Performance Assessment of a Standards-Based High School Biology Curriculum

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IN response to what was widely perceived as inadequate teaching of precollege science in the United States, the National Science Foundation supported the development of the *Benchmarks for Science Literacy* (AAAS 1993) and the *National Science Education Standards* (NRC 1996). One of the specific problems addressed by these national standards efforts was that secondary science historically has been taught primarily through lecture with emphasis on long lists of trivial facts and vocabulary words, which often are to be memorized (Bowyer 1990; Brandwein 1981; Champagne & Hornig 1987). This practice has been widely supported by traditional, encyclopedic science textbooks which continually grow in size as more information is added to each new edition.

Both AAAS and the NRC attempted to aid science curriculum developers in content selection by identifying a small subset of the most important science concepts rather than a long set of facts that attempt to cover an entire subject, as is the case for many traditional science curricula. Also, unlike the dominant traditional curricula, AAAS and NRC strongly recommend that science curricula devote significantly more time to developing scientific thinking skills and understanding the nature of science. Both organizations promote student learning through engaged investigation as opposed to passive listening and speak also to the desirable role of the teacher as being distinctly student-centered and inquiry-oriented.

Science curricula recently funded by the National Science Foundation have aligned themselves with the *Standards* and *Benchmarks* by reducing numbers of concepts and topics and de-emphasizing less central concepts and topics in favor of additional activities that require student thinking, decision-making, inquiry, collaboration and communication. Observers of students using these new curricula have noted that they are engaged extensively in serious discussion and scientific inquiry.

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Since the national standards and corresponding curricula developed to meet the standards are quite recent, there is yet little research literature on the effectiveness of these curricula. *ChemCom* (Sutman & Bruce 1992, 1993; ACS 1998), a high school chemistry curriculum developed with funding from the National Science Foundation and the American Chemistry Society predated the *National Science Education Standards.* Developers of *ChemCom* say that it matches the standards, especially in its 1993 and 1998 editions. One study of *ChemCom* at the University of Texas (Mason 1998) compared student achievement in college general chemistry by students who had either a traditional high school chemistry curriculum or the 1988 or 1993 editions of *ChemCom.* After eliminating variables such as having taken AP Chemistry or a second year of advanced chemistry in high school, there were no statistically significant differences in performance between students who had one year of *ChemCom* versus those who had one year of a traditional chemistry course in high school.

Biology: A Community Context (Leonard & Penick 1998a) is an introductory high school biology curriculum developed in response to the national standards and needs. Funded by a $2.3 million National Science Foundation grant to Clemson University, the project goal was a teacher-developed curriculum that would be standards-based, activity-oriented, inquiry-centered and overtly constructivist. As part of the evaluation component, we were interested in knowing if this standards-based curriculum would produce any greater learning of selected science concepts identified in the *Standards* and *Benchmarks* and any greater understanding of scientific inquiry skills than did the traditional curricula that dominate schools today. *BACC* was designed to encourage broad goals (Penick & Bonnstetter 1993) by following a research-based instructional strategy (Leonard & Penick 1998b; Penick 1999).

Instructional Methodology

Much research about teaching and learning was used to support the development of the *Standards* and *Benchmarks*. Over the years, a variety of research demonstrates that when students learn actively by being engaged (much the same way as do scientists) they have fuller and more lasting understanding of scientific concepts, science process skills, and the nature of science than they do if instructed primarily by lecture and discussion indicated (Piaget 1964; Mullis & Jenkins 1988; Smilansky & Halberstadt 1986). This active participation is scientific inquiry.

Students benefit from direct experiences with other students as well as the materials, concepts and processes, and best understand them in that manner. With this rationale, considerable laboratory, field and other types of classroom investigation need to precede, rather than follow, discussion, explanation and lecture. Thus, standards-based curricula would be expected to be highly activity-oriented, student-centered, and have the textual narrative that explains scientific concepts placed carefully in the student textbook after the corresponding inquiry activities. In this manner, student investigations are more experimental in that they are seeking answers to questions rather than merely doing laboratory work to confirm answers already given, what Schwab (1963) called a "Rhetoric of Conclusions." At the same time, by doing the activity first, students develop a need to know and learn more, thus encouraging reading and communication with others.

The Experiment

During the summer of 1997, 16 high school biology teachers representing very diverse educational settings all over the United States, ranging from suburban to urban and rural, as well as small and large, were given an intensive, one-week training on the methodology and contents of *Biology: A Community Context* by the authors (Leonard & Penick) and Project Manager (Speziale) of the curriculum (see Table 1). Teachers were immersed in all the components of the curriculum (student text, teacher guide, initial inquiry video, and assessment package). Teachers conducted selected and representative activities from the student text and discussed concepts, activities and strategies with the authors, seeking a more thorough understanding of the nature of science and the curriculum. Other discussions emphasized the curriculum's instructional methodology, the nature of scientific inquiry, the constructivist view of learning, active learning and the critical sequencing of the different kinds of classroom instruction.

During the full 1997-98 school year the same 16 high school biology teachers each taught at least one class using the standards-based curriculum, *BACC*, and at least one other class using their existing traditional curriculum and text. Many of these teachers actually taught multiple classes of both *BACC* and their traditional curriculum. Since neither students nor classes were randomly assigned at each school, there was some concern about equivalency of student ability in the intact classes using the two different curricula. To accomplish the best possible equivalency given these limitations, each teacher was asked to teach approximately half of their biology classes using each curriculum and to make assignments of classes to each of the two so as to achieve the best possible balance of student ability using each curriculum.

During the first week of school, teachers administered two pretests: "A Test of Understanding Biology Concepts" and "A Test of Science Process Skills. Both tests were constructed by the authors and *BACC* staff, reviewed by biology teachers, and revised accordingly. The concept test and the process tests each emphasized higher-order critical thinking skills. The items on the concept test featured biological knowledge and ideas while the process test featured the more traditional processes of science in a biology

(continued on p. 313)

Table 1. Characteristics of teachers and test sites.

School	*Location*	*Type*	*Teacher Qualification*
1	Cleveland, OH	Urban	MA
2	Derry, NH	Suburban	BA
3	Edwardsville, IL	Rural	MA
4	Fallbrook, CA	Rural	MA
5	Fairfield, CA	Suburban	MA+
6	Fresno, CA	Urban	BA
7	Fresno, CA	Urban	MA+
8	Hannibal, MO	Rural	Ph.D.
9	Myrtle Beach, SC	Suburban	BS
10	Tarpon Springs, FL	Rural	MA
11	Topeka, KS	Urban	MA
12	Van Nuys, CA	Suburban	BA
13	Van Nuys, CA	Urban	MA+
14	Wakefield, RI	Rural	BS
15	Washington, DC	Urban	MS+
16	Wellesley, MA	Urban	BS

context (see Table 2 for sample items). All students in the study repeated the same two tests as posttests during the last week of the school year. Data were analyzed for class differences in mean scores between *BACC* and the traditional classes.

Observations of Differences Between Standards-Based & Traditional Instruction

Teachers used the *BACC* curriculum and their existing traditional curriculum with the corresponding intact classes during the entire school year. For the *BACC* class, teachers were asked to use classroom methodologies learned in the summer workshop and consistent with *BACC*. For the traditional classes, teachers attempted to use methodologies consistent with their past practices in classrooms using a traditional curriculum.

There were both intended and observed differences in the instruction using these different curricula. The primary instructional methodology intended in *BACC* was investigative inquiry because there were more than a hundred inquiry activities directly in the student text. Individual students spent about 75% of their time in active investigation. The traditional biology curriculum students spent about 90% of their time listening or reading. One of the authors visited and observed all of the sites twice during the school year. In nearly all observations of *BACC* classes, students were doing activities for the majority of the period. This included what would be recognized as laboratory and field experiments as well as student forums, group presentations, and small and large group discussions. In the classrooms using the traditional biology curricula, lecture or reading were observed most of the time. Those laboratory exercises that were observed in the traditional classrooms were primarily dissections or activities that required students to read and follow directions.

The role of the teacher in the classrooms using the different curricula was also vastly different. In *BACC* classrooms the teacher staged activities in which the

Table 2. Sample test items for biology content and science process tests.

Biology Concepts

#2. All of the following are characteristics of living things except:

a. unlimited growth size
b. adaptability to an environmental condition
c. the ability to reproduce
d. the ability to respond to environmental stimuli
e. growth

#4. 25 milliliters of 50 percent glucose solution is placed in a large test tube. If aerobic respiration takes place, what kind of gas would be produced?

a. gaseous alcohol
b. carbon dioxide
c. methane
d. oxygen
e. nitrogen

#17. If an animal cell had a constant 2 percent glucose content inside and the blood outside the cell had a constant 4 percent glucose content introduced, what would the level of glucose be inside the cell after a short period of time?

a. 0 percent b. 2 percent c. 3 percent d. 4 percent e. 6 percent

Science Process Skills

#2. Julie carried out a long-term experiment in which she measured the mass of a seedling and the dry soil in which it was placed. Five years later the mass of the tree that grew from the seedling and the dry soil were measured. She found a very large increase in the mass of the plant and almost no loss of mass in the soil.

On the basis of the results from Julie's five-year study, choose the response that best fits her experiment.

a. Conclusion: Air is needed for this to occur.
b. Conclusion: Plants get their nutrients from the soil.
c. Conclusion: Water creates the mass for the plants.
d. Conclusion: Soil provides the nutrients needed by the plant.
e. Conclusion: Plants do not gain mass by using up soil.

#22. You are collecting data on the diversity of organisms that live in a forest. What kinds of information would be important to collect?

a. the different kinds of insects you saw
b. where organisms were found
c. the kinds of plants you saw
d. a and c only
e. all the above

students participated. Although the teacher guided some discussions (especially summary discussions), students spent much more time contributing than did the teacher. The teacher's guiding presence was always noted, however. In the traditional classroom, the teacher was not only the focus of instruction but was also the most active and dominant contributor.

There were also differences in the sequencing of the kinds of actions taken by students. Activities in the *BACC* classroom appeared to proceed from concrete to more abstract. Students began by manipulating materials in attempts to investigate biological phenomena and questions raised in class. This was followed by guided discussions, short teacher explanations, and reading assignments related to the same concepts. In the traditional classrooms, abstractions of the concepts were first presented by lecture or demonstration, followed by brief opportunities for students to ask questions, laboratory work, then assignments involving vocabulary words or questions in the textbook. Actual investigations occurred only about once a week and were rarely student initiated or planned.

The spirit of the national standards appeared quite prevalent in *BACC* classrooms. Here there was a greater balance in student time spent on development of biology concepts, science process skills, and understanding the nature of science. Traditional classes focused exclusively on development of biology concepts, as evidenced by clear attempts by the teacher to "cover the material" in all or part of a chapter in the text (teacher's own words). *BACC* classes spent more time on selected biological concepts and more time relating the concept to the students' lives in familiar settings. There appeared to be little time for students to reflect, evaluate or investigate concepts in the traditional classes, whereas these aspects were observed regularly in *BACC* classes.

In spite of differences between the BACC and traditional classes, there were also similarities. The teachers appeared well prepared in both kinds of classes. The students acted attentive, interested, and relatively responsive to the teacher's requests for actions or responses. It would appear that these students had been well trained in traditional methodologies and felt comfortable with them. Some students appeared frustrated with the uncertainties presented to them in the *BACC* curriculum. The major differences in observations of the implementation of the two curricula and in the intended way in which classroom procedures were carried out are summarized in Table 3.

Findings

Overall, *BACC* students received lower scores on the pretests of both science concepts and processes than did the students in the more traditional classes. The difference between the two class means was significant at the .005 level on the pretests of science processes. Several teachers mentioned that counselors, on seeing the small size (576 pages) of the *BACC* student text, sometimes systematically put students of perceived lower ability in these classes and students of perceived higher ability into the traditional classes with the larger textbook (usually over 1000 pages). This practice was consistent with historical observations of counselor practice years earlier with the *ChemCom* curriculum. Table 4 shows these pretest differences as well as posttest results and standard deviations.

At the end of the school year, students completed the same tests of concepts and processes as posttests.

Table 3. Comparisons of BACC and traditional classroom instruction.

Characteristic	*BACC*	*Traditional Text*
Primary Instructional Methodology	75% investigative inquiry; discussions and forums	75–90% lecture; less than 20% lab; some worksheets
Role of Teacher	Orchestrates activities; guides discussion	Authoritative center of instruction
Sequence of Instructional Activities	Direct experiences first, followed by discussion	Lecture, reading, sometimes followed by lab
Relationship to National Standards	Highly correlated by design; demonstrated in activities and readings	Correlations claimed but demonstrated only in some readings
Number of Concepts & Topics Covered	Fewer than 180 in greater depth	Broad coverage of over 400 concepts
Science Process Skills	Highly emphasized on daily basis	Little or moderate emphasis perhaps weekly
Understanding the Nature of Science	Direct experiences and reflections	Little systematic development
Emphasis on Terminology	Terms not bolded, used only in context	Thousands of terms bolded in text; intended to be memorized
Applications Of Concepts	Related to student's local community	Related to next biological concept(s)

Table 4. Pre-and posttest scores on biology concepts and science processes.

	Mean	N	SD	t	p
TEST ON BIOLOGY CONCEPTS (40 questions)					
Pretest—All BACC Classes	13.38	372	5.59	1.68	.90
Pretest—All Traditional Classes	14.06	368	5.45		
Posttest—All BACC Classes	18.5	365	8.03	3.43	.005
Posttest—All Traditional Classes	16.5	298	6.96		
TEST ON PROCESSES SKILLS (30 questions)					
Pretest—All BACC Classes	10.52	395	4.79	3.95	.005
Pretest—All Traditional Classes	11.97	379	5.39		
Posttest—All BACC Classes	14.06	376	5.65	3.07	.005
Posttest—All Traditional Classes	12.69	308	5.93		

Not only did the *BACC* classes score significantly higher on the posttests of both science concepts and processes, there was less attrition in the *BACC* classes than in the more traditional classes. Three hundred seventy-two *BACC* students completed the "Test of Understanding Biology Concepts" pretest and 365 completed the posttest, a loss of only 2% compared with the more traditional students completing the same test going from 368 to 298, a loss of 19% during the school year. The same pattern was repeated on the "Test of Science Process Skills" with *BACC* classes losing only 5% and the traditional classes again losing 19%. While some of the losses may be related to student errors in coding their names, there may also be an element of taking the test more seriously in the BACC classes. An anecdote from one of the field test sites may have meaning here.

At a large, urban high school, one class of biology students began the year with BACC. *After only a few weeks of class, the local fire marshal closed the school, citing building safety as a factor. All the students were moved to the library of a nearby middle school, and divided up into classes with almost no materials or equipment. The field test teacher persevered, having students do the activities as best they could. Then, after several months in this facility, they were all allowed back into the high school. At that point, the teacher noted that a large number of his students in the more traditional class had dropped out, while all of the* BACC *students were still attending regularly. When he asked students why they were still there, he heard a lot of statements along the lines of, "This class is fun. It is one of the few reasons we even come to school."*

It was notable that, although the *BACC* classes scored significantly lower on the science process skills pretest, after a school year of *BACC* they scored significantly higher on that posttest. Of particular interest were the differences between pretest and posttest gain scores for the two groups. *BACC* students gained 2.68 more points than the traditional classes on the biology concepts test and 3.83 more points than the traditional classes on the test for science process skills. These differences in gain scores represent approximately one-half standard deviation.

Following up on the anecdote about class attendance, student comments obtained through a structured survey revealed that students in general liked *BACC*, felt they had done well (and even better than in prior science classes), and enjoyed the activities, finding them useful. Their comments also were consistent with observations from visiting the classes. The comments (and percentage of students responding in this manner) that we felt were most typical of our observations are shown in Table 5.

Inferences & Conclusions

Many have proposed that our traditional science curriculum provides for too much breadth and

Table 5. Representative student comments about *Biology: A Community Context.*

The activities in the text were:		
too difficult (6%)	about right (89%)	too easy (5%)
I found the activities:		
interesting & helpful (77%)	uninteresting (23%)	
The readings were:		
too difficult (13%)	about right (81%)	too easy (6%)
The amount of work for this course was:		
too much (23%)	about right (72%)	not enough (5%)
Compared with other science programs, I performed:		
better (86%)	worse (8%)	same (6%)
Compared with other science programs, I learned:		
more (80%)	less (16%)	same (4%)
I enjoyed using this material:		
agree (76%)	disagree (23%)	sometimes (1%)

precious little depth (Sutman & Bruce 1992, 1993). Various anecdotes of teachers teaching fewer concepts but finding that students scored better on exams have been reported (Yager 1990; McComas 1989). Yet, implementation of innovative NSF-funded curriculum is scattered and accounts for only a small fraction of all student materials purchased in the United States. Some of this may be due to a lack of research on the effects of these innovative curricula but equally likely is that few teachers have used such curricula and felt the impact of students feeling as they reported in Table 3. As a related aside, Japanese cars did not come to dominate the U.S. market because drivers read research reports about their quality of construction. Instead, consumers noted the fit and finish, the quality appearance, the fuel economy, the ride and handling, and their reliability. Much of the rush to buy Japanese cars was fueled by word-of-mouth based on experience with the product. Table 5 describes some very happy consumers and Table 3 shows some possible reasons why they may have been happy.

These findings are quite gratifying as we would have been satisfied to find that *BACC* students did as well as more traditional students. Having them do better and also report they really liked the curriculum more was surprising. We were also gratified to find that experienced biology teachers can implement successfully a standards-based high school biology curriculum. And, contrary to some popular mythologies, they also can change their behaviors to match the rationale and methodology of the innovative curriculum. Moreover, these teachers appeared to be persuaded that a standards-based approach is desirable, reasonable and practical to implement.

Based on the limited population used in this study, this standards-based biology curriculum was more productive in teaching an understanding of key biology concepts and science process skills than were more traditional curricula. This study provides some evidence that recently developed, NSF-funded curricula are accomplishing the goals of the *National Science Education Standards* and the *Benchmarks for Science Literacy*.

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