Each collaborative presentation describes the roles of one group to the other group, including methods, results, and conclusions. These presentations and the ensuing interdisciplinary discussion highlight a variety of outcomes that neither group would likely discover or be aware of without the other. The student presentations are about 15 min and are made three weeks following the water analysis. Because the presentation preparation is not trivial, extra credit is awarded to encourage students to volunteer. The extra credit earned is based upon the quality of the presentation. Interestingly, the students who participated in these oral presentations generally felt that the students not involved in the presentation missed out on a valuable learning experience. Seeking to refine this student-presentation process, we tried a more inclusive approach where, after being split into four groups, all the students from a single lab section (approximately 24 students) prepared and presented group posters. Though this modification was not rigorously evaluated, it is our opinion that although the presentation (in either form) is a particularly valuable part of the student learning experience, the value is strongly dependent upon individual student interest and is probably best suited for those individual students who are sufficiently interested to volunteer for that component of the project.

In addition to their interaction with the geology students, the general chemistry students also interact with upper-level chemistry students who are responsible for the preparation and calibration of the IC instruments. These third-year students are from a laboratory-only analytical chemistry course, although undergraduates in a second-year quantitative analysis course could also function in this role. In addition to being a valuable experience for these third-year students, their participation also lessens the pressure on the chemistry faculty in their preparation for the project. These students also make their own presentation to the general chemistry students, communicating their supporting role in the research process, and its critical contribution to the accuracy of the general chemistry students' data. This vertical integration in the chemistry program also extends to the fourth-year instrumental analysis course, where students are involved in development and refinement of the instrumental methods used by the third-year and general chemistry students.

Hazards

The only potentially significant hazard of this laboratory work as performed by students and described in this manuscript is the 70% isopropyl alcohol solution. Isopropyl alcohol is flammable and may cause eye, respiratory tract, and skin irritation. The carbonic, nitric, sulfuric, and dipicolinic acids as used in the ICs are so dilute that they pose no serious health or safety hazards.

Evaluation

The outcomes of this work have been evaluated through the use of anonymous student-feedback surveys and with student focus groups. The student-feedback survey collected demographic information and asked students to indicate the degree to which they agreed or disagreed with a series of Likert-scaled statements about the project and their perceptions of science. Focus groups (involving 6–10 students and each lasting 30–40 min) were also conducted for three consecutive semesters with each involved group of students: general chemistry students (4 groups), introductory geology students (2 groups), and third-year analytical chemistry students (2 groups). Feedback from focus groups that contained randomly selected students (about 1/2 of the groups) did not differ noticeably from focus groups where participating students were self-selected. Third-year chemistry students were so few in number that a group of the whole was used for that focus group. The focus-group discussions were co-facilitated by an external evaluator from the College of Education and a chemistry faculty member who had not interacted with these students. The focus group transcripts were analyzed and summarized by the external evaluator and an evaluation specialist from the Center for Assessment and Evaluation of Student Learning at WestEd (a NSF-sponsored educational research center).

Student Surveys

The survey data for the participating general chemistry and geology students, collected during 2003 and 2004, are summarized in Figures 1 and 2, respectively. The responses shown in these figures have been simplified into a three-point Likert (agree, neutral, and disagree) from the original five-point scale used to collect the data. Some of the most encouraging information from these surveys is that the majority of the chemistry students felt that (i) the project was fun and interesting, (ii) their work was similar to that of a research scientist, and (iii) the IC instruments were an effective aid to their understanding. One student said, "It gave me more perspective on what scientists actually do, it puts you in that position and makes you think about how important the job is." Only 16% disagreed with the first statement "the project increased how much I like science in general." In addition, 8% of the respondents agreed with the statement *(11)* that they were "more likely to consider majoring in chemistry". Although that percentage may not be large, it has significant potential impact because of the large number of general chemistry students.

Overall, a larger portion of geology students relative to the chemistry students agreed that they found the project fun and interesting (statements 2 and 3), but fewer felt that they had done work similar to a real scientist (statement 4). These differences make sense, considering that the geology students (having collected the water samples from their own residences) were not directly involved in the chemical analysis. They may have considered it more fun because they were able to look at the data and apply it to answering questions (private water vs city water) and it was done in a different format (small group in-class discussion) than the usual lecture presentation. Overall, this project strongly models typical arrangements in the real world at the interface of geology and analytical chemistry.

A more detailed analysis of the general chemistry student responses was done to look for possible trends with student demographics, including GPA, gender, age, and academic rank. According to Table 1, trends with level (academic year) are most apparent for statements 5 and 9. Upper-level students were more likely to disagree with statement 5 "I found the project confusing" and more likely to agree with statement 9 "the instrumentation was an effective aid to my understanding." The data in Table 1 also indicate trends with age for statements 10, 11, and 12. Older students were more likely to disagree with statement 10 "I found this project boring" and agree with statements 11 and 12 "I am more likely to consider majoring in chemistry, (or) ... geology", respectively. The data in Table 2 indicate little in the way of trends in response with respect to GPA even though strong dependence of response on GPA is indicated in Table 3. The extent of response dependence on GPA, gender, age, and academic level are summarized in Table 3. The strongest dependencies (*p*-value <0.05) were found to occur for statements 3 and 10 (level), 2, 6, and 10 (age), and 1, 2, 8, 10, and 12 (GPA). No significant dependencies were observed for gender for any of the statements.

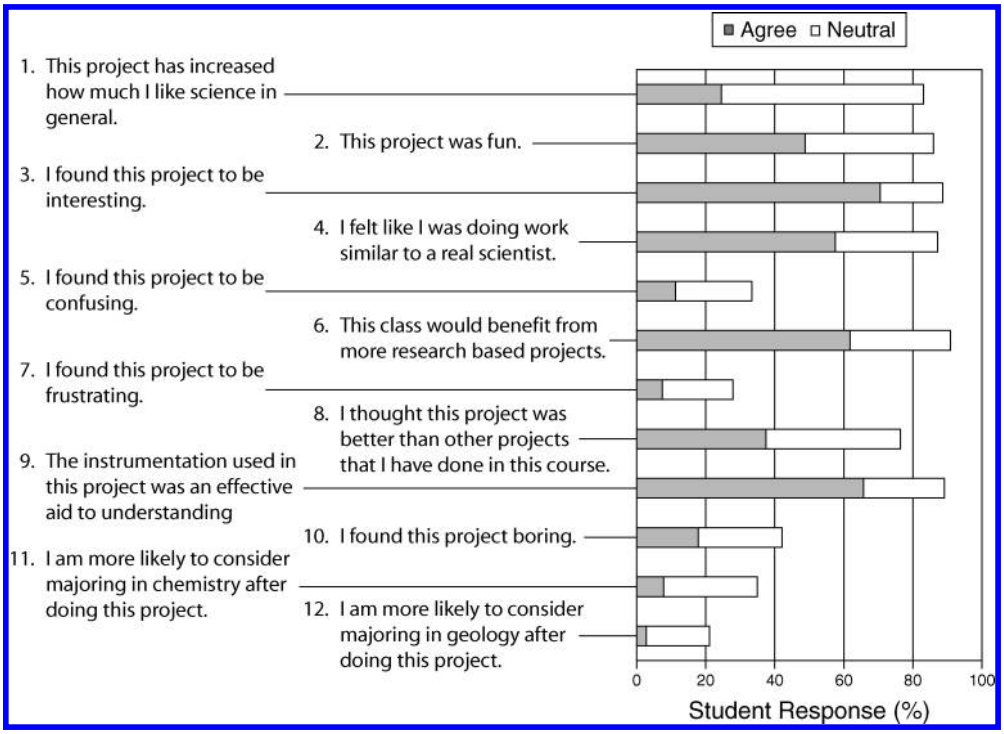

Figure 1. Survey responses from general chemistry students.

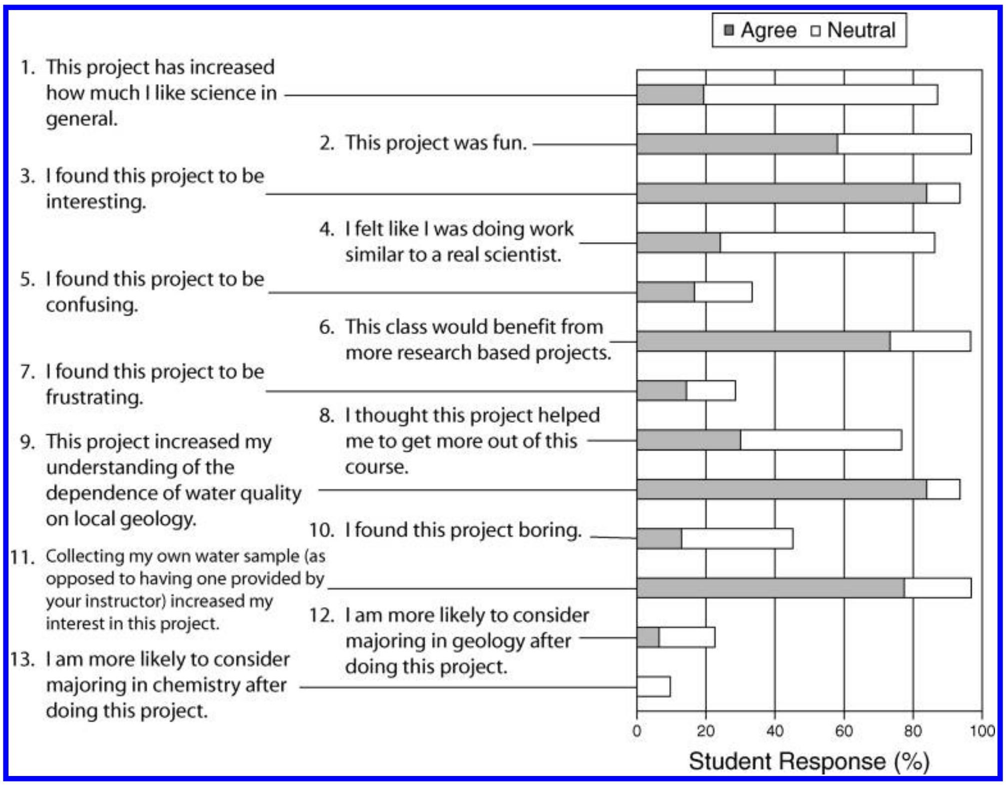

Figure 2. Survey responses from introductory geology students.

Focus Group Analysis

The students who participated in the focus groups were supportive of the project, the departments' mutual collaboration, and the real-life connections of the project. All of the students appeared to greatly appreciate the instructional innovations represented by the project, as well as the intent and hard work by the instructors to provide such instruction. The students approached the focus-group conversation seriously and constructively. Their suggestions centered primarily on how to make the

Table 1. Average General Chemistry Student Responses to the Survey Statements

Metric	n	S1[a]	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
First Year	189	3.02	2.67	2.41	2.49	3.59	2.45	3.67	2.90	2.42	3.32	3.82	4.40
Second Year	121	2.95	2.55	2.32	2.57	3.64	2.36	3.86	2.78	2.38	3.53	3.83	4.18
Third Year	98	2.84	2.55	2.12	2.36	3.73	2.07	3.99	2.85	2.27	3.49	3.70	4.28
Fourth Year	35	2.97	2.83	2.51	2.65	3.81	2.49	3.86	2.97	2.29	3.54	4.20	3.75
Male	232	2.90	2.70	2.41	2.47	3.68	2.39	3.79	2.80	2.31	3.38	3.84	4.22
Female	217	3.00	2.54	2.23	2.52	3.62	2.29	3.81	2.92	2.44	3.51	3.78	4.28
Difference		−0.09	0.16	0.18	−0.05	0.06	0.10	−0.02	−0.12	−0.13	−0.12	0.05	−0.06
18 Years	82	3.10	2.78	2.54	2.54	3.60	2.63	3.58	2.98	2.50	3.15	3.90	4.38
19 Years	115	2.95	2.52	2.17	2.45	3.43	2.35	3.70	2.88	2.29	3.43	3.82	4.50
20 Years	66	2.94	2.62	2.44	2.52	3.67	2.24	3.94	2.86	2.50	3.48	3.79	4.21
21 Years	56	2.93	2.63	2.21	2.52	3.69	2.09	4.00	2.76	2.11	3.46	3.75	4.00
22–24 Years	43	3.00	2.56	2.37	2.38	4.00	2.37	3.93	2.88	2.34	3.59	3.92	3.50
>25 Years	49	2.77	2.61	2.24	2.33	3.69	2.35	3.78	2.71	2.45	3.71	3.68	3.82

[a] 1 = strongly agree, 2 = agree, 3 = neutral, 4 = disagree, and 5 = strongly disagree. S1–S12 are given in Figure 1.

Table 2. Average General Chemistry Student GPA's According to Student Response

Response	S1[a]	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Strongly Agree	3.31	3.40	3.29	3.12	3.39	3.31	3.08	3.17	3.29	3.20	3.50	3.50
Agree	3.26	3.26	3.35	3.36	3.33	3.34	3.36	3.37	3.33	3.47	3.48	3.00
Neutral	3.34	3.38	3.32	3.32	3.30	3.34	3.34	3.29	3.33	3.33	3.28	3.17
Disagree	3.54	3.46	3.35	3.40	3.36	3.38	3.36	3.46	3.48	3.38	3.32	3.50
Strongly Disagree	3.16	3.17	3.17	3.38	3.23	3.16	3.25	3.06	3.21	3.08	3.38	3.39

Table 3. *p*-Values for Dependence of Response on Demographic Variables for General Chemistry Students[a]

	S1[a]	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Level	0.369	0.082	**0.000**	0.099	0.228	*	*	0.267	0.118	**0.044**	*	*
Gender	0.090	0.282	0.105	0.118	0.481	0.584	0.483	0.283	0.198	0.212	0.752	*
Age	0.616	**0.032**	0.440	0.923	0.180	**0.001**	0.056	0.420	0.508	**0.007**	*	*
GPA	**0.022**	**0.047**	0.672	0.073	0.379	0.818	0.241	**0.001**	0.503	**0.001**	0.165	**0.005**

[a] *P*-values reported for GPA are determined by ANOVA, all other *p*-values are determined by a contingency table. (Contingency tables are used for categorical data in a similar way that ANOVA is used for continuous numeric data.) The most significant dependencies (with *p*-value less than 0.05) are indicated in boldface type. Asterisks indicate cases where insufficient number of data points exist for one or more specific response types, e.g., fourth-year students who strongly agreed with statement _______, preventing valid calculation of the *p*-value.

project run better and, in particular, how to further refine the student communication process within the project. The feedback from the focus groups has been broken down into three categories, (i) benefits perceived by the students, (ii) challenges perceived by the students, and (iii) other challenges (Table 4).

Benefits (Student Perceptions)

The students often mentioned that they got to know their partners well in this project. They felt that working with others in this type of laboratory setting was beneficial and more consistent with real-world business and scientific communities where professionals benefit from working in teams by sharing expertise, checking each other's work, and being accountable to one another.

Students who identified themselves in the focus groups as being somewhat "science phobic" especially commended the project, and typically discussed how it had generated more personal interest for them than had the other laboratory activities within the course. After being involved in this project, one preservice elementary teacher decided that, instead of avoiding anything with math or science in it because they are "boring," she would "prepare a learning unit for her education class on the water cycle rather than on language arts."

The students were generally impressed that the two departments were working together and felt that the different knowledge areas of the classes were complementary. They also thought that this collaborative approach modeled the real world. The chemistry and geology students both mentioned that they were impressed with the interconnections between chemistry and geology that were illustrated within this project. They thought that the project did a good job of showing how both sciences can help shape the world. When asked to share what they thought

Table 4. Results from the Focus Group

Benefits (Student Perceptions)
Working with partners and teams
Having the Chemistry and Geology Departments work together
Seeing the interconnections between chemistry and other disciplines
Doing hands-on experiments in an applied project
Learning about use of equipment, data analysis, and measurement error
Student presentations
Challenges (Student Perceptions)
Different information from instructors
A perception of insufficient access to lab instructors
Lack of understanding of overall planning and advance preparation
Unaware of the collaboration between departments
Challenges (Other)
Mistakes by third-year analytical students
Lack of commitment by instructors

was most valuable about the experience one student said, "...being able to connect the two sciences and to learn more things about each because otherwise we learned facts but not their significance."

The students were frequently complementary of the hands-on approach to this laboratory work and mentioned that they thought that they learned substantially more in this type of active instructional environment. The students thought that learning about the individual equipment use, various data analysis strategies, and measurement error were all useful benefits of this particular project.

Students who directly participated in giving a presentation further indicated that they viewed this component of the project to be a particularly valuable learning experience, both in terms of chemistry and of public speaking.

The third-year analytical students who assisted the introductory-level students had an interesting perspective on the project as they worked to support students across multiple laboratory sections. These students reported that the collaborative features of the project appeared to be well received by the introductory-level students. They also confirmed that the perceived real-life context of the project was a positive aspect of their ongoing interactions with the introductory students during their support of the project.

Challenges (Student Perceptions)

The students felt that there were times when they received different instructions from different instructors, including information related to the overall importance and background of the lab. They also mentioned cases where the lab instructors seemed uncertain about a particular aspect of the project. The students mentioned cases where they thought the lab instructors seemed too busy with equipment preparation and consequently were not always available to fully answer their questions.

Early student feedback indicated that they felt they would have a better understanding of the underlying purpose of the project if they were more aware of the overall planning and preparation for this joint project. This was primarily addressed by having the lab instructors "preview" the project in the week or two leading up to the week of the water analysis. Small additions were also made to the background material in the students' lab manual. These modifications seem to have successfully addressed this need.

The students often mentioned that the collaboration and communication between departments was a positive feature of the project but that they were not always aware of this collaboration. They felt that a more complete awareness of this departmental collaboration early on in the project would help them better understand its overall structure, its collaborative effort, its general purpose, and the different responsibilities of students in each department.

Comments from the third-year analytical chemistry students confirmed that a more complete initial overview of the project would probably be beneficial to the introductory students. They also felt that additional instruction on the equipment and the electronic database would improve the introductory students' technical efficiency in undertaking the laboratory procedures of the project.

Challenges (Other)

Additional challenges identified in the project were associated with the third-year analytical chemistry students getting the instruments fully prepared. These problems included improper preparation of standards and eluent, incorrect programming of the method, and failure to make full use of the required peer review of their work. Consistent laboratory instructor "buy-in" or a full acceptance of and commitment to the project has also been a periodic challenge. The particular laboratory instructors teaching general chemistry and their personal interests and attitudes naturally vary from semester to semester. The geology lecturer has also varied (from professorial faculty to part-time instructor), though with less impact on the overall success of the project.

The ability to effectively address such challenges and variations in a project such as this relies extensively each semester upon the leadership, time, and efforts of the faculty with a strong interest in the project's coordination, oversight, and successful implementation. This leadership role has been principally filled by two analytical chemistry professors and one geology professor, with some additional departmental and university support. Successful replication of this type of effort will depend significantly on finding faculty members who have sufficient interest and expertise.

Conclusions and Future Work

Overall, the project was seen as innovative and relevant by the students, who appreciated the interdisciplinary effort by the two departments. The few chemistry students who have been involved in this project at all three levels (chemistry student, geology student, and upper-level analytical chemistry student) have also affirmed the value of this experience in their feedback. Education students, who will eventually be designing science lessons and learning experiences for their own classrooms, have had a chance to be involved in a focused student research experience that may provide them with a better understanding of both the benefits and challenges of engaging their own students in collaborative research endeavors. Geology students enjoy this project because it is relevant to their lives (their samples from their homes) and because they get to apply things learned previously in this class (mineralogy, groundwater, chemical weathering) to something they understand, water. The students appreciate the opportunity to model interdisciplinary scientific behavior and develop an appreciation of how scientific knowledge advances.

We believe that the integration of real, meaningful, collaborative, interdisciplinary student research into our general chemistry curriculum has (i) positively influenced the attitudes of our students and (ii) helped students experience for themselves something that scientists do on a regular basis. Given the nature of this research and the relatively high level of interest indicated by the participating students, we also believe that active student participation in this collaborative, environmental research has increased their scientific literacy. A student captured this outcome in their statement "This is real life... real ways of measuring with computer programs and machines, not just hypothetical situations of mixing in tubes."

It is our opinion that the correlations with age and academic rank are a manifestation of the students' generally increasing maturity with age and experience rather than a result of this project. Although it is not clear within this short time frame, there was anecdotal evidence (such as from the focus groups) to suggest that this project has increased the number of students majoring in chemistry.

We plan to continue this project because its value has been clearly demonstrated by student feedback. We are also planning to broaden the impact of the project by collaborating with area high school and community college students, whose role would be similar to that of the geology students. We are also developing a new project where general chemistry and geology students collaborate on the analysis of lead in soil (a major local environmental contaminant). For this project, the students will use an inductively coupled plasma mass-spectrometer.

Acknowledgment

We gratefully acknowledge the support of the University of Nebraska at Omaha for providing the funding for the six ion chromatographs, the UNO Departments of Chemistry and Geography/Geology for research assigned-time support, Mike Timms of West Ed for evaluation assistance, Andrew Swift for statistical analysis assistance, and Paul Clark and Steve Hamersky (UNO College of Education) for their considerable work on the project Web site. This research was supported in part by a grant from the National Science Foundation (CCLI Grant No. DUE-0411164). We would also like to thank Jennifer Kopanic for presenting this work at the 234th ACS National meeting Boston August, 2007. Ms. Kopanic graduated with a BS in chemistry in May 2007, as one of a handful of students who participated in all three capacities: general chemistry student, geology student, and upper-level chemistry helper.

Literature Cited

1. Gess-Newsome, J. *Am. Educ. Res. J.* **2003**, *40*, 731–767.
2. Tosun, T. *Sch. Sci. Math.* **2000**, *100*, 374–379.
3. Sinniah, K.; Piers, K. *J. Chem. Educ.* **2001**, *78*, 358–362.
4. Pursell, C. J.; Chandler, B.; Bushey, M. M. *J. Chem. Educ.* **2004**, *81*, 1783–1786.
5. Demay, S.; Martin-Girardeau, A.; Gonnord, M.-F. *J. Chem. Educ.* **1999**, *76*, 812–815.
6. Miller, L. S.; Nakhleh, M. B.; Nash, J. J.; Meyer, J. A. *J. Chem. Educ.* **2004**, *81*, 1801–1808.
7. Malina, E. G.; Nakhleh, M. B. *J. Chem. Educ.* **2003**, *80*, 691–698.
8. Stewart, B.; Kirk, R.; LaBrecque, D.; Amar, F. G.; Bruce, M. R. M. *J. Chem. Educ.* **2006**, *83*, 494–500.
9. Lincoln, T. N. *CUR Quarterly* **1995**, 189–192.
10. McGowin, A. E.; Hess, G. G. *J. Chem. Educ.* **1999**, *76*, 23–24.
11. Breslin, V. T.; Sanudo-Wilhelmy, S. A. *J. Chem. Educ.* **2001**, *78*, 1647–1651.
12. Wenzel, T. J. *J. Chem. Educ.* **2001**, *78*, 1164–1165.
13. Juhl, L.; Yearsley, K.; Silva, A. J. *J. Chem. Educ.* **1997**, *74*, 1431–1433.
14. Shibley, I. A., Jr.; Zimmaro, D. M. *J. Chem. Educ.* **2002**, *79*, 745–748.
15. Dougherty, R. C.; Bowen, C. W.; Berger, T.; Rees, W.; Mellon, E. K.; Pulliam, E. *J. Chem. Educ.* **1995**, *72*, 793–798.
16. Shibley, I. A., Jr.; Milakofsky, L. K.; Nicotera, C. L. *J. Chem. Educ.* **2001**, *78*, 50–53.
17. Schauble, L.; Lehrer, R. Tackling the Question: What Science Should Students Learn? Principled Practice in Mathematics and Science Education. Wisconsin Center for Education Research, University of Wisconsin-Madison: Madison, WI, 1999
18. Kesner, L.; Eyring, E. M. *J. Chem. Educ.* **1999**, *76*, 920–923.
19. Cancilla, D. A. *J. Chem. Educ.* **2001**, *78*, 1652–1660.
20. Koether, M. C.; McGarey, D.; Patterson, M.; Williams, D. J. *J. Chem. Educ.* **2002**, *79*, 934–935.
21. Journal Editorial Staff, *J. Chem. Educ.* **2000**, *77*, 176A.
22. Olesen, B.; Hopson, D. *J. Chem. Educ.* **1983**, *60*, 232.
23. Brunning, R.; Schweiger, B. Integrating Science and Literacy Experiences to Motivate Student Learning. In *Reading Engagement Motivating Readers through Integrated Instruction*; International Reading Association: Newark, DE, 1997; pp 149−167.
24. *Atlas of Science Literacy, Project 2061*, American Association for the Advancement of Science: Washington, D.C., 2001.
25. Learn Science by Doing. http://water.unomaha.edu/learn (accessed May 2010).
26. Rowan, B. *The Shape of Professional Communities in Schools*, American Educational Research Association Annual Meeting: Chicago, April, 1991, 91-136.

Supporting Information Available

Student manual/procedure; instructor's notes; grading key; Web site screen shot; instrument operation for the general chemistry lab; upper-level components; instructions for collecting water samples. This material is available via the Internet at http://pubs.acs.org.