Designing Undergraduate Research Experiences for Nontraditional Student Learning at Sea

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ABSTRACT

The environmental science curriculum at the University of Washington, Tacoma (UWT) is based on an experiential learning model that enhances undergraduate education by involving students in ongoing research projects that extend beyond the classroom into the broader scientific community. Nontraditional student learning is especially enriched by access to unique hands-on field experiences that foster a sense of scientific ownership. During the summers of 2001 and 2002, undergraduate students from UWT participated in two very different marine research courses designed by environmental science faculty. By comparing these two course designs, we have identified two primary issues of importance when setting up a field research program at sea. First, learning outcomes are dependent on the platform chosen for the research cruise, and thus the vessel to be used must be considered when designing a curricular model. Second, planning and implementation considerations need to be addressed regardless of the platform chosen. Planning challenges include early advertising, minimizing costs, and scheduling for nontraditional students; while implementation considerations include research group configurations and the structure of the post-cruise working environment.

INTRODUCTION

UWT was founded in 1990, by the State of Washington, as a two-year, upper-division public undergraduate institution. This campus was created to increase access to four-year baccalaureate degrees for place-bound, time-bound students of the South Puget Sound region. UWT is a commuter campus with a population of approximately 2000 students, both full and part-time, with 69% women and an average age of 31. More than 50% of the students work 20 or more hours per week, 61% receive some form of financial assistance, and 59% are the first members of their families to attend college. UWT, therefore, serves a large, nontraditional student population, and for most of its students this campus provides the only opportunity to complete an advanced undergraduate science education.

As a result of the organizational structure of Washington's educational system, most of UWT's incoming students (83%) come from the state's community colleges, where there is limited access to inquiry-based learning experiences through undergraduate scientific research. Science education forums regularly reiterate that undergraduate research experiences are invaluable for truly engaging students in the excitement of science, and necessary for adequately preparing these students for science-related careers or graduate programs (Taylor and Barnard, 1980; Sigma Xi, 1989; Tobias, 1992; Sigma Xi, 2000; Wenzel and Austin, 2001). Moreover, access to scientific research opportunities is especially important in educating nontraditional students (Eves et al., 1990; Tobias, 1990; Secord and Greengrove, 2002).

Environmental Science Model at UWT - All the natural sciences at UWT are organized within a framework of an environmental science curriculum (Secord and Greengrove, 2002) housed within the Interdisciplinary Arts and Sciences (IAS) Program, which serves over half the UWT student population. The curriculum is consistent with national models that incorporate an interdisciplinary approach in the study of environmental science, which includes not only the technical and quantitative aspects, but also the larger societal context that impacts the role that science plays in addressing environmental problems (Hungerford and Peyton, 1986; Weis, 1990; Weis et al., 1992; Simmons, 1994; UNESCO, 1995; Wilke, 1995; Archie, 1996).

From its inception in 1996, the environmental sciences program has been built upon the premise that experiential learning is the most effective means of educating and retaining nontraditional students in the sciences (Kern and Carpenter, 1984; Kern and Carpenter, 1986; Eves et al., 1990; Tobias, 1990; Shiber, 1999; Secord and Greengrove, 2002). As a result almost every science course taught at UWT, for majors and non-majors alike, offers students the opportunity to participate in hands-on laboratory and field-based activities. This commitment to inquiry-based, hands-on science education has not only helped retain science majors, but it has also inspired non-science students to pursue one of the environmental science degrees offered at UWT. Therefore, our goal of expanding undergraduate research opportunities through field-based oceanography is a natural extension of our existing environmental science curriculum (Greengrove and Secord, 2003).

Serving Nontraditional Undergraduate Students - UWT's proximity to Puget Sound and the Pacific Northwest coast provides a unique opportunity to develop undergraduate marine-based field courses and research projects for nontraditional students. Many of the marine educational experiences that presently exist are tailored to traditional, full-time college students who do not work or have children. Presently, these seagoing oceanographic programs are primarily limited to piggybacking on faculty-based research cruises, floating classrooms on large cruise ships, and seagoing programs run by private organizations. Floating classrooms on large cruise ships (e.g. University of Pittsburgh's Semester at Sea), while getting numerous students out to sea, actually offer little in the way of hands-on oceanography. Participation in a faculty research cruise does introduce students to real oceanographic data collection, but these cruises are not designed for undergraduate learning and often allow only limited student involvement. On the other hand, privately run oceanography programs (e.g. SEA's Sea Semester) are specifically designed for undergraduates, but unfortunately these programs are often too long and

Figure 1. The RV *Clifford A. Barnes*, during the 2001 undergraduate cruise.

expensive to be viable for the majority of UWT's nontraditional students.

Therefore, UWT has experimented with approaches differing from those above in order to create an undergraduate oceanographic research experience that is designed to allow participation by our nontraditional students (Greengrove and Secord, 2003). This has required that we minimize costs and keep ship time to two weeks or less. Over two summers we have had the opportunity to test two very different marine research course models, and as a result we have gained insights into how a successful nontraditional undergraduate experience at sea can be achieved.

COURSE DESIGN AND TEACHING METHODS

The oceanography course, "Research at Sea", was taught during the summers of 2001 and 2002 by two UWT environmental science faculty members: a physical oceanographer and an environmental chemist. In order to make it possible for any UWT student, rather than just environmental science majors, to fully participate in oceanographic research, it was necessary to cover introductory oceanography prior to the start of each cruise. The curriculum was divided into three stages: (1) During the spring quarter students participated in an onshore course covering Pacific Northwest history and oceanography; followed by a second onshore component immediately prior to going to sea in the summer that included an introduction to field methods. (2) Participants then embarked on a one to two week hands-on course at sea where students worked in research teams to collect and analyze oceanographic data. (3) After returning from sea, student groups synthesized their results and presented their findings in a final mini-research symposium.

Pre-Cruise Onshore Instruction - The spring quarter interdisciplinary, pre-requisite course, titled "Maritime History and Science in the Pacific Northwest", covered introductory oceanography within the broader context of the natural resource history of the region. This treatment engaged both science and non-science students alike by connecting regional applications of basic oceanography concepts to cultural, economic, and literary historical events in the Pacific Northwest. The combination of traditional oceanography with subjects normally relegated to the humanities and social sciences was instrumental in enticing many of the non-science students to also participate in the summer course. The spring quarter course was open to 50 students with 20 places reserved for those committed to continuing in the summer course. Therefore this course served both as a science requirement for all students, as well as a prerequisite for the summer course.

Both in 2001 and 2002, the summer "Research at Sea" course began with three weeks of intensive shore-based instruction. This shore component included library research and experimental design for onboard group project work, an introduction to oceanographic instrumentation and data analysis, basic navigation and charting techniques, and information sessions designed to prepare students for the logistics of the cruise. In addition, students were briefly introduced to various journaling techniques to provide the basis for producing a creative writing piece related to their seagoing experience. Students were divided into research groups at the beginning of the onshore portion of the course, which allowed the groups time to get to know each other and share information gathered for their projects (Basu and Middendorf, 1995; Manner, 1995). Groups were chosen by professors in an attempt to equally distribute student skills. Characteristics considered in forming groups included science background, data analysis and graphing familiarity, physical abilities necessary for sailing a tall ship, leadership potential, and interpersonal skills. Group projects were kept relatively straightforward and were organized as general summaries of chemical, physical, and biological oceanography. Limited ship time, a lack of access to onboard instrumentation for sediment analysis and lower student numbers precluded adding a geological component to the student research projects.

Puget Sound Cruise: Summer 2001 - The first year, the design of the summer course was somewhat thrust upon us at the last minute. Construction of what was to be our ship, which would carry 20 students from Tacoma, Washington, to Portland, Oregon, was not completed on time. Our contract was cancelled with less than a month's notice, and we were forced to find an alternative vessel. Fortunately, we were able to secure the RV Clifford A. Barnes (Figure 1), owned by the University of Washington, for a weeklong cruise. This unplanned change has had the unforeseen advantage of allowing us to compare and contrast two very different cruise designs. As the 65 ft. Barnes was not intended for open ocean work, we constrained our cruise to the relatively protected waters of Puget Sound, the eastern portion of the Strait of Juan de Fuca, and the San Juan Islands (Figure 2). Unfortunately, this ship only sleeps six scientists. As we had seven students and two professors, we were forced to dock or anchor each night of the

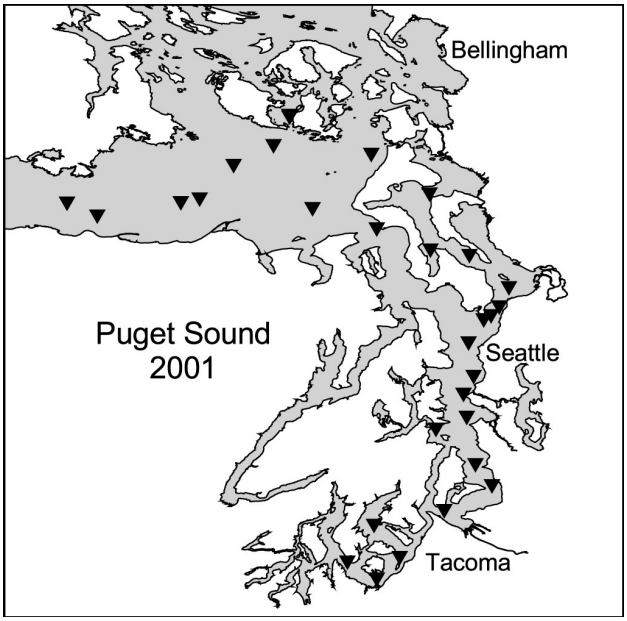

Figure 2. Sampling stations for the 2001 research cruise. The cruise track included 30 stations in the Strait of Juan de Fuca and the Main Basin, Whidbey Basin, and South Basin of Puget Sound.

seven-day cruise and send a professor and two students ashore to sleep in a campground or motel.

The Barnes was outfitted with a real-time CTD and bottle carousel. Other onboard instrumentation was brought from UWT or rented from the UW School of Oceanography and placed in the small lab adjacent to the back deck. The Barnes facilities allowed for plankton identification and enumeration, dissolved oxygen determination, nutrient analyses, and chlorophyll measurements. Computer availability was limited to two laptops used between meals on the galley table.

Two research groups were formed such that each team had at least three members. All students and faculty worked together the entire day so that interaction was constant among all participants. Since piloting, navigation, and shipboard chores were performed almost entirely by the ship's captain and mate, students spent, on average, around 12-16 hours per day on sampling, analysis, and data interpretation, which allowed us time to occupy 30 stations during the weeklong cruise.

Pacific Northwest Coast Cruise: Summer 2002 - The following year UWT chartered the newly completed SSV Robert C. Seamans (Figure 3), a ship owned and operated by the Sea Education Association (SEA) of Woods Hole, Massachusetts. The ship, a 134-ft. square-rigged topsail schooner, was completed in 2001 by J.M. Martinac Shipbuilding, a company located within sight of UWT on Commencement Bay, Puget Sound. This was the first tall ship built in Washington in over a decade and the only one built in Tacoma for the sole purpose of providing undergraduate research opportunities at sea. As the Seamans was designed explicitly for open ocean work, our cruise track this year stretched for 13 days from Tacoma to San Francisco (Figure 4). Eleven hydrocast stations were occupied over a coastal longitudinal transect from Washington to California. UWT arranged return air travel to Tacoma. Twelve students, one professor from Highline Community College, and two professors from UWT were onboard, in addition to the SEA crew. No prior sailing experience was required.

Figure 3. The SSV *Robert C. Seamans*, chartered for the 2002 undergraduate cruise (Photo courtesy of SEA).

The Seamans was designed for oceanographic research with a wet lab and a dry lab, as well as a combination library and student computer room. This ship was equipped with an internally recording CTD and bottle rosette, acoustic Doppler current profiler (ADCP), CHIRP bathymetric profiling system, and a continuous flow-through system measuring surface temperature, salinity, and raw fluorescence while underway. Other onboard instrumentation allowed for the measurement of dissolved oxygen, nutrients, and chlorophyll, as well as plankton enumeration and identification.

For the duration of the cruise, students were divided into three watches that rotated duties through five shifts on a 24-hour schedule (7am-1pm; 1pm-7pm; 7pm-11pm; 11pm-3am; and 3am-7am). Therefore, each watch rotated through all shifts every three days before repeating. Watches took turns sailing the ship, collecting oceanographic data and samples, analyzing samples, and performing other shipboard operation chores. Because the watch schedule reduced interaction between groups to mealtimes and a two-hour ship meeting each day, it was decided to create watches that would be self-sufficient research groups as well. Subsequently, each of the three professors onboard was assigned primary responsibility for a particular student group. Although the original intention was for professors to be able to "float" from watch to watch, this occurred very infrequently due to sleep schedules and the necessity for professors to participate in sailing and other ship duties on a short-handed cruise.

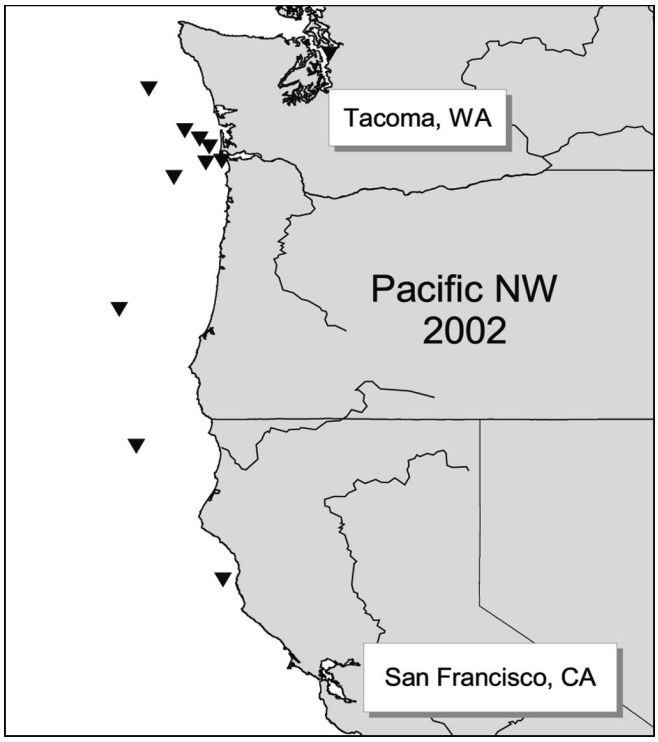

Figure 4. The eleven sampling stations from the 2002 cruise. The cruise track begins in Puget Sound and follows the Pacific coast from Cape Flattery to San Francisco Bay, with extensive sampling near the mouth of the Columbia River.

Post-Cruise Onshore Work and Presentations - Student research groups synthesized the data collected while at sea and upon return to Tacoma. In addition, the majority of plankton identification work had to be completed after the cruise, due to the difficulty in using microscopes onboard a moving vessel. Members of each team worked together to summarize and interpret the results relevant to their particular project in the context of previously published historical data. They then compiled a group research paper in scientific format and presented their findings at a mini-symposium scheduled two weeks after the cruise.

PLANNING AND IMPLEMENTATION CONSIDERATIONS

The alternative designs of these two field-based, undergraduate research courses not only allows us to compare these particular models, it also provides us with a basis for discussing common problems and considerations inherent in similar programs. Our analysis has elucidated some guidelines related to planning and implementation that may be generalizable, and therefore helpful to anyone developing a field based marine course for undergraduates.

Recruiting - In order to expand our pool of prospective students, we attempted to recruit students from local community colleges, other four-year universities and colleges in the region, as well as all campuses of the University of Washington. Through this experience we learned that there are numerous roadblocks to recruiting students outside UWT, regardless of how close the institutions are geographically. Even intra-university recruiting was difficult across campuses. Problems included the general lack of a central advertising platform for off-campus opportunities, difficulties related to the conversion of academic course credits from one place to another, the need for word-of-mouth promotion of the course by faculty, and a general negative perception regarding the academic rigor of offerings at another institution.

Scheduling and Costs - Even though a large number of nontraditional students are excited about the prospect of participating in field-based intensive learning experiences, there are two hurdles to actually enrolling: the cost of the course and the time required for the field component. The cost of the course was minimized to the extent possible, but it remains imperative to provide financial planning assistance for nontraditional students with families and other budgetary constraints. Students may be eligible for financial aid to cover course tuition and fees, but the paperwork requires time to be approved. Many aid providers also require a breakdown of course fees prior to approval, so this should be provided to students upfront. For those not eligible for financial aid, commitment to this course means planning far enough in advance to save up the money or to request a non-academic loan. Therefore, providing adequate lead-time for student financial planning is essential for effective recruiting.

Total fees per student for the summer course (not including tuition) were $1700 in 2001; whereas the cost per student in 2002 was $2800. However, the cruises ran for different lengths of time, so a more accurate comparison is cost per student per day: $243/student/day in 2001 and $215/student/day in 2002. In addition, expenses were partially subsidized in 2001 by the organization that cancelled our original contract. Without this aid, costs would have been greater than $315/student/day the first year, approximately $100 more than in 2002. This discrepancy between the two years can be attributed largely to the capacity of each vessel. The charter cost for the Seamans per day is roughly twice that of the Barnes, but the Seamans can accommodate over 20 students, whereas the Barnes is overtaxed with just seven. It is often more economically feasible to offer a field experience at sea if a larger number of students can be recruited for a bigger research vessel. Thus, to better ensure that we have a large enough number of students to fill a 20-person research cruise, course planning and development requires extensive advance recruiting which limits the frequency of a larger course offering to every other year. On the other hand, smaller vessels lend themselves to more frequent local cruises with fewer students and a greater focus on ocean science and data collection.

In addition to costs, the time required for the field component of this course is an important consideration for nontraditional students. With families and work schedules, students need sufficient time to be able to organize their lives around the course. For many, due to work vacation limitations and the need for childcare, two weeks is the maximum possible time they can feasibly devote to being away from home. Therefore, to increase accessibility for the majority of nontraditional students with time and financial constraints, we recommend (1) advertising the course at least 9-12 months in advance, (2) providing as much financial aid assistance as possible, (3) seeking outside funding sources to help defray the cost of vessel charter, (4) constraining the course as best as possible within the regularly scheduled academic calendar, and (5) limiting the field component to two weeks or less.

Research Group Formation - Group composition and size are critical factors affecting interpersonal dynamics and research team success. Although a few onboard interpersonal squabbles resulted as a result of instructor-created groups, confrontations were limited and did not seem to unduly color the positive aspects of the cruise. The importance of evenly distributing the level of science background and other student skills among groups only became evident at the end of the cruise when students began to synthesize and interpret their data. Two lessons regarding group dynamics were garnered from our experiences. First, good leadership was the overriding factor in producing a quality group project, much more so than science background. The organization of group work by student leaders (self-selected) enabled groups with minimal science background to synthesize and interpret results, whereas other groups with extensive science background floundered without leadership. Second, each year one or more students "disappeared" after we returned to Tacoma. This made group size important, as the remaining students had to fill in the gaps. This seems to become more of a problem the more enticing the trip itself becomes. Some students participate solely for the allure of the voyage and not for the education, and at the end of the trip they forfeit their grade and leave other group members to produce the final project. Therefore, groups should have at least three students, and non-academic characteristics of group members should be considered carefully by instructors for group formation.

Post-Cruise Coursework Design - Finally, the single most important lesson learned from our experiences is to allow sufficient structured class time at the end of the cruise for the completion of student projects. A consistent complaint from students both years was that there was not enough time to complete their work. Four factors contribute to this problem: (1) the length of the research cruise, (2) the lack of scheduled class time at the end of the cruise, (3) constraints imposed by the summer academic calendar, and (4) competing personal commitments.

The most opportune time for completing student research papers and presentations would be onboard ship. Their attention is still focused on the task at hand, there are limited outside distractions, and students can't "disappear." However, there is barely enough time to collect sufficient data for group projects in the present cruise schedule, and extending the cruise means higher costs and less student participation. Therefore, in reality the cruise would have to be much longer to be able to collect sufficient data and to allow the novelty of being at sea to fade, such that students could focus on paper writing and presentations. Considering the financial and time constraints of our students, this is not a viable option.

Once off the ship, outside time commitments begin to take precedence, making it difficult for students to stay focused. Although course instructors were available for help and guidance throughout the post-cruise period both years, the course schedule was left open allowing students to create their own schedules for working on their projects. This did not work. Therefore, it is necessary to schedule structured class time following the cruise.

BARNES VS. SEAMANS

Having considered the various course designs for both years, which design would we recommend on the basis of demonstrated student learning? The answer is both. The Barnes cruise allowed students to focus solely on science, permitting them to acquire a large sum of knowledge in a week's time. The Puget Sound region offers a variety of oceanographic conditions, while the short distances involved made it possible to collect a large amount of data in a short time. In addition, docking or mooring each night allowed extra downtime for group discussions, catching up with sample analysis, or getting off the boat and relaxing in town. Finally, the smaller ship's crew made this cruise a much more intimate experience for all involved.

Interestingly, we were able to collect much more data in 7 days aboard the Barnes than in 13 days aboard the Seamans. This is due primarily to the time spent sailing the Seamans. However, the Seamans experience really approaches student learning from a much broader perspective. Although many would suggest that time spent sailing does nothing for advancing scientific knowledge, our experience has led us to a different conclusion. A palpable change took place when students began to handle the task of sailing the ship on their own. In the process of learning how to sail a tall ship, students learned the importance of teamwork and cooperation, and they gained confidence in their own previously untested abilities. This confidence then transferred to the scientific research they were conducting, resulting in (1) a greater interest in understanding the science they were involved in, (2) greater confidence in their own interpretation of the data, and (3) the development of a sense of ownership of the data collected. This sense of ownership signals the realization that they, as "real scientists," are contributing to the body of viable oceanographic data. Thus, the Seamans makes up for the smaller amount of data collected by reinforcing student learning in a truly interdisciplinary educational framework, and provides a unique experience not normally available to nontraditional students.

CONCLUSIONS AND STUDENT FEEDBACK

On the whole, student feedback from both years has been overwhelmingly positive. Course evaluations have been high and students continue to speak favorably of their experiences. One student called the course "…an incredible intellectual experience," and another said "…the total experience was one I will take with me for a lifetime." This is evidence of the impact that intensive scientific field experiences can have on undergraduate learning. Most student participants, both non-science and science majors alike, have been pleasantly surprised with the amount of knowledge they mastered in a relatively short time, and student research projects usually met or exceeded faculty expectations.

As hoped, positive educational outcomes have extended beyond the boundaries of the course itself. Student interest in ocean science was enhanced, and viable data collected on the cruise provided fodder for subsequent individual undergraduate research projects and peer-reviewed student presentations at several regional research conferences. Less tangible benefits include increased student excitement regarding science and more post-cruise contact between students and faculty, as well as greater student-student interaction on a campus where the non-residential status creates little opportunity for educational community building.

Unexpectedly the most negative comments in course evaluations were from the 2002 cruise aboard the Seamans. Judging from student feedback, a dichotomy of student reactions resulted in response to the physical and

emotional strains related to the 24-hour ship schedule and the lack of port calls. Most students responded to these personal challenges successfully, and subsequently focused on the positive aspects of the cruise in their evaluations. However, the Seamans experience required a larger personal adjustment than the Barnes, which resulted in some negative impressions of the course. The lack of sleep, constant boat motion, physical demands, personal inconveniences, and 24-hour interpersonal interactions in a relatively small space made psychological adjustment a necessity on the Seamans (see also McClennen and Meyer, 2002). On the other hand, the intensity of the Seamans cruise created a very strong, positive response in those who succeeded under the challenging conditions, resulting in more sustained post-cruise educational outcomes. From our experience, it is impossible to predict student adaptability to living and working at sea.

In contrast, student ratings were unanimously high for the 2001 cruise on the Barnes, a surprise since the actual cruise was so much different than originally planned. The much more intensive research schedule, the much smaller quarters, and the shift from a tall sailing ship on the open ocean to a motorized vessel restricted to Puget Sound, were offset by less demanding physical conditions, more time for data synthesis onboard, shore leave, and a regular sleep schedule. This resulted in greater student satisfaction and fewer personal confrontations between group members. Unfortunately, this venue was actually more expensive than the Seamans on a per day basis and limited in the number of students that can be accommodated.

Although there are positive and negative aspects related to both the 2001 and the 2002 programs, both were solid successes. Choosing a vessel that best suits educational goals and participating students, early planning of program logistics, thoughtful formation of research groups, and careful design of the post-cruise schedule are critical factors in determining the success of an undergraduate field-based oceanographic course. This experience has reinforced our belief that field-based intensive research is invaluable for advancing student learning and creating the excitement needed to recruit and retain promising undergraduates, both traditional and nontraditional, in the sciences. Therefore, we will continue to investigate ways to offer such opportunities to UWT students in the future.

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REFERENCES

Archie, M., 1996, Environmental Education Materials: Guidelines for Excellence, Washington, DC, NAAEE.

Basu, A., and Middendorf, J., 1995, Discovering new knowledge through collaborative learning in groups, Journal of Geoscience Education, v. 43, p. 317-321.

Eves, R. L., Davis, L. E., and Seward, W. P., 1990, Nontraditional students as a pool of potential high-quality geology and earth-science-education majors, Journal of Geological Education, v. 38, p. 197-199.

Greengrove, C., and Secord, D., 2003, Undergraduate marine research: summer field program for nontraditional students, Journal of College Science Teaching, v. 32, p. 316-321.

Hungerford, H., and Peyton, R. B., 1986, Procedures for developing an environmental education curriculum: A discussion guide for UNESCO training seminars on environmental education, Environmental Education Series, v. 22, UNESCO.

Kern, E. L., and Carpenter, J. R., 1984, Enhancement of student values, interests and attitudes in earth science through a field-oriented approach, Journal of Geological Education, v. 32, p. 299-305.

Kern, E. L., and Carpenter, J. R., 1986, Effect of field activities on student learning, Journal of Geological Education, v. 34, p. 180-183.

Manner, B. M., 1995, "Sink or swim" together in a geology classroom, Journal of Geological Education, v. 43, p. 332-334.

McClennen, C. E., and Meyer, A. W., 2002, Transferable elements of the educational program Sea Semester, Journal of Geoscience Education, v. 50, p. 266-270.

Secord, D., and Greengrove, C., 2002, Environmental science as a vehicle for building natural sciences and EE into a new interdisciplinary urban public university, The Journal of Environmental Education, v. 34, p. 32-37.

Shiber, J. G., 1999, Teaching nontraditional students, Journal of Chemical Education, v. 76, p. 1615-1616.

Sigma Xi, 1989, An Exploration of the Nature and Quality of Undergraduate Education in Science, Mathematics and Engineering: A Report of the National Advisory Group of Sigma Xi, The Scientific Research Society, New Haven, CT, Sigma Xi.

Sigma Xi, 2000, Reshaping Undergraduate Science and Engineering Education: Tools for Better Learning, 1999 Sigma Xi Forum Proceedings, Research Triangle Park, NC, Sigma Xi.

Simmons, D., 1994, The NAAEE Standards Project: Papers on the Development of Environmental Education Standards, Washington, DC, NAAEE.

Taylor, D. M., and Barnard, W. M., 1980, A National Science Foundation student-originated studies project, Journal of College Science Teaching, v. 9, p. 269-271.

Tobias, S., 1990, They're Not Dumb, They're Different: Stalking the Second Tier, Tucson, AZ, Research Corporation.

Tobias, S., 1992, Revitalizing Undergraduate Science: Why Some Things Work and Most Don't, Tucson, AZ, Research Corporation.

UNESCO, 1995, Interdisciplinary approaches in environmental education, Environmental Education Series, v. 14, UNESCO.

Weis, J. S., 1990, The status of undergraduate programs in environmental science, Environmental Science and Technology, v. 24, p. 1116-1121.

Weis, J. S., Lemons, J., Foust, R., Godshalk, G. L., Miller, G. L., and Wener, R. B., 1992, Report of the workshop on undergraduate environmental science education, The Environmental Professional, v. 14, p. 363-370.

Wenzel, T. J., and Austin, R. N., 2001, Environmental chemistry in the undergraduate laboratory, Environmental Science and Technology, v. 35, p. 327A-331A.

Wilke, R., 1995, Environmental literacy and the college curriculum, EPA Journal, v. 21, p. 30-34.