Assessing the Impact of Geoscience Laboratories on Student Learning: Who Benefits from Introductory Labs?

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ABSTRACT

Laboratories serve as an integral part of geoscience education at most colleges and universities. While anecdotal evidence supports the beneficial impact of laboratories on science class learning, little quantitative research backs this statement. This study compared classroom data from students who completed a geoscience laboratory in conjunction with an introductory-level lecture-based course to those who completed the lecture course only. Laboratory-enrolled students performed better in the lecture class, resulting in an increase of 5.5% in their final class score. Even after controlling for GPA, laboratory enrollment accounted for a statistically significant proportion of the variance. Nontraditional students (age 25 and over) primarily benefited from the laboratory. Nontraditional students enrolled in lab performed 21.1% higher overall than their lecture course only nontraditional counterparts, and 4.9% higher overall than traditional students who enrolled in both the laboratory and lecture courses. Geoscience laboratories play a significant role in student learning and appear particularly important for nontraditional students.

INTRODUCTION

Laboratories play a central role in teaching geosciences at most United States colleges and universities. They provide students with hands-on learning experiences commonly absent from, or minimized in, lecture-based courses and can help students develop practical problem-solving skills related directly to course content through inquiry, discovery, measurement, observation, and data gathering. For students whose major area of study is in the geosciences, laboratory skills help prepare them for further study in the discipline, employment in science fields, and entrance into graduate programs. For students majoring in other disciplines, introductory geoscience laboratories fulfill general education requirements, serving to broaden their understanding of the natural world. Geoscience laboratories provide these students with skills in observation, problem solving, mechanical manipulation of materials, models and equipment, and skills in scientific reasoning and interpretation designed to broaden their educational experiences.

Assessment of student learning in the geosciences, particularly in higher education, has increased in the past several years (Perkins, 2004) but quantitative study of student learning still lags behind other disciplines (Libarkin and Anderson, 2005). As greater emphasis is placed on assessment of student learning in higher education, institutions increasingly find themselves needing to offer quantitative evidence of continuous improvements in student learning. This study may provide a basis for evaluating the effect of introductory laboratories on overall performance in introductory geosciences courses.

Numerous studies have supported the benefits of science laboratories and other inquiry- or project-based learning at the primary and secondary education levels (Bates, 1978; Blosser, 1983; Baird, 1990; Bybee, 2000). Those studies strongly support the idea that laboratories provide opportunities for inquiry-based learning, conceptual and scientific procedural knowledge. The National Research Council (1996) advocated the use of science laboratories as an especially important part of inquiry-based science education. However, the research evidence (Bybee, 2000; Hofstein and Lunetta, 2003) has not directly supported the usefulness of science laboratories in learning content of courses (e.g., higher exam grades).

Much of the recent research related to student learning in the geosciences at the college and university level has evaluated student attitudes and/or understanding related to specific concepts before and after engaging in a particular activity (Huntoon et al, 2001; Cooper et al, 2002; Gosselin and Macklem-Hurst, 2002; Hall-Wallace and McAuliffe, 2002; Greer and Heaney, 2004; Owen et al, 2004; Patterson and Harbor, 2005). In all of these studies, pre- and post-test measures evaluated student attitudes and comprehension, and assessed the effectiveness of projects, teaching techniques, the use of software, and technological devices on student learning. More comprehensive assessments studies (Williams et al, 2004; Libarkin and Anderson, 2005; Sibley et al, 2007) evaluated a broader range of concepts or subject area knowledge through examination. Relatively few studies (McConnell et al, 2003; Alley et al, 2007 are notable exceptions) have evaluated the effect of teaching and learning strategies on student exam scores or course performance (i.e., total course scores and grades). Studies examining the impact of introductory geoscience laboratories as tools for enhancing learning in associated lecture-based courses at the university level appear lacking.

In this study, we evaluated the effectiveness of introductory geoscience laboratories on student learning at a four-year, commuter-campus university. The campus serves a mainly undergraduate student population (87%) with a mean age of 28; 40% of students are over the age of 25. Women comprise 70% of the student population and 43% are part-time students. The campus is ethno-culturally diverse with a student population of 58% Caucasian, 22% African American, 13% Hispanic, and 7% reporting other ethno-cultural heritages.

Given the lack of previously published research assessing the effectiveness of introductory labs at the

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university level, readers should see the questions asked and hypotheses tested as exploratory in nature. First, this study examined the achievement of students who completed a laboratory in conjunction with an introductory-level lecture-based course compared to those who completed the lecture course only. We hypothesized that students taking the laboratory would perform better than those who did not. Second, the study explored the possibility that a specific group of students, non-traditional students, might benefit more from laboratories than traditional students.

Despite reporting higher levels of intrinsic motivation and interest in academic pursuits (Bye et al., 2007), non-traditional students face other serious challenges to academic success. These include family responsibilities, work obligations, and the length of time spent away from an academic environment before beginning or returning to college. Based on past instructors' experiences, we predicted that non-traditional students would perform better when also enrolled in a laboratory section.

METHODS
Participants

Undergraduate students (N = 108) enrolled in three introductory geosciences classes during the spring 2008 semester participated in this study. Students' ages ranged from 18 to 58. Mean (*M*) age was 23.68 and the Standard Deviation (*SD*) was 6.85; 57.4% were female. Students' class standing varied substantially: 25% freshman, 33.3% sophomore, 15.7% junior, 13% senior, and 13% other (e.g., graduate students, second degree seeking students); 71.3% of study participants were traditional students, and 28.7% non-traditional (25 years or older) students. The students reported a mean grade point average (GPA) of 2.98 (*SD*=0.58). The sample was diverse and representative of the campus: 58.3% Caucasian, 16.7% African American, 10.2% Hispanic, 4.6% Mixed Ancestry, and 10.2% other (Fig. 1). Current semester credit hours ranged from 4 to

24, (*M*=12.83, *SD*=3.20); 12 credits reflects full-time enrollment.

Materials

Research Packet. Early in the semester, students who agreed to participate in teaching-related research completed a questionnaire packet. This packet included an informed consent document and a demographics sheet. Information gathered using single items on the demographics sheet included participant sex, age, class section, lab section (if enrolled), cumulative grade point average (GPA), ethno-cultural identity, and course load in credit hours. Self-report of GPA, and other demographic variables, represents a commonly accepted research methodology in the social sciences (Frucot and Cook, 1994). Although students do not always report exact values, the correlations between self-reported information and that obtained from other sources usually appear quite high. For example, Frucot and Cook (1994) reported a correlation in excess of *r*=.90 between self-reported cumulative GPA and that obtained from a registrar's office. Thus, researchers view such self-report data as trustworthy.

Procedure

During the second week of the semester, all students in attendance learned about the research. At the beginning of a lecture class, a professor associated with this study and not teaching the course asked students for permission to use their class data in a study addressing geosciences laboratories impact on learning in geosciences courses. None of the authors of this paper served as instructors in any of the courses surveyed or any of the laboratories in which the students had enrolled. Students who agreed to participate completed a research packet. In compliance with local Institutional Review Board guidance, the course instructor exited the room during the research packet completion and did not receive any information regarding
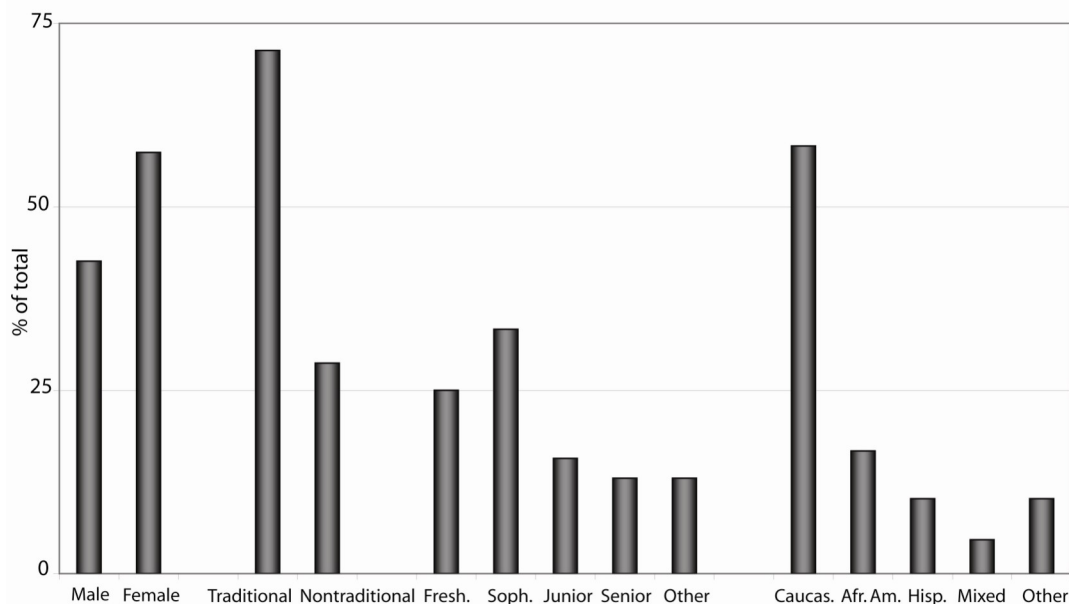

FIGURE 1. Gender, age, college standing, and ethnicity of study participants.

study participation until after submission of semester grades. One instructor taught all classroom sections. Students could enroll in one of four laboratory sections taught by three different instructors. At the end of the semester, the classroom instructor provided indices of classroom learning in the form of total course points, homework exercise grades, quiz grades, and exam grades.

Introductory Geoscience Lectures and Laboratories

Students enrolling in introductory geosciences courses have two options. They may enroll in the lecture section only or in a lecture section and a laboratory section concurrently, depending on their own needs and programmatic requirements. Students receive university credit separately for the lecture section and the laboratory section.

During the semester in which this study was conducted, students were assessed in the lecture section based on their performance on homework assignments, quizzes, and examinations. Students could receive up to 1000 points in the course, and grades were assigned based on the percentage of total possible points a student earned.

Introductory geoscience laboratories use selected workbook-style laboratories from the American Geological Institute/National Association of Geoscience Teachers publication (2007). The university laboratory space contains all the materials and equipment necessary to conduct the full laboratories, including mineral and rocks samples, mineral testing equipment, topographic maps, and stereoscopes--a standard for most college- and university-level introductory geoscience laboratories.

DATA ANALYSES

The results section contains a variety of analyses, in several sections, used to address the main questions in this paper. The data analyses in the first results section addressed the size and distribution of the sample, relative to the number of students enrolled in all of the introductory lecture session. In addition, this section addressed the question of whether it appeared reasonable to use total course points as a stand-in for classroom performance or whether quizzes, exams, and homework scores should receive separate consideration. Strong correlations (r) could justify combining the scores together. An r indicates the strength of a relationship between two variables; values close to 0 indicate no relationship and the strength of the observed relationship increases as r values move closer to 1 or -1. The first section also addressed differences across sections using F tests (also called Analysis of Variance tests or ANOVAs) to see if all sections could be combined for further data analyses or if laboratory or class sections differed from each other. A one-way F test, like a t test, can indicate if groups differ from each other. However, the F can test for differences between two or more groups whereas the t-test can only look for differences between two groups.

The second results section used a two-way F test to examine the impact of multiple Independent Variables (laboratories and traditional/non-traditional status) on one dependent variable (classroom performance). A two-way F allows researchers to consider both whether identified groups for each Independent Variable impact the Dependent Variable (i.e., do the groups differ when ignoring the other Independent Variable, and whether the identified Independent Variables work together to determine Dependent Variable differences). As an aid to understanding these results, this section also reported Means (Ms) and Standard Deviations (SDs) for groups compared and included a graphical representation of this data. A series of additional one-way F tests, conducted as post-hoc analyses (Gravetter and Wallnau, 2007) examined the impact of laboratory enrollment, separately, for both traditional and non-traditional students.

The third results section further explored the impact of laboratories on learning, through the use of a one-way F, to confirm the impact of laboratories on learning and explored possible variables that might have a relationship to classroom performance other than students' status and laboratory enrollment status. This analysis used correlations (r) and F tests to determine if certain demographic variables (i.e., GPA, credit hours enrolled, previous experience with college laboratories, high school science classes) might provide a better, alternative explanation for the observed classroom learning outcome. For the one variable, GPA, where a relationship existed with total class performance, a multiple-regression was conducted. A multiple regression attempted to predict a dependent variable (classroom performance) based on multiple independent variables (GPA and laboratory enrollment). By entering the GPA first into the prediction, this allowed the researchers to determine if laboratory enrollment predicted classroom performance above and beyond past academic achievement as indicated by GPA. Multiple-regression allows researchers to generate a statistic, F_{change}, to determine if the Independent Variable entered second actually improved the prediction above and beyond that of the Independent Variable entered first. If so, then the results will indicate what percentage of additional variability (variance = r^2) the second variable accounted for beyond that accounted for by the first variability.

RESULTS

Description of Sample Size and Identification of Total Score as Performance Indicator

Of the 162 students enrolled in the course, 118 attended classes on the day of data collection, and 108 (91.5%) chose to participate in this study. The number of participants involved in subsequent analyses varied based on missing data. Among the 108 students who participated in this study, 42 (38.9%) had enrolled in one of the four laboratory sections mentioned above.

Initial comparison of correlations between the graded indices suggested strong correlations among them and the total points earned in the course. This appeared for correlations between the total course scores and quizzes (r=0.72, N=107, p<.001); total course scores and exams (r=0.92, N=108, p<.001); and total course scores and homework exercises (r=0.80, N=108, p<.001). Given this pattern of relationships, subsequent analyses focused on the overall course score, rather than individual course

indices. The total course score could run as high as 1000 points.

Examination of class performance indicated no statistically significant differences across the three class sections, $F(2, 105)=0.12$, $p>.05$, or across the four laboratory sections, $F(3, 38)=0.75$, $p>.05$. Thus, subsequent data analyses merged the data from all course and laboratory sections.

Impact of Laboratories on Traditional and Nontraditional Students

A 2 X 2 ANOVA examined the impact of laboratory enrollment for students of various ages. Classroom performance served as the dependent variable. Student age (under age 25 for traditional students and age 25 or above for nontraditional students) and laboratory enrollment status (enrolled or not enrolled) served as the independent variables. The ANOVA suggested a statistically significant interaction, $F(1, 101)=6.22$, $p<.05$, between the two independent variables.

The impact of laboratory enrollment on the different age groups is summarized on Figure 2 and in Table 1. Even though GPA is similar and performance in the lecture course is nearly identical for both traditional and non-traditional students (Fig. 2), visible differences exist between laboratory enrolled and lecture-only students. Traditional students enrolled in the laboratory ($M=815.54$, $SD=110.71$) increased performance by only 2.6% over traditional students not enrolled in the laboratory ($M=794.99$, $SD=103.78$). Nontraditional students enrolled in the laboratory ($M=855.40$, $SD=69.43$) earned almost 150 points more (21.1%) than nontraditional students not enrolled ($M=706.25$, $SD=203.13$) in the laboratory section. Furthermore, non-traditional students enrolled in the laboratory earned almost 40 points more (4.9% higher) than traditional students enrolled in the laboratory. However, non-traditional students who did *not* take the laboratory lagged behind traditional lecture-only students by nearly 89 points (i.e., performed 12.6% *below* lecture-only traditional students).

Impact of Laboratory Enrollment on Classroom Performance

As a follow-up to the statistically significant interaction, the main effect of laboratory enrollment was examined. Students enrolled in the lab had higher total course scores ($M=833.57$, $SD = 95.37$) than those not enrolled in the lab ($M=778.08$, $SD = 131.31$), $F(1, 103)=5.54$, $p<.05$. Thus, laboratory enrollment resulted in an increase of 5.5% in the final grade.

Additional post-hoc analyses examined each student group separately, traditional and non-traditional students, to determine whether laboratory enrollment resulted in improved classroom performance for each student group. Based on modified F test analyses (Gravetter and Wallnau, 2007), laboratory enrollment clearly benefitted non-traditional students, $F(1, 101)=12.27$, $p<.001$. However, the laboratories failed to clearly improve class scores for traditional students, $F(1, 101)=0.52$, $p>.05$, in the learning of course material.

Examination of correlations between GPA and total points suggested a positive relationship ($r=0.36$, $N=100$, $p<.001$) when examining all students. To test if the benefit of laboratories existed beyond that associated with better academic preparation, a multiple regression was run to control for the impact of past academic success on class performance. This used a two-step regression with class performance as the dependent variable; GPA (first Independent Variable) entered on the first step and laboratory enrollment (second Independent Variable) entered on the second step. Even after controlling for GPA, laboratory enrollment accounted for a statistically significant additional proportion of the variance (2.6%) [F_{change} (1, 94)=4.01, $p<.05$]. Students taking the laboratory along with the classroom course reported taking more college level laboratories ($M=1.07$, $SD=2.19$) than those who did not take the laboratory ($M=0.26$, $SD=.70$), $F(1, 102)=7.45$, $p<.01$. In order to determine if students' histories with science laboratories could have impacted the relationship between current lab enrollment and class performance, correlations between class performance, years of high school science ($r=-.14$), and the number of laboratories completed at the college level ($r=.07$) were examined. Neither of the correlations proved significant (all $p>.05$).

Finally, correlations were calculated to examine possible relationships between credit hours and course performance to determine if taking a smaller number of

TABLE 1. IMPACT OF LABORATORY ENROLLMENT FOR TRADITIONAL AND NON-TRADITIONAL STUDENTS

Group		Class performance in total points (standard deviation)	Performance increase (lab + lecture vs. lecture only)	Performance increase for non-traditional students compared with traditional students in the same courses
Traditional Students	Lab + Lecture	815.54 (110.71)	2.6%	
	Lecture only	794.99 (103.78)		
Non-traditional Students	Lab + Lecture	855.40 (69.43)	21.1%	4.9%
	Lecture only	706.25 (203.13)		-12.6%[1]

[1]negative number denotes decrease in performance
F(1, 101)=6.22, p<.05

credits might account for some of the variability in classroom performance The correlations between classroom performance and credit hours proved non-significant for the entire sample (r=0.10, N=106, p>.05), as well as for non-traditional (r=0.08, N=31, p>.05) and traditional (r=0.12, N=75, p>.05) students (Fig. 3).

SUMMARY OF PRIMARY RESULTS

This study examined: a) whether enrolling in a laboratory would help with learning, and b) whether one group of students, non-traditional age students, might benefit more from laboratory exposure. The results of this study supported the contention that students enrolled in laboratories perform better than students enrolled only in the lecture sections of an introductory Geosciences course. The interaction analyses, and the post-hoc analyses, indicated that non-traditional students benefited substantially from enrolling in the laboratories. These students performed dramatically better than non-traditional students enrolled only in a lecture. Non-traditional students enrolled in the laboratory also outperformed traditional students enrolled in the lab and lecture, whereas non-traditional students who did not

take the lab, lagged behind their traditional counterparts.

In an attempt to understand why the laboratories helped, and to rule out alternative explanations for the benefits of laboratories, additional analyses addressed possible impacts of academic ability (GPA) and student history with science laboratories. GPA accounted for some of the variance in classroom performance, as expected, but enrollment in the laboratory still accounted for significant variance in classroom performance. The variables related to historical experience with science laboratories showed no relationship to lecture class performance.

DISCUSSION

Why did laboratories benefit non-traditional students so dramatically? The answer cannot simply reflect spending more time exposed to concepts and material relevant to class. If this explained the outcome, traditional students should also show a similarly large benefit from enrolling in the laboratories. Participation in lab may influence the way in which students study for the lecture-based course in one of several ways. Enrolling in laboratories may increase the amount of time spent studying for the class by non-traditional students in
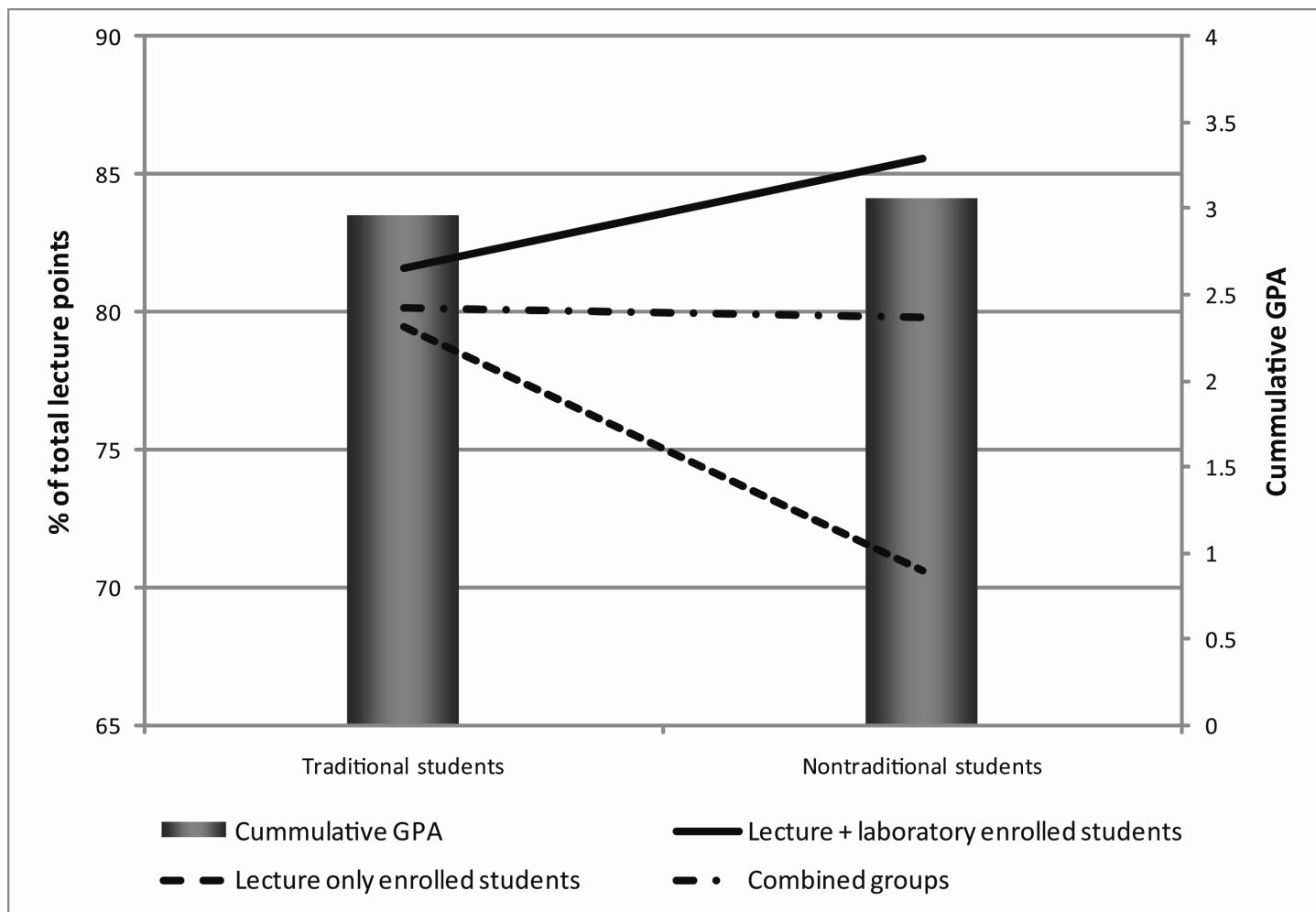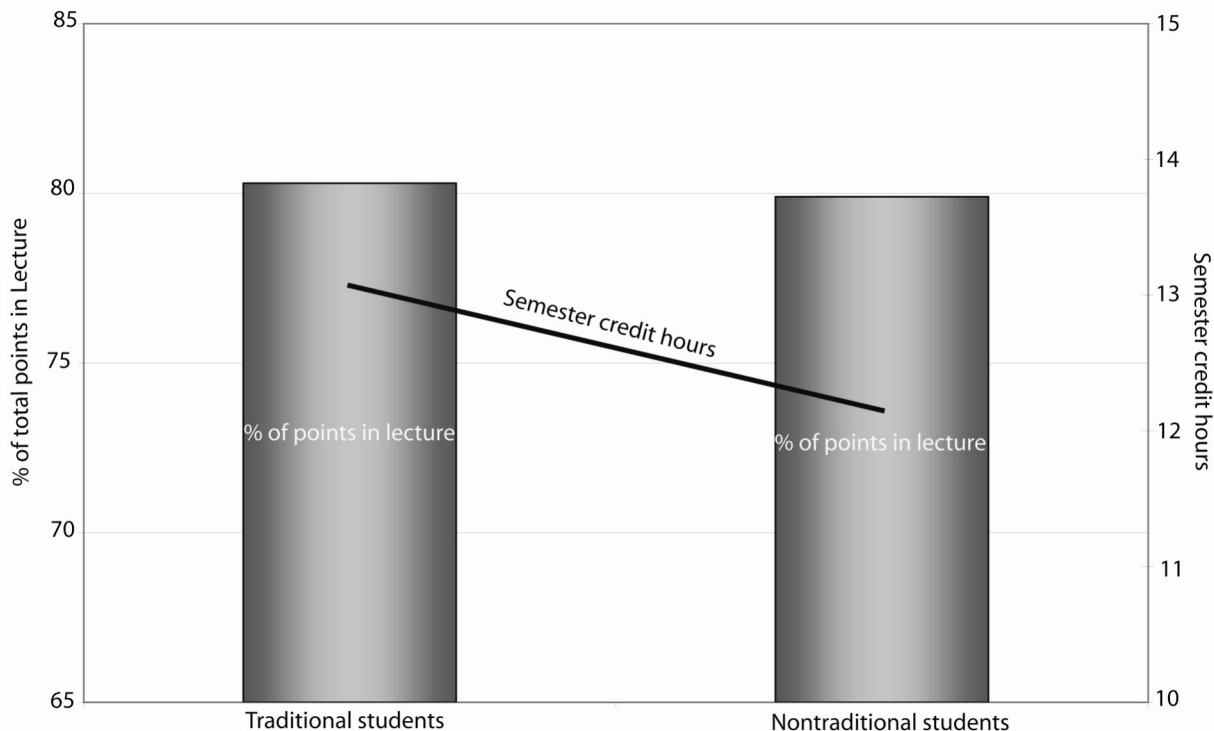

FIGURE 2. Percent of total course points (left axis) and cumulative GPA (right axis) for traditional and non-traditional students. Lines reflect course scores for lecture and laboratory (solid line), lecture course only (small dashes), and both groups combined (long and short dashes). Mean course points as a function of student age and laboratory enrollment.

FIGURE 3. Students' performance in class compared to semester credit hours.

relation to traditional students. Furthermore, structured laboratory activities may provide an organizational template by which students with poorer study skills can focus their efforts for the lecture-based course. The laboratory may even provide these students with a substitute for studying while still exposing them to certain concepts covered in the lecture-based course. Future research could address these explanations in more detail by asking students to track time spent studying or by surveying students on specific study habits and skills. Alternatively, the non-traditional students in the current sample may have a differential preference for hands-on, active learning strategies and this may account for the substantial benefit. Future research could address this through classroom assessment of preferences for different approaches to learning, as suggested by Strange (2008). At present, these hypotheses remain speculative but provide a basis for future research.

Future research studies should consider several additional areas for investigation. First, why did the laboratory experience fail to significantly benefit traditional students? Conducting qualitative interviews (Hoepfl, 1997) with traditional students who did well and poorly in a lecture section, while enrolled in a laboratory section as well, could provide one way to start exploring this unexpected finding. Initial questions should focus on perceived strengths and weaknesses of laboratories as learning environments and perceived relationships between laboratory activities and lecture sectional informational content. Also, the use of a geoscience knowledge questionnaire at the beginning and end of the course might provide data to further explore this unexpected finding. Specifically, this would provide evidence that class performance differences came from

exposure to the laboratory learning environment, rather than from information learned before taking the introductory geoscience course. Second, the data in this study came from introductory geoscience lecture classes taught by the same instructor during the same semester. This leaves open the question of whether the results generalize to other geoscience instructors, students in other semesters, and other physical sciences. Finally, only the students in class on the day of data collection participated in the study. Thus, students with better school performance overall, who probably attend classes more regularly, may appear at higher than normal rates in the current study. Attempting to gain permission multiple times during the semester could counteract this potential bias in study participant selection.

Future studies should also consider outside-of-school factors that may play a role in impacting classroom performance. Although credit hours showed no relationship with classroom performance, other variables may play a role here, especially among non-traditional students. Variables that might impact classroom performance could include the degree of available social supports to allow time for studying, time spent engaged in active employment, and amount of time dedicated directly to child care. It may prove possible, in future research, to address these additional variables through self-report of hours worked or through assessing sources and levels of stress in students' lives.

This type of study presents one substantial inherent challenge. For ethical reasons, Geosciences departments cannot randomly assign students to enroll in laboratories, or refrain from enrolling in such laboratories, while taking geosciences lecture courses. Students in the current study had already made their laboratory enrollment decision

before this study began. This may have skewed the results because students who perceived a benefit from the laboratory may have already decided to enroll.

In this sample, non-traditional students enrolled in the laboratory appeared to learn more (have higher final class scores) than those who did not enroll in the laboratory. Overall, this study provides preliminary support for encouraging non-traditional students to take science laboratories when enrolling in introductory science lecture sections.

CONCLUSIONS

This study examined:
    a) whether enrolling in a laboratory would help with learning, and
    b) whether one group of students, non-traditional age students, might benefit more from laboratory exposure.

Major results of this study are as follows:
    a) Students enrolled in laboratories performed better, overall, than students enrolled only in the lecture sections of an introductory Geosciences course.
    b) Non-traditional students benefited most from enrolling in the laboratories. These students performed dramatically better than non-traditional students enrolled in a lecture-only section.
    c) Non-traditional students enrolled in the laboratory also outperformed traditional students enrolled in the lab and lecture, whereas non-traditional students who did not take the lab, lagged behind their traditional counterparts.

Alternative explanations for the benefits of laboratories were ruled out by additional analyses addressing possible impacts of academic ability (GPA); student history with science laboratories and courses; and student course loads (credit hours). With respect to these variables, we found:
    a) GPA accounted for some of the variance in classroom performance, as expected, but enrollment in the laboratory still accounted for significant variance in classroom performance.
    b) Credit hours, experience with science classes, and science laboratory experiences showed no relationship to lecture class performance.

Acknowledgements

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