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Undergraduate Research in Kentucky: Biological Sciences

Using Water Quality Monitoring as a University-Level Teaching Tool

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ABSTRACT

Juniors and seniors at Morehead State University gathered water quality data for a variety of monitoring projects from 1994 to 1997. This research experience indicated that intermediate-level students benefitted most. These students were more attentive to detail in lab than normal, and the majority of the data collected was reliable and accurate, as long as the analysis techniques were simple. Most students were less reliable at gathering data that required more complex procedures, such as measuring total phosphorus and nitrogen. Although student involvement increases the supply costs, the educational benefits suggest government/university collaborations of this type can be beneficial for all participants.

INTRODUCTION

Students learn more about the scientific method by being actively engaged in research than they do by reading about it. Undergraduate students gain confidence, skill, and an appreciation of the scientific method by being involved in research projects (Lanza and Smith 1988; Lord 1989). Although the virtues of student involvement in scientific research are well known, most projects rely on academically exceptional students, usually working one-on-one with a researcher.

Over the last 3 years I have engaged in the experiment of using large (20 to 40 students) undergraduate laboratory classes to monitor water quality for various government agencies. These projects encouraged students to think critically (i.e., gather information, process information, evaluate evidence, draw conclusions) in an active learning environment. My goal was to use the ideals of scientific inquiry (based on logic and the evaluation of evidence) to increase student appreciation and understanding of water analysis, which they had previously thought was complicated, boring, and sometimes even dangerous. An additional goal was for students to gain an understanding and appreciation of how new knowledge is obtained.

Students were asked to learn both content and process. Although most professors agree that learning the scientific process is important, few integrate class research, which is one of the best ways to teach how knowledge is gained (Foster 1989; Janners 1988; Postlethwait 1980). My definitions of active learning and critical thinking are more traditional than some current education experts espouse. Ironically, many contemporary proponents of "critical thinking" fail to use the scientific method when making claims of success (Morgan 1995). Similarly, "active learning" is not unknown to those of us who have been immersed in laboratory experiences throughout our educational careers.

Field activities are not prevalent at the post-secondary level, despite the evidence that students find field biology exciting and engaging (Hall 1996). Research suggests that field experiences allow students to concentrate on process skills in a non-distractive environment and encourages camaraderie among students as well as student-professor interactions (Hall 1996; Wheater 1989). It has been suggested that student participation in monitoring projects enhances student interest and learning (Zaimi et al. 1994)

Unlike a pre-prepared laboratory exercise, the projects used in this study enabled the students to engage in research that could have consequences on how water resources in the region would be managed. The merging of learning and performance goals should motivate students and enhance learning success (Dweck 1986). Additionally, since the students' water analyses could have important consequences (beyond performing for a grade), material retention should increase (Carey 1986). Based upon the theory that a field research experience would increase learning, this study endeavors to use a large number of undergraduate students for environmental monitoring projects and to discover benefits and pitfalls of the educational experience.

MATERIALS AND METHODS

Participants included all the students taking four ecology courses (required of all biology majors, including pre-professional students and environmental science majors) and two limnology courses (required of all environmental science majors; an elective for biology majors). Over 120 undergraduate students, with various interests and abilities, participated in the projects. The average ACT composite score for the students involved was 23.2—better than the average MSU student (1992 to 96 mean composite ACT = 19.8); and the national mean for undergraduates (1992–1996 composite national norm = 21.4). The minimum prerequisites for the courses were junior or greater rank, college algebra, and eight semester hours of college chemistry, botany, and zoology; therefore all the students were familiar with the chemical and biological equipment that would be used for their research.

Three water quality monitoring projects involved students: (1) appraising local streams for the Health Department during 1994–1995 to make recommendation on sewage upgrades; (2) assessing the trophic status and water quality of Grayson Lake during the 1995–1997 growing seasons to determine the effects of different management schemes; and (3) monitoring the effects of different types of fertilizer on ponds at the Minor Clark Fish Hatchery during spring 1997.

Before working on the research project, students had two or three 2-hour lab periods during which they practiced field sampling and the chemical analysis of soluble reactive phosphate (SRP), nitrate, nitrite, and ammonia. Limnology students also learned how to measure total phosphorus (TP), total Kjeldahl nitrogen (TKN), total suspended solids, and chlorophyll a. Students used standard methods (APHA 1985) or the simplified Hach equivalents (Hach Company 1994). All students were required to take field water samples and become familiar with operation and calibration of field instruments to measure dissolved oxygen, pH, conductivity, and Secchi depth. Students always worked in groups of two to five. After all the samples were analyzed by the student groups, I or a graduate student repeated the analyses to check for reliability.

After the project, each student was required to write a report (including results and statistical analysis) using a scientific format (i.e., introduction, materials and methods, results, recommendations, amd literature cited) that was suitable for submission to the funding agency. Students knew their reports would not only be graded but possibly given to the agency to aid in decision-making. Reports were generally worth about 20% of their lab grade; lab grades were worth about 1/3 of their final grade for the course.

Student outputs were analyzed to see if there was any learning enhancement for a particular group. I compared their overall ACT score to their scores on both the laboratory project and their final score in the class. Data included all the students involved in the project for which all scores were available (ACTs were not on file for some transfer students). Since more than 30 students took both ecology and limnology, I included their scores from only the first time they did the project so there would be no bias toward those repeating the assignments and activities. Graduate students, too, were removed from the data set.

RESULTS

As most people who have taught or taken laboratory courses know, one of the common problems creating poor results is that many students try to "cookbook" their way through procedures in the fastest possible manner. This also usually results in students not understanding the underlying assumptions behind much of what they did or how the results apply to the hypothesis tested. In contrast, the laboratory atmosphere during most of our projects was extraordinarily dynamic.

Compared with other labs, students tended to be much more attentive to details and much more concerned with doing procedures correctly. For example, it was not uncommon for a student to question if or how they may have done something wrong and to repeat procedures until they were satisfied with the outcomes. Students recognized the lab procedures when questioned about them on exams and were able to interpret results with relative

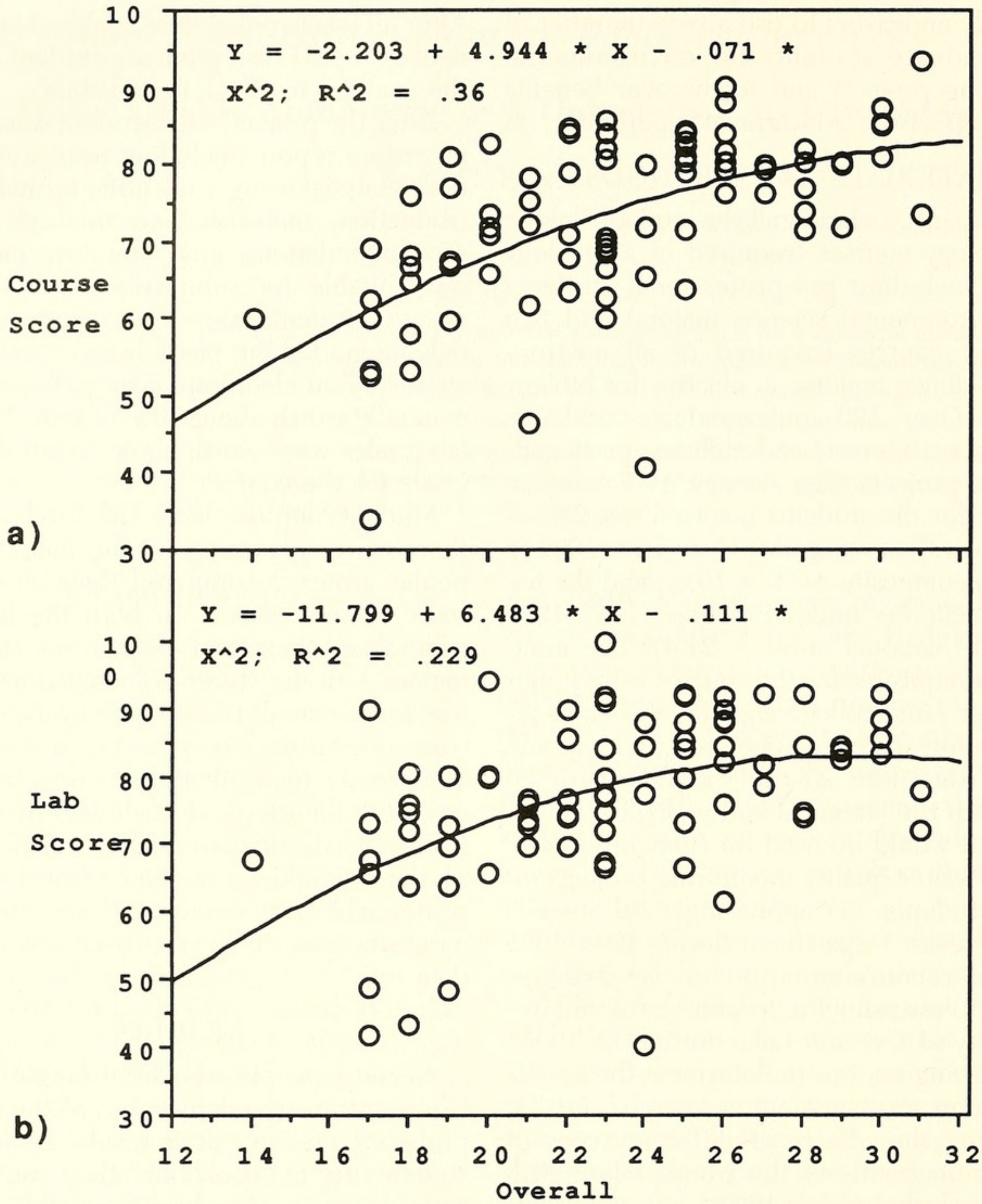

Figure 1. Relationship between overall ACT scores and student performance in water monitoring projects at Morehead State University. Best-fit of second-order regressions between ACT and (a) final score in the course and (b) score on a research report based upon the research activity.

accuracy in reports. I assumed this attention to detail was because the students knew that their data were going to be used for a management decision in the region.

A comparison of ACT scores to their performance on their research reports showed that students with high ACT scores tended to perform better than those with low ACT scores (Figure 1). It is interesting to look at the performance by mid-range and high-performing students (arbitrarily chosen as students with a composite ACT > 19). Mid-level students (abitrarily chosen as students with ACT scores 20 to 26) achieved scores just as high or higher than the 'A' students when given a problem-solving activity. A linear regression slope of ACT vs. lab score for students with ACT composite scores greater than 19 is only 0.72 (correlation r = 0.22; n = 65). The slope for these same students vs. their final score in the course is 1.28 (correlation r = 0.41; n = 65), showing that mid-range students performed better on the research project than on other course projects and exams.

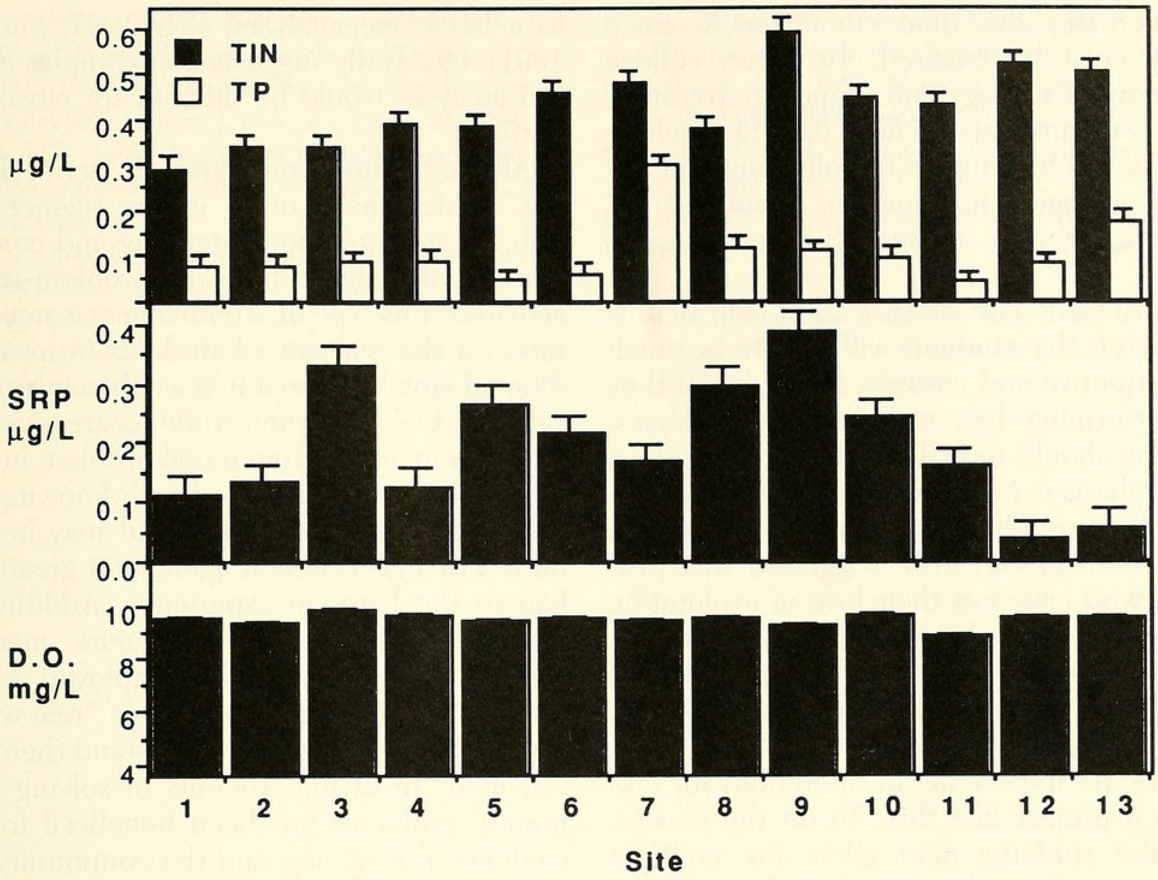

Figure 2. Results from water monitoring projects at Morehead State University. Student measurements of dissolved oxygen (D.O.), total phosphorus (TP), soluble reactive phosphorus (SRP), and total inorganic nitrogen (TIN) concentrations in 13 sites along Triplett Creek and its tributaries from Sep 1994 to Aug 1995. Error bars represent one standard deviation.

A concern when using students for monitoring and research is whether the data they collect are reliable and accurate. Most students were able to perform well on simple tasks, and data from different lab groups usually agreed fairly well (Figure 2). Measurements that required the use of electronic meters (e.g., Hydrolab, YSI D.O., conductivity meters, and pH meters) or a Secchi disk in the field were always accurate. In the lab, students were equally competent with spectrophotometric measurements using Hach Accuvac ampules or 1–2 step chemical procedures.

On more complex analyses, such at TP and TKN digestions, or nitrate using cadmium reduction columns, students were much less effective at obtaining accurate information. When the data were incorrect, values often deviated from standards by an order of magnitude; these problems could usually be traced to contamination, errors during sampling, or errors in specific procedures.

Not all classes were able to perform even the simple tasks effectively; the limnology class from spring semester 1997 had a greater than 40% failure rate in lab work. This class was less attentive to detail and more cavalier in attitudes toward the project than previous classes.

DISCUSSION

Lanza and Smith (1988) suggested that the success of undergraduate research projects should be gauged by the quality of the research and the amount of student growth. Our projects were usually successful at increasing both. More importantly, the data suggest that middle-range students gained more from this experience than other students did. Poor students did not increase in performance; no harm was done to successful students. This could be an important area to explore with a more controlled study.

From the standpoint of the instructor, running a laboratory as part of a monitoring project increases the time commitment, since quality must be ensured. However, college professors of ecology and limnology routinely gather vast amounts of field data in teaching students the techniques of collecting and analyzing ecological information. It only takes a bit more effort to make this data gathering "real."

The obvious educational advantage of this approach is that students will tend to be much more attentive and motivated than when they are performing less consequential analyses. Cheating should most likely be reduced since the emphasis is on solving a relevant problem rather than simply getting a number to put in a box. Lord (1989) even suggested that professors who have lost their love of exploration as a result of teaching the same course for many years may rediscover the excitement of learning when they get undergraduate students involved in research.

There are important considerations for taking on a project like this. To do the checks, train the students, and allow for multiple groups to analyze the same samples, we performed at least four times as many tests as we would have if monitoring under normal conditions. Consequently our material and supply costs increased about four-fold. To some extent these financial costs were offset (i.e., I would have run some of these tests as part of the labs for teaching purposes under normal circumstances). Since water analysis labs are included in all the major limnology ad ecology laboratory manuals, I assume many other professors would be in a similar situation. It could be assumed that I simply took money that would be "wasted" and put it to a more practical use (Zaimi et al. 1994).

This study also has implications for the use of citizens in water quality monitoring. Like our students, citizens and school children are often highly motivated to monitor lakes and streams. It should be noted that our students sometimes failed at relatively simple tasks, although their training in chemistry and using instrumentation was far in excess of average persons. Furthermore, some of my students' errors occurred due to contamination of sample containers in the field. Citizen volunteers usually limit the water analysis they perform to fairly simple techniques and measurements, and they send water and chlorophyll filters off to a lab to be analyzed (Ely 1997; Simpson 1991). Our study suggests that complex chemical analyses would be difficult for citizens to perform.

Although the main tenet of "active learning," which many of us in the sciences call "lab," is to foster understanding and comprehension of material by using problem-solving activities, this type of attentiveness is not common for the majority of students in most traditional labs. Although it is a subjective observation, I feel that when students are given the opportunity to confront a real problem in their geographic area, combined with knowing that their results are important (and may be submitted to a government agency), it greatly enhances the learning experience. Additionally, our environmental science majors, many of whom may eventually be employed in the Commonwealth, gain the type of "real world" experience they need to understand their chosen field. Involving students in solving community problems has been beneficial for the students, the agency, and the community.

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LITERATURE CITED

[APHA] American Public Health Association, American Water Works Associate, and Water Pollution Control Federation. 1985. Standard methods for the examination of water and wastewater. American Public Health Association, Washington, DC.

Carey, S. 1986. Cognitive science and science education. Am. Psychol. 41:1123–1130.

Dweck, C.S. 1986. Motivation processes affecting learning. Am. Psychol. 41:1040–1048.

Ely, E. 1997. Volunteer lake monitoring. Lakeline 17:12, 13, 60, 61.

Foster, J.M. 1989. Teaching experimental science: enzymes and the laboratory. Pages 39–46 in F.R. Weaver (ed). Promoting inquiry in undergraduate learning. New directions in teaching and learning no. 38. Jossey-Bass, San Francisco, CA.

Hach Company. 1994. DR/2000 spectrophotometer handbook. Hach Company, Loveland, CO.

Hall, D.W. 1996. Bringing hands-on experience to teaching insect field biology. J. Coll. Sci. Teach. 24:195–200.

Janners, M.Y. 1988. Inquiry, investigation, and communication in the student-directed laboratory. J. Coll. Sci. Teach. 17:32–35.

Lanza, J., and G.C. Smith. 1988. Undergraduate research: a little experience goes a long way. J. Coll. Sci. Teach. 17:118–121.

Lord, T.R. 1989. Promoting student research at the two year college. J. Coll. Sci. Teach. 18:174–177.

Morgan, W.R. 1995. 'Critical Thinking'—What does that mean? J. Coll. Sci. Teach. 24:336–340.

Postlethwait, S.N. 1980. Improvement of science teaching. Bioscience 30:601–604.

Simpson, J.T. 1991. Volunteer lake monitoring: a methods manual. EPA 440/4-91-002.

Wheater, C.P. 1989. A comparison of two formats for terrestrial behavioural ecology field courses. J. Biol. Educ. 23:223–229.

Zaimi, O., A.C. Blizzard, and G.J. Sorger. 1994. Teaching water quality analysis with community collaboration. J. Coll. Sci. Teach. 23:105–110.