Science Majors vs Nonmajors: Is There a Difference?

Marshall D. Sundberg and Michael L. Dini

The well-documented scientific illiteracy of American students demands that we make improvements (Alliance 1990). But should we concentrate our reform efforts primarily on our nonmajors?

Much current attention is placed on restructuring the curriculum and redefining nonmajors' course content in an effort to improve their science literacy. It is ironic that although scientific literacy of our students, compared to that of students in other countries, is measured by traditional test instruments, often covering basic conceptual topics, many proponents of change would have us discard much of this material as being irrelevant or at least uninteresting. Only recently have specific suggestions been given as to basic content topics that might serve to define biological literacy.

Project 2061 (AAAS 1989) lists six major topics under the category of "The Living Environment," including:

- Diversity of Life
- Heredity
- Cells
- Interdependence of Life
- Flow of Matter and Energy
- Evolution of Life.

Similar items were listed in Hazen and Trefil's "Science's Top 20 Greatest Hits" (1991). Their standard of biological literacy, items 17–20, included: *cell biology, the genetic code, evolution by natural selection, and the interconnectedness of life.*

Nastase and Scharmann (1991) suggest that we should " . . . treat an introductory nonmajors' course differently from a majors' course, in order to improve nonmajors' attitudes toward biology." This is not an uncommon theme in recent literature on improving biology education at the college level (Scharmann and Harty 1986; Lawson 1988; Lawson, Rissing, and Faeth 1990). A driving force behind this movement is the belief that nonmajors have special needs and thus we must teach them differently from their science major classmates. This belief is perpetuated by student complaints that " . . . courses are largely irrelevant to their lives and the effort required far exceeds the benefit reaped" (Alliance 1990). Such complaints are most frequently expressed by students who are not interested in science *per se*, but who are required to take science courses and want the information they must learn to be geared toward their own interests. In response to these complaints we are told that: "new approaches to the teaching of biology at all levels must emphasize the conceptual framework of biology, reduce the excessive terminology that characterizes so many courses, consider the strengths and limitations of the scientific process, and deal explicitly with human problems for which biological data and methods can suggest solutions" (NSF 1989).

In this paper, we will argue that our reform efforts should not be directed solely to redefining the content of the nonmajors' course in an effort to make it more "interesting" to students. Certainly we should make our courses interesting and redesign is one way to do this. But at the same time we should not lose sight of our goal—to increase scientific literacy. Another alternative which may better serve all students is to concentrate on four or five key concepts and dispense with the dichotomy between majors and nonmajors at the introductory level where " . . . too many entry-level courses, *whether*

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Table 1. Comparison of Student Objectives for a Representative Chapter (Basic Chemical Principles) of Majors' vs Non-majors' Biology

Majors: The Nature of Molecules

1. Describe the subatomic structure of an atom.
2. Distinguish between atomic number and atomic mass.
3. Distinguish between ions and isotopes of a given element and give an example of the importance of each.
4. Describe the basis for the chemical identity of a given element.
5. Describe the basis for the chemical bonding of elements into molecules.
6. List in order of relative strength the various bonds found in living organisms.
7. Describe the chemical basis of reduction and oxidation (redox) reactions.
8. List five ways water is essential to life as we know it.
9. Describe the chemical basis of pH and the mathematical scale used to define pH: describe the biological importance of pH.

Nonmajors: Chemical Foundations for Cells

1. Understand the structure of atoms and explain how the distribution of electrons affects bonding.
2. Know the difference between ionic, covalent and hydrogen bonds, the circumstances under which each forms, and the relative strength of each.
3. Know what is meant by the "polar" nature of water and be able to describe how this affects essential chemical/physical properties of water in cells and in the environment.

geared to majors or to students satisfying general education requirements [our emphasis], fail to stimulate and involve students—much less educate them" (Sigma Xi 1989). Majors and nonmajors alike should receive instruction with an intent to stimulate interest, involvement and higher-order thinking involving key concepts rather than instruction to initiate majors into the field via content-oriented "trial by fire" or to provide nonmajors with a dilute version of the "real thing."

The purpose of this study was to examine student understanding of basic biological concepts in two courses, one designed for majors and one intended for nonmajors. The topical content of both courses was identical; both follow the guidelines listed above. The depth of coverage varied, however, with the majors' course treating topics in considerably more detail and the nonmajors'course concentrating on a few basic concepts.

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COMPARING MAJORS TO NONMAJORS

At Louisiana State University, we track-direct students interested in a science major into an introductory principles of biology course that serves as a prerequisite for second-semester courses in either botany, microbiology, or zoology. We offer nonmajors a two-semester sequence of general biology; the first semester covers basic biological principles followed by a second semester concentrating on diversity and organismal biology. Both are lecture courses and both have a corresponding laboratory course designed to reinforce the basic principles covered. The general education requirements of the university mandate that all students complete three science courses, including a two-semester sequence in either biological or physical science. The nonmajors' biology sequence is the alternative most commonly chosen by students to fulfil this requirement. We teach both the introductory majors' and nonmajors' courses in multiple sections of 200-250 students per section. The same major concepts are covered in both the major's and nonmajor's principles courses: biological chemistry and cell biology, genetics (including molecular genetics), ecology, and evolution.

Although the major concepts are the same in both courses, the depth of coverage and content of the textbooks used vary considerably. For instance, the majors' course uses Campbell's *Biology* and the course objectives list 12 to 15 specific objectives for each assigned chapter (Table 1). To nonmajors we assign an equivalent number of chapters, on the same topics, from Starr and Taggart's *Biology: The Unity and Diversity of Life*. In this course only three, or at most four, major objectives are listed for each chapter (Table 1). In addition to having "lower expectations" regarding the amount of content to be covered, we encourage instructors in the nonmajors' sections to concentrate on current applications and the social relevance of topics covered. The charge to instructors in the majors' sections is to provide an adequate foundation for advanced courses.

As part of a mandated program-wide evaluation, we decided to administer a pretest/post-test to all sections of first-semester biology during the 1990-1991 academic year. Our original intention was to construct separate instruments based on the learning objectives for each course. Given the time constraints imposed on us, however, we realized that we would be unable to construct and validate two separate instruments in the time allotted. Consequently, we turned to the 1986 Advanced Placement biology examination as a source of questions. Upon making this decision we realized that there would be an additional benefit beyond having a set of already validated questions. Because data are available on national student performance during the year the examination was given, we had a nationally based norm against which to compare our students' performance.

Again because of the time constraints involved in incorporating two additional examinations into the already "full" course syllabi for each section of introductory biology, we decided to concentrate on only two of the four topic areas each semester. Thus, we would require only an additional half hour from the first and last lecture periods of each section. During the fall semester we assembled a test using all thirty of the Advanced Placement multiple-choice items dealing with ecology and evolution, including genetics. During the spring semester, we constructed a similar examination using all thirty-three items dealing with cell and molecular biology. The same examination was administered to all majors' and nonmajors' sections. Instructors were not shown the examinations ahead of time and they were collected upon completion of the pretest so as not to influence an instructor's teaching during the semester (to avoid the temptation to "teach to the test"). We were confident that:

(1) our majors would demonstrate significantly better preparation than the nonmajors on the pretest;

(2) the majors' post-test performance would meet or exceed the national norm;

(3) and majors' post-test scores would significantly exceed the corresponding nonmajors' scores.

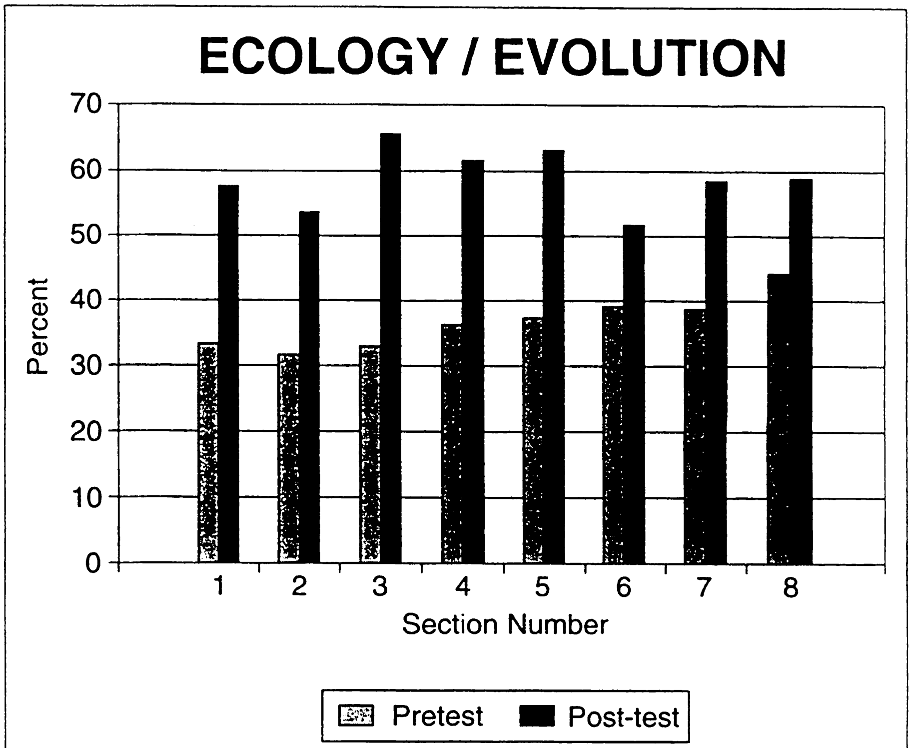

Figure 1. Average pretest (open bars) and post-test (solid bars) scores are represented for nonmajors' (1-6) and majors' (7,8) sections of introductory biology. Scores are presented as percent of 30 questions and as the total number of correct responses. In all cases post-test scores are significantly higher than pretest scores: p=0.0001, sections 1-7; p=0.0003, section 8.

ECOLOGY AND EVOLUTIONARY BIOLOGY

We administered the 30-question pretest on the first day of classes to all sections of majors' and nonmajors' introductory biology, a total of over 1,200 students. We were immediately surprised and disappointed as the pretest scores were reported. The average score for nonmajors was indeed lower than that for majors, approximately 34 percent vs 40 percent, but this amounted to only a three-question difference, a less dramatic result than expected (Figure 1). More disturbing was that although all freshmen entering LSU are required to take high school biology (as well as chemistry, physics, and math through algebra), even the students in the majors' course scored well below 50 percent (Figure 1).

For various reasons, only five sections reported reliable post-test results. This sample seemed inadequate for comparison so we decided to follow the entire cohort of students into their second-semester course and administer the same post-test on the first day of the new semester. We asked students to identify their instructor from the previous semester so their class post-test scores could be compared to the appropriate pretest scores. Not only did this provide us with a more reliable sample among and between sections and courses, but it also provided us with an indicator of student retention. The retention results for the three sections where we could make this comparison (65.6, 63.0, 58.3) were not significantly different from the immediate post-test results (65.7, 63.6, 58.4, respectively). Retention scores are plotted with pretest scores in Figure 1.

The first observation is that the scores of all sections increased significantly. The average retention (post-test) score for nonmajors was 58.7 percent, an increase of 68 percent over the corresponding pretest scores. Surprisingly, the retention scores for majors, average = 58.5, showed an increase of only 43 percent over the pretest average. The level of achievement, and presumably comprehension of the material, was virtually identical between the two groups, and the gain for nonmajors' over their initial understanding was more than half again as great as observed for the majors. We interpret this to mean that majors, who received a much more rigorous treatment of the material, came through the semester with the same degree of understanding as the nonmajors!

While more than 1,200 students took the initial pretest, approximately 15 percent of these withdrew before the end of the semester, thus post-test scores represent a substantially lower number of students than do pretest scores. The sample size of retention scores was further reduced because of the number of students who chose not to continue immediately into a second-semester course. To examine the effect of this bias, and to test the variation between and within sections, we performed an analysis of covariance on a random sample of 20 students from each of four nonmajors' and both majors' sections (Table 2). The difference between pretest scores for each section and the covariate (pretest) averages for this sample suggests a bias of about five percentage points due to the decrease

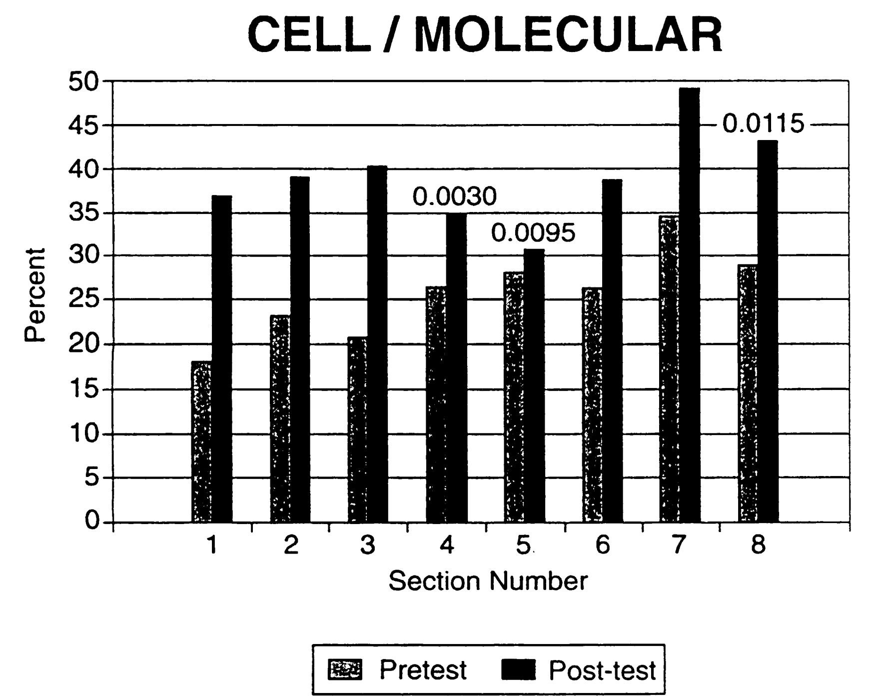

Figure 2. Average pretest (open bars) and post-test (solid bars) scores are represented for nonmajors' (1-6) and majors' (7,8) sections of introductory biology. Scores are presented as percent of 33 questions and as the total number of correct responses. In all cases post-test scores are significantly higher than pretest scores; unless otherwise indicated above the post-test bar, p=0.0001.

in student population. The dependent mean for section "8," which appears unusually high, reflects sampling bias—these 20 students happened to score extremely well on both their pre- and post-tests. Even with this known bias, the differences in adjusted means between sections were only marginally significant and the adjusted means of all nonmajors' sections exceeded that of the other majors' section.

The above results also provided us an opportunity to examine the effectiveness of two very different approaches to the topics covered. Most sections were taught in the traditional "bottom-up" sequence, beginning with basic chemistry, cell structure, and function, and culminating in ecological principles. Two sections, 3 and 5 (Fig. 1) were taught "top down," beginning with ecology and ending with molecular biology. Although these two sections happened to produce among the highest post-test averages, they are not significantly different from any other section, note particularly section 4. The inconclusive results concerning order of topic presentation suggests that instructor differences are a more important variable (the instructors of sections 3 and 4 received university teaching awards during two of the past three years) than order of topic presentation.

CELL AND MOLECULAR BIOLOGY

On the first class day of spring semester we administered a 33-question pretest, covering concepts in cell and molecular biology, to all students, approximately 1,700, enrolled in first-semester biology. Half of the sections in both the majors' and nonmajors' courses were taught by instructors who had taught the same course during the fall. For these instructors we had a complete analysis of student performance on all topics covered in the course. Initial pretest results confirmed our expectations. *First*, the majors were somewhat better prepared in cell/molecular biology than the nonmajors. The average score for majors was 31.7 percent while nonmajors scored 23.7 percent. *Second*, the difference between majors and nonmajors was not great—fewer than three answers out of 33 (Figure 2). Based on our results with ecology and evolution, we expected to find only a small difference between the two groups, but we also expected that the difference would be somewhat greater on the more abstract molecular topics. In fact, the difference was slightly less. *Third*, our students proved to be less familiar with concepts in cell and molecular biology than they were with concepts in ecology and evolution (compare Figures 1 and 2).

All sections were taught "bottom up;" we administered the post-test during midterm week, immediately following instruction on these topics. There was a significant increase in student performance in all sections. The average post-test score for nonmajors was 36.7, a 55 percent increase, while majors' scores increased an average of 46 percent to 46.2 (Figure 2).

A sample of 20 randomly selected students from each section was chosen so we could examine the bias due to a smaller post-test sample size. Again, the sample (covariate) mean differed from the pretest mean by less than five percentage points. Interestingly, the difference was greater in the nonmajors' sections where about 15 percent of the students enrolled withdrew from the course prior to the post-test. There was a smaller difference in the majors' sections although their withdrawal rate was nearly 40 percent during the semester testing was performed. Analysis of covariance indicates only marginally significant differences between sections (Table 3), with the greatest differences being between different nonmajors' sections rather than between majors' and nonmajors' sections.

WHERE ARE THE DIFFERENCES?

Our current curriculum was designed in the belief that a substantial difference exists in the level of preparation of students entering the majors' vs nonmajors' tracks. However, our study suggests that this dichotomy is inconsequential for freshman biology at LSU, at least as class enrollment is currently determined. The greatest differences in student preparation occur between various nonmajors' sections, some of which score as high or higher on initial examination than do majors' sections. Based on past student performance in the majors' sections, it seemed clear to the faculty that many of our students have inadequate preparation and unrealistic expectations in comparison to the standards we set for college science majors. In retrospect then, it was not too surprising to find little difference in pretest scores between students enrolled in these two different tracks.

The most surprising, in fact shocking, result of our study was that the majors completing their course did not perform significantly better than the corresponding cohort of nonmajors. In fact, on ecological and evolutionary concepts, some sections of nonmajors outperformed the majors and the highest individual scores on both exams were by nonmajors! Furthermore, students in the nonmajors' sections consistently showed greater improvement during the semester than did their fellow students in majors' sections. The philosophy behind our curriculum is that the majors' course must lay a solid foundation of biological concepts AND CONTENT in order to prepare these students for upper-division courses. Consequently, we have selected a rigorous textbook and set high standards. For nonmajors we have deemphasized content to concentrate on a relatively few basic principles and place them into a social perspective. Our study suggests that the approach taken in our nonmajors' course, considered "watered-down" by some of our colleagues, actually does a better job of meeting our majors' course objectives than does our majors' course.

Table 2. Analysis of Covariance: Ecology and Evolutionary Biology

Source	Adj. SS	df	Var. Est.
Between	3,273.96	5	654.79
Within	20,933.77	113	185.25
Total	24,207.73	118	

F-ratio 3.53
significance 0.0055

Section[1]	Covariate Mean	Dependent Mean	Adjusted Mean
1 (m)	38.55	57.15	59.26
4 (m)	38.25	59.35	61.61
5 (m)	43.60	62.10	61.58
6 (m)	41.40	57.15	57.77
7 (M)	44.95	51.10	59.88
8 (M)	48.85	77.10	73.85

[1]Section numbers refer to those in Table 1. Retention sample size was smaller than 20 for sections 2 and 3, therefore they are not included in this analysis. Non-majors' sections are indicated by (m), majors' sections by (M).

An interesting aside, worth further investigation, is that simultaneous enrollment in the laboratory may not have a significant impact on student understanding of basic concepts. Because of space and faculty constraints, fewer than 40 percent of the nonmajors simultaneously enroll in both the lecture and corresponding laboratory course while nearly 80 percent of the majors simultaneously enroll in both corresponding courses. Nevertheless, student performance on the test instruments was dramatically greater for nonmajors. This supports a position stated by the Commission for Undergraduate Education in Biological Sciences in the late 1960s that although a major objective of traditional laboratory courses is to reinforce concepts presented in lecture, there are more effective ways to do so (Holt, Abramoff, Wilcox, and Abell 1969).

We are satisfied that students completing our nonmajors' course have attained at least the *minimal* level of biological literacy expected of college graduates, as defined by criteria presented above (AAAS 1989; Hazen and Trefil 1991). Post-test scores for both our nonmajors and majors on the ecology/evolution questions are very near the 64 percent scored on the same questions nationally and would have

Table 3. Analysis of Covariance: Cell and Molecular Biology

Source	Adj. SS	df	Var. Est.
Between	3,841.28	7	548.75
Within	21,210.81	145	146.28
Total	25,052.09	152	

F-ratio 3.53
significance 0.0012

Section[1]	Covariate Mean	Dependent Mean	Adjusted Mean
1 (m)	25.40	38.95	41.51
2 (m)	24.30	39.15	42.63
3 (m)	25.80	46.50	48.72
4 (m)	28.50	37.35	37.32
5 (m)	30.35	32.30	30.72
6 (m)	24.60	40.45	43.68
7 (M)	37.76	44.19	36.42
8 (M)	31.62	43.46	40.82

[1]Sections correspond to those in Figure 2. Nonmajors' sections are indicated by (m), majors' sections are indicated by (M).

converted to an Advanced Placement score of "3"—the level we accept for equivalency to our nonmajors' course. It is unlikely, however, that a greater number of our majors than nonmajors would have scored the equivalent of a "4" on the A.P. exam, our level of acceptance for equivalency in the majors' course. The cell/molecular scores seemed well below the reported national average of 57 percent but again they fit into the range of an Advanced Placement score of 3. Results from this series of examinations suggest that students are beginning to think more critically about scientific concepts. Furthermore, retention scores suggest that students are retaining the information learned beyond their final examination.

These results also suggest that the nonmajors probably UNDERSTAND basic biological concepts as well as the majors, who were exposed to significantly more detail in the majors' course. The majors simply may be overloaded with details which they do not learn well, and which may even interfere with what they do know.

The nonmajors' course also seems to be doing a reasonable job of improving student attitude toward science. We are currently developing an instrument to evaluate attitudinal change, but student evaluations of their instructors provide a first estimate of our effectiveness. The highest teaching evaluations in the College of Basic Sciences are for instructors in nonmajors' biology.

As an independent check on the validity of our conclusions, we obtained ACT scores for all students who completed either course during this study and submitted ACT science subtest scores as part of their application to the university. We tested the null hypothesis that there was no difference between sections. Analysis of variance showed significance at the 0.007 level. Closer examination revealed that this significance was due to a single majors' section that had ACT scores significantly higher (at 5 percent) than even the other majors' sections. Furthermore, nearly half of the nonmajors' sections (7/17) averaged higher ACT science scores than the lowest majors' section.

As pointed out at the beginning of this paper, there is a growing consensus among college and university biologists that nonmajors should somehow be taught differently than majors. Based on the data presented above, we suggest that majors and nonmajors should NOT be taught differently. Rather, BOTH should be taught differently from the traditional content-oriented approach. The approaches being developed and implemented for teaching nonmajors may be equally effective in teaching majors.

The question may be asked: is it necessary, or even desirable, to impose the dichotomy between majors and nonmajors at the freshman level? Our study suggests that such a dichotomy is based on false assumptions, faculty beliefs, and an ingrained tradition which has little pedagogical support. If this is true, we will be better off, both in terms of effective student learning and in utilization of scarce resources, by doing away with this division. In order to accomplish this we must do several things.

- First, we must be willing to test our assumptions and challenge our beliefs to determine if they have any scientific basis.
- Second, we must convince our scientific colleagues, with studies such as this, that with respect to majors, "less is more." We would do a disservice to everyone if we developed a common introduction to biology for all students, then taught it the way majors are traditionally taught.
- Third, and finally, we must convince ourselves, our colleagues in arts and humanities, and our administrators, that "all students are created equal." It is not necessary for us to provide a special track of biology for the majority of the college population. Freshmen without a career interest in science, and even science-anxious students, are capable of understanding basic concepts of biology and the process of science if these concepts are made relevant and not overburdened with excessive and confusing detail. At the same time students who move on to a science major will have a more solid foundation upon which to construct their understanding of science. ❑

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