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In the Classroom

Environmental Chemistry in the General Chemistry Laboratory, Part II: Evaluation of An Alternative Curriculum

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Our hope was that this new laboratory curriculum would serve to motivate students and help them develop their skills as scientists.

This is the second of two closely-related articles describing an innovative approach to teaching first-year chemistry. The first article provides details of the methods for teaching the course, and this article discusses the student evaluation data obtained for the project. The goals of the project were threefold: (1) to increase students' interest in science early in their academic careers, particularly women and minority students; (2) to raise students' awareness of the connections between chemistry and real-life issues; and (3) to engender a more sophisticated view of science among students. To achieve these goals, we created a module-based laboratory curriculum in which each module is centered on a specific environmental question that the students

THE CHEMICAL EDUCATOR

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must answer. This article focuses on the project's evaluation, which compares the performance and attitudes of students in the environmental laboratory to those in a traditional one. Classroom performance results indicate that although the students in the environmental laboratory entered the class less prepared than the students in the regular laboratory, both groups performed equally well at the end of the chemistry course. Students in the environmental group ranked the laboratory significantly higher on a department evaluation survey than students in the regular group, indicating their heightened satisfaction with the laboratory experience. Compared to the regular-laboratory students, the environmental students also displayed a greater awareness of the relationship of chemistry to everyday life and a more sophisticated view of science.

Introduction

For more than a decade, many chemistry educators and national leaders have claimed that the traditional chemistry curriculum fails to meet the needs of our students and our society. By several accounts, students find chemistry courses difficult, boring and irrelevant to their lives [1–3]. This dissatisfaction results in high attrition rates from the introductory courses, and disproportionately affects women and underrepresented minority students [4]. A scientifically-literate public is a desirable outcome of the educational process, yet there is a widely-held perception that the science literacy of the average U.S. citizen is declining [5–8]. Even the business and industrial communities are reporting that graduating students have not been taught critical thinking and teamwork skills, nor do they emerge from undergraduate institutions with the broad, interdisciplinary perspective on science required to perform optimally on the job [9, 10]. Clearly, there is a need to rethink the way we presently teach chemistry.

In this project, we developed a set of context-based laboratory experiments, tested them in pilot sections of the first-year laboratory program, and gathered data on the effectiveness of this approach in helping students learn and in improving their attitudes towards chemistry. Our hope was that this new laboratory curriculum would serve to motivate students and help them develop their skills as scientists. The goals of our program were threefold:

1. To interest students in science early in their academic careers, particularly women and minority students.

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S 1430-4171 (96) 04053-8

2. To increase students' awareness of the connections of chemistry to real-life issues.

3. To raise the level of sophistication of students' view of science.

This paper describes the evaluation of this approach in the context of the above goals. The preceding paper provides an overview of the environmental experiments performed by the students.

The Course and Laboratory

More than 2,000 University of California at Berkeley students enroll each year in the introductory first-year chemistry course, Chemistry 1A, which includes two hours of lecture, one hour of discussion, and four hours of laboratory per week. The experiments performed by the students in regular laboratory sections of 28 students typically involve a simple procedure illustrating a chemical concept. They are completed during one laboratory period. Beginning in 1993, several special environmental laboratory sections were offered as an option to 60–70 self-selected students each semester. These students attended the same lecture and were given the same exams, but performed different laboratory experiments. In this "modular" laboratory program (see previous paper), three to four weeks of laboratory work are integrated around one overarching theme related to environmental chemistry. The environmental laboratory employs a variety of alternative approaches to teaching, including context-based experiments, collaborative learning, and role-playing activities [11].

Methods of Data Collection and Analysis

The environmental laboratory was evaluated over the course of five consecutive semesters, beginning with the Spring semester of 1993 and ending with the Spring semester of 1995. An anonymous affective survey served as the main instrument for evaluating the effectiveness of the new curriculum. Given at the end of the semester, the survey was composed generally of two types of questions: student background and student attitude. The background questions asked students to describe themselves—gender, ethnicity, class rank, intended major, intended career, and plans for taking future chemistry courses. The attitude questions asked students to discuss their experiences in the laboratory.

ISSN 1430-4171
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S 1430-4171 (96) 04053-8

The questionnaire evolved over the course of five semesters, so not all questions were answered by all students. In order to obtain comparative data, three limited surveys of the regular laboratory sections were carried out in the Fall 1993, Fall 1995, and Spring 1996 semesters. The data from the Fall 1993 survey yield the best comparison between the two groups, because the surveys were identical and the return rate of completed surveys was high. Consequently, most of the analyses that compare the two groups are drawn from the Fall 1993 incarnation of the survey.

In analyzing the survey data, we employed a small number of statistical methods. The most prevalent was to compare the number of students in the environmental group who provided a particular answer on the survey to the number of students in the regular group who also gave that answer. To check for statistical significance in cases like this, we used a Chi-square test. If the number of students in one group was less than five, we used a Fisher Exact test. Unless otherwise noted, all tests were two-tailed.

Some of the data consist of students' answers to open-ended questions, such as, "What is the most important thing you learned in this laboratory course?" Students' responses to these questions were coded, and the frequencies of each type of response from each group were tallied. Again, we employed a Chi-square test to determine statistically significant differences in the number and kinds of open-ended responses students gave in each laboratory group. As a check for the reliability of the coding scheme, a second rater coded 20% of the data.

Finally, the data also include means of students' overall rankings of the course. The mean rankings from the two groups, environmental and regular, were compared using a z-test.

Subjects

At the end of the Fall semester of 1993, 79 students were enrolled in the environmental laboratory, while over a thousand students had opted for the more traditional regular laboratory. A random subset of 466 students in the regular class was surveyed. Henceforth, the former group will be referred to as the environmental group and the latter as the regular group.

ISSN 1430-4171
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S 1430-4171 (96) 04053-8

TABLE 1. Group differences in gender and class rank.[a,b]

	Gender		Class Rank	
	M	F \	First-Year Students	Other
Environmental group (N = 214)	39%	61%	76%	24%
Regular group (N = 1,242)	54%	46%	88%	12%

[a]Environmental group data from Spring 1993, Fall 1993, Fall 1994 & Spring 1995; regular group data from Fall 1995.

[b]We compare these data by assuming that the gender and age of the students in the two groups do not change systematically across semesters.

Demographic Differences Across the Two Groups

The students in the two groups were self-selected; anyone who wished to enroll in the environmental laboratory was allowed to do so. Consequently, the two populations were not identical. Information obtained from surveys indicated group differences in the gender, age, ethnicity, intended major, and previous experience in chemistry. This is not surprising, for it indicates that the environmental laboratory attracted certain types of students. We shall offer post-hoc explanations of these differences as we examine each one. In the Results section, the demographic differences will provide insights into students' performance on graded assignments in the class.

The introductory chemistry course at Berkeley is typically populated by slightly more men than women, and most students are in their first year of college. In contrast, the environmental laboratory consistently enrolled more women than men (see Table 1). This difference in the two groups is reliable ($\chi^2 = 16.99$, $p < 0.0001$), suggesting that the environmental laboratory was more inviting to women than the regular laboratory.

Also displayed in Table 1, the environmental laboratory enrolled a smaller number of first-year students than the regular laboratory. This difference is significant ($\chi^2 = 21.47$, $p < 0.0001$) and may have been due in part to the possibility that the first-year students

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http://journals.springer-ny.com/chedr
S 1430-4171 (96) 04053-8

TABLE 2. Group differences in ethnicity.[a]

	Caucasian	Asian	Other minority
Environmental group (N = 110)	44%	40%	16%
Environmental group (N = 1,242)	29%	51%	20%

[a]Environmental group data aggregated over Spring 1993, Fall 1993, & Spring 1994; regular group data from Fall 1995.

were less familiar with the complex listing of the schedule of classes and failed to notice the listing of the environmental laboratory sections at the end of the General Chemistry Laboratory listings.

The ethnic makeup of the two groups also differed. The environmental group was composed of fewer Asian students, more White/Caucasian students, and about the same number of other minority students as the regular group (see Table 2). These group distributions are reliably different from one another ($\chi^2 = 9.57$, $p < 0.05$). The regular-group ethnicity data came from the Fall 1995 semester, so this comparison assumes that the ethnicity distributions do not change significantly in the span of a few years. In light of the low enrollments of Asians and other minority groups such as Latinos and African Americans, it seems that more active recruitment measures are necessary to influence these students to choose the environmental laboratory over the regular laboratory.

The intended majors of students in the environmental group were oriented more towards Environmental Science and less towards a straight Biology major than the students in the regular group (see Figure 1). This is no surprise, because we would expect the environmental laboratory to attract students interested in environmental issues. It is interesting to note that only 5–6% of the student population in the entire course intended to major in chemistry. The difference between the intended majors of the environmental group and those of the regular group is statistically significant ($\chi^2 = 17.86$, $p < 0.01$).

THE CHEMICAL EDUCATOR

ISSN 1430-4171
http://journals.springer-ny.com/chedr
S 1430-4171 (96) 04053-8

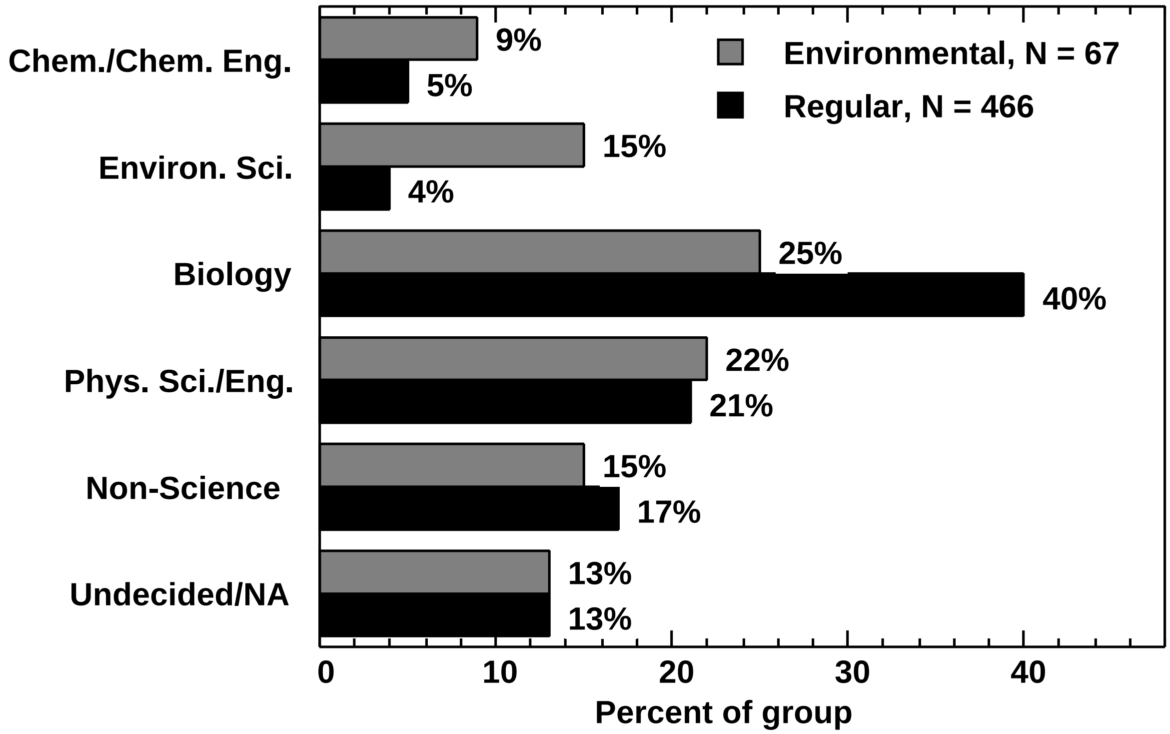

FIGURE 1. COMPARISON OF INTENDED MAJORS OF ENVIRONMENTAL LABORATORY STUDENTS WITH REGULAR LABORATORY STUDENTS IN THE FALL SEMESTER OF 1993.

TABLE 3. Comparison of chemistry backgrounds of environmental and regular laboratory students.

	Percent of Students Taking the AP Chemistry Test	Average Score on the AP Chemistry Test
Environmental Laboratory Students (N = 68)	7%	2.8
Regular Laboratory Students (N = 465)	15%	3.2

Finally, the two groups in the Fall 1993 class may have differed with respect to their preparedness upon entering the course. As shown in Table 3, a larger fraction of the

THE CHEMICAL EDUCATOR

ISSN 1430-4171
http://journals.springer-ny.com/chedr
S 1430-4171 (96) 04053-8

students in the regular group than in the environmental group had taken the Advanced Placement Chemistry Examination in high school (Fisher Exact test, $p = 0.01$). Although not statistically significant, those students who completed the AP Examination in the regular group scored slightly higher on that test than their counterparts in the environmental group. These data suggest that the regular group may have been better prepared than the environmental group.

In the next section, we discuss the results of the survey.

Results and Discussion

Overview

The evaluation of the environmental laboratory sections for this course is composed of two main parts: (1) a description of the environmental group's attitudes toward the environmental laboratory and (2) an analysis comparing the environmental laboratory and the regular laboratory.

In the first section of the results, we explore the environmental group's response to the environmental laboratory. The results indicate that students found the modular approach more conducive to understanding and remembering the concepts, because it allowed them more time to process the information than a one-week experiment would. Of the five modules tested during the course of the three-year period, the students' favorite modules were those that they understood the best and that were most relevant to their own lives. We also found that the environmental students felt as if they had worked harder and learned more than the regular students. In addition, most, but not all, of the students enjoyed working in groups.

The second section reports our analysis of the differences in class performance on exams, as well as differences in attitudes and perceptions of the environmental and regular groups. As we shall see, despite a slight disparity in the preparedness of the two groups, there were no differences in their performance on the exams in the course. The attitudinal data indicate that the environmental group enjoyed the laboratory more than the regular group did and emerged with a broadened perspective on the process and limitations of science. These findings are supported by the higher rankings given to the environmental laboratory as compared to the regular laboratory and by students' comments about what they valued most from the laboratory section of the course.

THE CHEMICAL EDUCATOR

ISSN 1430-4171
http://journals.springer-ny.com/chedr
S 1430-4171 (96) 04053-8

Student views of the Environmental Laboratory

Response to the Modular Approach

The vast majority of the students in the environmental section were in favor of the modular approach. In answer to the question, “Did you like the modular approach, where several weeks were spent on the same topic?” 90% of the students responded “Always” (57%) or “Mostly” (33%). This suggests that they appreciated working on the same topic for several weeks.

Students were asked to rank the different modules on a scale of 1 to 10, where 1 = “didn’t enjoy it at all,” to 10 = “really liked it.” The data are summarized in Table 4. All of the modules received fairly high rankings from the students. The Water Chemistry module, a perennial favorite, always ranked above 8.0. This suggests that students valued the wide variety of techniques used as well as the field trips to the lakes and parks. The most difficult modules for the students seemed to be those involving a large amount of organic chemistry-the Pesticide, PCB, and Hair Dye modules. In spite of the difficulty of the organic modules, the Pesticide module emerged as a favorite in later semesters after the experiment had been revised to clarify areas of difficulty.

Student Perceptions of Workload and Material Learned

We wished to know how students perceived the amount of work they were doing and the amount of material they learned in the environmental laboratory, as compared to their perceptions of the workload in the regular laboratory. While it is unrealistic to expect the environmental students to know exactly what went on in the regular labs, it seemed that students with friends in the regular group noticed the difference in the expectations for the two classes. We will return to this issue below. Table 5 shows the questions asked of students and their responses.

As illustrated by Table 5, most of the environmental students thought they worked harder and learned more than their peers in the regular laboratory sections. Student comments on this question pointed to the fact that they learned *different* material and more of it than the regular laboratory students. The response to these two questions was independent of students’ expected grade in the course, as reported on the survey at the end of the semester when the majority of the course work had been graded (Question 1: $\chi^2 = 2.24$, $p = 0.69$; Question 2: $\chi^2 = 3.83$, $p = 0.43$). This result suggests that the course was not perceived as a “piece of cake” by the good students and that the material was accessible to students at all levels.

ISSN 1430-4171
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S 1430-4171 (96) 04053-8

TABLE 4. Student rankings of the Environmental Chemistry Modules.

Module	Student Ranking on a Scale of 1-10
The Chemistry of Water	8.0-8.5[a]
Lead in the Environment	7.4-7.9[a]
Pesticides in the Food Supply	7.7-8.0[a]
Hair dyes and Health Effects	6.8-6.9[b]
Independent Project	8.0
PCBs in the San Francisco Bay	N/A[c]

[a]Range of average response over three semesters.
[b]Range of average response over two semesters.
[c]This question was not asked the semester the PCB module was used.

In order to gauge the frame of reference that students used to compare their own workload to that of their peers in the regular laboratory, we asked how they arrived at their conclusions. Most students (83%) reported that they had friends in the regular laboratory sections. A small number of students (5%) indicated that they had previous experience in the regular laboratory sections. The remaining students (11% of the total) had no such justifications for comparison. Instead, they based their opinions on the experience of working unusually hard in the laboratory part of the course.

Perceived Value of Class Activities

A variety of alternative teaching techniques were explored in the course of the work, including teamwork, role-playing and collaborative learning, peer grading, independent study, and travel to sites of environmental interest for first-hand site observation and sample collection. We assessed student attitudes to these alternative techniques by asking them to rank a variety of class activities on a scale of 1 to 10 with respect to their

THE CHEMICAL EDUCATOR

ISSN 1430-4171
http://journals.springer-ny.com/chedr
S 1430-4171 (96) 04053-8

TABLE 5. Student assessment of workload and material learned.

Question	Percent of Students (N = 278)					
	Much More	More	About the Same	Less	Much Less	No
1. How hard do you think you worked compared to the students in the Regular laboratory?	24%	46%	22%	4%	0	4%
2. How much do you think you learned compared to students in the regular laboratory?	30%	43%	18%	5%	1%	3%

value for helping them learn environmental chemistry. The data are summarized in Table 6.

In general, students felt as if most of the activities in the class were useful for learning about environmental chemistry. The field trips were perceived as the most useful activity, with a rating of 8.4. Our own observations were that the field trips served to excite the students about the site being investigated and motivated them to do a good job with the analyses. They were able to correlate the data with a place they had visited and were often able to discover problem areas in the site.

An activity that ran a close second to the field trips was reading the laboratory manual. This result is a good indication that the manual was pitched at the appropriate level for the students and was capable of keeping their interest in the subject matter. The “in-class worksheets,” where much of the detailed chemistry was presented, were not generally well-received; perhaps the worksheets were simply more difficult than the other activities.

ISSN 1430-4171
http://journals.springer-ny.com/chedr
S 1430-4171 (96) 04053-8

TABLE 6. Student rankings of class activites for effectiveness in helping them learn environmental chemistry[a].

Activity	Mean score (out of 10)
Field Trips	8.4
Reading Lab Manual	8.3
Talking to instructor	8.0
Performing Experiments	7.8
Writing Reports	7.8
Prelab Lecture	7.3
Pesticide Debate	7.1
Working in groups	6.9
In-class Worksheets	6.3
Talking With Friends	6.2
Using Kaleidagraph™	6.2

[a]Data from Spring 1994, Fall 1994, and Spring 1995

Group Work and Contextual Learning

All of the modules were developed to maximize student participation and decision-making in order to develop students' abilities to work as part of a team. The students in the environmental laboratory frequently worked in groups ranging in size from two to seven students, both in the field and in the laboratory. Group work has been shown to benefit many students and facilitate learning of difficult concepts [12]. Our evaluation sought to assess whether the students enjoyed group work and whether they thought the

THE CHEMICAL EDUCATOR

ISSN 1430-4171
http://journals.springer-ny.com/chedr
S 1430-4171 (96) 04053-8

TABLE 7. Student assessment of group activities

Question	Percent of Students (N = 278) Always	Mostly	Sometimes	Never
1. Did you like working in groups?	25%	46%	26%	3%
2. Did working in groups help you understand the material better?	14%	37%	40%	8%
3. Did working in groups make it too easy to ignore some of the material that you personally weren't directly responsible for?	12%	18%	57%	12%
4. Did every member of the group contribute?	26%	57%	12%	5%

group learning approach helped them learn the material. The data are summarized in Table 7.

Most of the students liked working in groups; however, there was still a sizable percentage of the class for which group work was thought to be enjoyable only "Sometimes" or "Never." Although many students enjoyed group work, students were less likely to think that working in groups was always beneficial for helping them understand the material. This suggests that, in order to reach all students, class work should include both teamwork and individual activities.

The most strongly negative result appeared for the question about responsibility in group work. Instructors are often concerned that group activities will permit students to ignore the work for which they are not personally responsible, and the data from question 3 lend credence to this concern. In the last year of the project we drew on other educators' work on collaborative learning to provide more structure to the group activities and clearly delineate individual responsibility [13]. This seemed to address the problem of

ISSN 1430-4171
THE CHEMICAL EDUCATOR
http://journals.springer-ny.com/chedr

S 1430-4171 (96) 04053-8

uneven student participation to some degree; however, this remains an area that requires constant attention on the part of the instructor.

Finally, there was general agreement among the students that most of their peers participated in the group activities. While participation is certainly not equivalent among all group members, it is reassuring to find that students felt that each member was involved in the activities.

Comparison of Environmental and Regular groups

In this section, we compare the performance and attitudes of the environmental and regular groups.

Examination Performance in the Course

Despite the possible advantage of the regular group over the environmental group in terms of high school chemistry preparation (see Table 3), there was no significant group difference in student performance on the examinations during the Fall of 1993. The environmental group's mean overall score in the course was 388 points out of 600, while the regular group's mean was 391 ($z_{610} = 0.33$, $p = 0.37$).

This null result is not too surprising, since the majority of points in the course are given for lecture-related work (e.g., tests, final exam, homework). The material learned in the environmental chemistry laboratory sections was not specifically tested, except for an occasional multiple-choice or short-answer question on some of the midterm examinations. Moreover, it is difficult to separate out factors that might influence this result, in either direction. For instance, because the environmental modules often covered a diverse set of chemical concepts, it was difficult to coordinate the laboratory experience with the lecture material. Some students in the environmental laboratory commented that they felt the laboratory was like a separate course, unrelated to the lecture. To cite a different example that may have contributed positively to the environmental group's experience, the instructor-to-student ratio was higher in the environmental laboratory than in the regular laboratory. In the former case, there were extra "instrument technicians" available to help students use an instrument for the first time. In addition, the faculty member in charge of the environmental course had significantly fewer laboratory sections to oversee than the faculty member in charge of the regular laboratory course and was able to be present in the laboratory more often.

THE CHEMICAL EDUCATOR

ISSN 1430-4171
http://journals.springer-ny.com/chedr
S 1430-4171 (96) 04053-8

TABLE 8. Comparison of departmental student rankings of the environmental laboratory to the regular laboratory. [a, b]

Semester	Means Ranking of Environmental Laboratory (sd)	Means Ranking of Regular Laboratory (sd)	*z* score of difference	*p* value
Fall 1993	5.72 (1.02)	4.48 (1.22)	8.93	<0.0001
Spring 1994	5.67 (1.41)	4.33 (1.26)	6.09	<0.0001
Fall 1994	6.05 (0.66)	4.29 (1.32)	15.78	<0.0001
Spring 1995	5.92 (0.84)	5.01 (1.13)	6.17	<0.0001

[a]On a scale of 1 to 7.
[b]Departmental rankings were not available for Spring 1993.

Ranking of the course

On a departmental evaluation in which students were asked to rank the overall laboratory experience on a scale of 1 to 7, the environmental laboratory outranked the regular laboratory every semester it was offered (see Table 8), with the four-semestermean ranking for the environmental laboratory at 5.89 and that for the regular laboratory at 4.56. These data reveal a higher level of student satisfaction with the environmental laboratory compared to the regular laboratory.

What Was the Most Important Thing You Learned in this Laboratory Course

Some of the most useful data for assessing student outcomes arose from an open-ended question posed to both the environmental group (over four semesters) and the regular group (during Spring 1996): “In a general sense, what is the most important thing you learned in this laboratory course?” The comments from the two groups were coded into six categories, with mixed comments placed into the highest level category. As a check for reliability, 20% of the responses were coded by two coders. Interrater agreement was found to be 94%.

The results are displayed in Table 9. Over the course of four weeks, two context-based modules (“Lead in the Environment” and “Water Chemistry”) were carried out by

THE CHEMICAL EDUCATOR

ISSN 1430-4171
http://journals.springer-ny.com/chedr
S 1430-4171 (96) 04053-8

TABLE 9. Comparison of Environmental Laboratory Students to Regular Laboratory Students in Perceptions of the Importance of What They Learned.

Category	number of students: regular lab (N = 314)	number of students: environ. Lab (N = 257)
1. Comments indicate a sophisticated view of science, a recognition of the limits of science or explicit mention of the complexity of real world issues.	4 (1%)	50 (19%)
2. Student mentions real world issues or the connection of chemistry to real world.	29 (9%)	87 (34%)
3. Student mentions learning chemistry concepts, techniques, or procedures.	152 (49%)	64 (25%)
4. Other Positive Comments.	45 (14%)	14 (5%)
5. Negative Comments.	35 (11%)	7 (3%)
6. No Answer.	49 (16%)	35 (14%)

students in the regular laboratory during this semester, so those students do not constitute a pure control group. If there is any bias, however, it is in the direction of similarity between the two groups. The full text of the comments are contained in Appendix A.

Comments in Category 1 (Sophisticated View of Science) indicated that students had taken a step back from the immediacy of the day-to-day details of what they were doing in the laboratory to take a broader view of the process and limitations of science. These attitudes were representative of students' recognition of the fact that scientific issues are complex and must be carefully scrutinized before conclusions are drawn. Some students indicated they had learned the importance of making their own judgments on the validity of information they collect or receive. The data show that significantly more students in

THE CHEMICAL EDUCATOR

ISSN 1430-4171
http://journals.springer-ny.com/chedr
S 1430-4171 (96) 04053-8

the environmental group responded in this way, as compared to students in the regular group (Fisher Exact test, $p < 0.001$). This suggests that the environmental laboratory helped engender a more sophisticated view of science and of the world in students.

Category 2 responses reflected students' recognition of the connections of chemistry to the real world. Typically, these comments suggested that the environmental students had gained a broader scientific and social perspective on environmental issues. While some students simply mentioned specific environmental issues, others had integrated this knowledge of environmental hazards with the information they had learned about risk assessment. Other comments indicated that students felt empowered by the course to use chemistry to solve problems. As might be anticipated, because the regular laboratory contained predominantly traditional first-year chemistry experiments and only four weeks of environmentally-related experiments, many fewer students in the regular laboratory indicated that they saw the connection of chemistry to the real world ($\chi^2 = 54.19$, $p < 0.001$) Interestingly, over 20% of the regular group who made comments in this category specifically mentioned the environmentally-related experiments.

Responses about the specific details of the processes of doing chemistry and learning traditional chemistry concepts were placed in Category 3. Students in both groups mentioned the need for focus and precision required to do good work. In addition, many students made comments related to learning specific laboratory procedures, techniques, data analysis, and scientific writing. A significantly larger proportion of the comments in this category, however, came from the regular group ($\chi^2 = 32.09$, $p < 0.001$). This suggests that the regular group was more concerned with learning standard laboratory procedures than the students in the environmental group.

Positive comments that did not relate to specific laboratory concepts fell into Category 4. These included remarks on how the laboratory experience helped students improve their study and time-management skills, see the connections between laboratory and lecture, and learn the value of cooperation and teamwork. Significantly more of the regular group's comments were in this category than those of the environmental group ($\chi^2 = 11.72$, $p = 0.001$).

Category 5 comments indicated a negative impression of students' experience in the laboratory. Many of these comments were simple, one-word answers, such as "nothing."

ISSN 1430-4171
http://journals.springer-ny.com/chedr
S 1430-4171 (96) 04053-8

A significantly larger proportion of the regular group's comments were in this category ($\chi^2 = 13.65$, $p < 0.001$). This suggests that a greater fraction of students in the regular laboratory were dissatisfied with the experience than those in the environmental laboratory.

In summary, the environmental group showed an increased "meta-awareness" of the process and limitations of science (Category 1) and mentioned the importance of real-world issues (Category 2) more often than the regular group. In contrast, the regular group focused more on the importance of learning particular techniques and chemistry concepts (Category 3). A greater number of students in the regular group also made generic positive comments about the course, such as the effect of the course on improving their study skills (Category 4). Significantly more of the regular students made negative comments about the laboratory experience (Category 5). Taken together, these comments suggest that the environmental laboratory was successful in helping a number of students step back from the details of the chemistry and reflect on how science works and how it applies to their daily lives. The data also suggest that the environmental group had a more positive overall experience than the regular group.

It is important to note that this question only asks students to comment on the *most important* thing they learned in the course. While students may have learned many things, they only commented on the aspect of the course that struck them as most important. Future studies on new modular curricula presently under development will attempt to assess student opinion in each of these areas.

Conclusions

Before concluding, it is worth noting the aspects of the laboratory experience that were altered in the environmental laboratory compared to the regular laboratory. First, students learned chemical concepts by tackling real-world environmental problems using state-of-the-art instrumentation. Traditional first-year chemistry experiments used primarily wet chemical methods in experiments designed mainly to demonstrate chemical concepts. In addition, novel approaches to teaching (e.g., field trips, group activities, collaborative learning, role playing/debate, independent projects) were fully incorporated into the curriculum of the environmental laboratory. This is in contrast to the approach used in the regular laboratory, where each student typically worked on a traditional experiment for which the result is known in advance. The quality of the

THE CHEMICAL EDUCATOR

ISSN 1430-4171
http://journals.springer-ny.com/chedr
S 1430-4171 (96) 04053-8

teaching in the environmental laboratories may have been better, because the instructor-to-student ratio was somewhat higher than in the regular laboratories. Finally, students specifically chose to enroll in the environmental laboratory course, thus a selection effect existed in the data set. Because some of these factors are independent of the new pedagogy of the environmental laboratory, we must evaluate the modular approach while controlling for those factors in order to make an unbiased comparison. Such an evaluation is currently underway.

The data indicate that we were largely successful in meeting our goals for the project. In spite of a heavier workload and higher expectations for student performance, the environmental laboratory was clearly a more positive experience for students than the regular laboratory. This conclusion is supported by the significantly higher Departmental ranking of the environmental laboratory compared to the regular laboratory. Although we were successful in enrolling more women students into the course, we were unsuccessful in recruiting minority students.

We were also successful in developing students’ scientific skepticism and recognition of the limits of science, in contrast to the traditional laboratory. Student comments indicated that they had gained a broadened perspective on the nature and process of science and were more critical of data obtained using scientific methods.

The inclusion of an environmental context in the chemistry experiments seemed to have had a significant impact on students’ awareness of the connections of chemistry to the real world, with more students in the environmental laboratory remarking on their perceptions of chemistry as useful and applied to their lives. Students also became more aware of the relationships between chemistry and society.

In conclusion, the student evaluation data indicate that a modular approach to teaching chemistry based on topics relating to the lives of students is an effective method of motivating students to work hard to learn chemistry. Because many variables were changed, it is difficult to pinpoint any one particular aspect of the program that made it a success with the students. We can comment, however, that the combination of changes made a significant, positive difference in the students’ perceptions of chemistry and of themselves as scientists.

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