A Vision of Biology Education for the 21st Century

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One need not look very far for interactive influences among the sciences, technology and the condition of human and other life forms on planet Earth. For instance, advances in agricultural techniques have promoted the emergence of highly efficient systems for irrigation and fertilization of arable land. This has resulted in a worldwide "Green Revolution" identified by enormous progress in agricultural productivity. Technology has provided us with many benefits, but also has unwittingly encouraged (due to the phenomenal population growth) overconsumption of nonrenewable and renewable natural resources, increased production of throwaway packaging and minimal recycling. Many times this has resulted in a stripped and denuded ecosystem, irreparably harmed.

The consistent exploration of bio-societal problems, ethical dilemmas and interactive environmental consequences is critical if educational systems are going to influence the survival of global society. The development of critical decision making skills and the courage to come up with thoughtful, logical and non-self-centered decisions should be accorded top priority in school science programs.

Programmatically, biological knowledge should lead to a means for understanding how science (as a way of knowing) operates and how scientific knowledge serves humanity. The hierarchical organization of life present in the biosphere-society-individual continuum must receive appropriate emphasis. The welfare of both the individual and society is best served by first addressing the welfare of the biosphere.

The study of the structural and functional aspects of the biosphere provides the "big picture" within which all species function. Such knowledge is needed to view the short- and long-term consequences of human actions. Buchwald (1984) identifies four basic issues which need to be understood if each of us is to be an informed and responsible citizen:

1. World population continues to grow at an exponential rate.
2. World consumption of nonrenewable resources continues to grow at an exponential rate.
3. Large-scale systems of a biogeochemical nature are being perturbed.
4. The first and second laws of thermodynamics are still an important guide to understanding the world's energy and material resources (p. 330).

These issues are central to our understanding of human ecology. Buchwald concludes by recommending that, "It is essential to develop the human ecological perspective in biology education, if not all education" (p. 333).

The National Science Teachers Association (NSTA) in 1987 commissioned the Search for Excellence in Biology Teaching Task Force.[1] The task force was charged to review previous attempts at defining excellence and then develop a new set of criteria for a program of excellence in biology.

The task force members worked more than two years to develop the Criteria for Excellence in Biology Teaching, grades 7–12. Focusing on bioethical concerns, the task force members concluded that what is critically reasoned about is more important than developing generic reasoning skills apart from a holistic approach to the understanding and appreciation of the biosphere-society-individual continuum. Biology teachers must deservedly note the importance and bearing of the holistic approach in teaching biology to their students.

This article is a distillation of the task force report (Wright & Powers 1990), highlighting the criteria for excellence in biology teaching, grades 7–12.

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A Biology Program that Focuses on the Biosphere

The task force developed its criteria based on the fact that biology should be taught as a twofold holistic curriculum. Such a curriculum focuses on biological knowledge that examines science as a process as well as interrelating that knowledge to the biosphere, society and the student. The criteria of excellence dealt with five subsections:

I. Goals in Biology Teaching
II. Criteria for Curriculum in Biology Teaching
III. Criteria for Instruction in Biology Teaching
IV. Criteria for Evaluation
V. Criteria for Instructional Staff in Biology Teaching.

I. Goals in Biology Teaching

A major feature of biology teaching is ranking goals in priority order based on holistic instructional design. A biology program for all students should:

1. Address the present and future needs and interactions of the biosphere, society and the individual
2. Encourage students to experience, understand and appreciate the dynamics of natural systems as a first step toward understanding and appreciating how human activity has affected these systems
3. Organize around a sociological and technological focus for the application of basic and fundamental concepts and principles of the biosphere
4. Pursue the development of creative and critical thinking skills applicable to the decision making process.

Ranking the goals, in turn, establishes the sequence for subsequent discussions on curriculum, instructional strategies, instructor criteria and evaluation. This provides an internal consistency in planning the program and reflects a more significant concern about developing a holistic course of study.

Science, regardless of its powers of explanation and prediction, is but one of several human activities that attempts to understand human experience. Also, because science is such a major force both for biological and social change, it is irresponsible for the educational system not to emphasize what science is and can do, as well as what it is not and cannot do. Biology and all other science disciplines, in addition to their traditional role of presenting the current state of knowledge, must serve as a means to examine the process of science itself as an integral part of scientific literacy.

Among the finest justifications for giving the biosphere, rather than the individual, a central focus are the writings of Leopold (1949), and they are valid to this day. Cutting across ecological concerns, the distinction is clear that the individual is protected best and has the greatest options for freedom of choice by first insuring the health and welfare of the community. Community, in Leopold's view, includes both biotic and abiotic components of the environment. In other words, humans are best cared for by focusing on the needs of the biosphere. The danger inherent in the traditional approach of having the individual as the central focus is well-documented in Hardin's *The Tragedy of the Commons* (1968), picturing the poor attention given to the biotic and abiotic environment. The analogy by Adam Smith (*The Wealth of Nations* 1937) shows the centuries-old economic concepts of the Western society assuming that continued progress for the greater community is best assured by first allowing maximum freedom for individuals to pursue their own personal goals. In fact, this has become a basic tenet for modern democratic societies. While such a belief was not too damaging to the biosphere in the sparsely populated world of the 18th century, it is disastrous for a world rushing toward a population of 6 billion to 10 billion people.

The perspecuity of this concern in having the biosphere as the central focus in biology education is further emphasized by Boyer (1987), who concluded: "All the forms of life on the plane Earth are interlocked. No core of learning is complete without introducing students to the ordered yet symbiotic nature of the universe. For this discovery, science is the key" (p. 96).

II. Criteria for Curriculum in Biology Teaching

After studying the goals, the committee arrived at 10 curricular items that reflect the proposed holistic-hierarchical approach to biology. The sequencing of the Criteria for Curriculum in Biology Teaching is more flexible than the sequence of the goals. The expansiveness of these criteria should allow for the development of ideas and strategies relating to areas beyond those usually addressed in the more limited traditional biology curriculum.

Thus, a desired biology curriculum should:

1. Demonstrate the use of biology as a vehicle by which:
   a) Science is viewed more as process rather than product
   b) Confidence is developed in the utility of scientific reasoning to solve problems
   c) The problems of everyday life are identified, examined and resolved through the extension of the processes of scientific reasoning.

A major feature is the attempt to correct the erroneous view of science as a mysterious "black box" pumping out facts. It is possible to consider the method of trial and error as a creative act possessing

many similarities to the methods employed in resolving the pressing problems in everyday life.

2. Exhibit an understanding that, even though biological explanations are tentative, scientific progress depends upon the assumption of order in the universe.

Thus, truth would be placed in an applicable context and would always to be sought with the realization that the goal could never be reached in absolute terms. A recognition of this view of scientific fact encourages students to appreciate the cultural influences affecting all citizens—scientist and nonscientist alike.

3. Distinguish between evidence for empirical and inferred explanations that are the foundations of scientific knowledge.

A correct understanding of any scientific explanation requires an ability to distinguish what is observable (thus, a testable measurement) from what flows from these observations as abstract deductions.

4. Within the organizational levels of biosphere-society-individual, provide for a competency of conceptual knowledge in the following major themes: diversity, structure and function, energetics, integration, continuity and change, cycles, nutrition, and behavior.

Rather than being the reason for a biology program as well as its primary end result, the acquisition of such knowledge is but a prelude to its use in the examination of problems and resolutions identified in the biosphere—individual continuum. For example, ergonomics (ERG + [EC] onomics)—the study of biotechnology—would serve as an extension of the conceptual knowledge in the above major themes.

5. Demonstrate an application of this conceptual knowledge in examining options for resolving problems of:
   a) Atmosphere (e.g. climatic changes)
   b) Hydrosphere (e.g. supplies and quality of water, aquatic resources)
   c) Lithosphere (e.g. soil fertility and erosion, mineral and energy resources)
   d) Biosphere (e.g. extinction, population dynamics, technological impacts).

The reason for learning "facts" is justified in this curricular item. The interdependence of life with the physical abiotic components in nature has been well established. Indeed, past and present human behavior represent evidence of the dangers to life from ignoring environmental interrelationships. The application of meaningful and relevant knowledge, in this context, can but reinforce a student's self-imitating traits so essential to the learning process.

6. Interface conceptual knowledge in biology with appropriate principles from: the physical sciences, mathematics and statistics, the social sciences, and the humanities.

Unless mere surface coverage of a topic counts as adequate education, which of course is not desired, an indepth understanding and working knowledge of biology cannot take place without knowing the richness of the above areas of knowledge.

7. Apply the interfaced knowledge to explore strategies for initiating and sustaining political and social change to protect and manage the biosphere.

Perhaps the greatest (and most intense) test of worth of the educational system (and endeavor) is how wisely and judiciously the knowledge learned is used in human society. Active involvement, rather than passive acceptance, by everyone provides a greater assurance for the continued health of the biosphere.

8. Offer a historical perspective of the evolution of biological thought.

A history of scientific ideas focuses on a more accurate description of scientific progress. The significance of trial and error and serendipity would emerge in an attempt at scientific progress. For example, Horace Wells and Gardner Q. Colton's discovery of nitrous oxide anesthesia in 1844 (New York Public Library Desk Reference 1989) and Paul Charpentier's discovery of chlorpromazine (tranquilizer) in 1950 (New York Public Library Desk Reference 1989) were serendipitous events.

9. Foster the ability to communicate biological ideas effectively through both verbal and written expression.

An ability to use lucid terms in discussing biology, even with its complex vocabulary, would reinforce those skills required for effective communication in everyday life. Being able to express an idea in writing is only one-half of its communication. Learning to convincingly interpret the idea for an educated audience is the other half.

10. Develop an awareness of the options for careers and avocations in the biological sciences.

Emphasis in education must be given to the many and varied positions available for professional employment. Society needs people skilled in lucid and coherent writing to communicate science to the public.

III. Criteria for Instruction in Biology Teaching

It should not be too much to hope for the education of citizens who seek out on their own, as both

intellectual pursuit and personal enjoyment, answers to nature's complex and varied phenomena.

A program of excellence in biology for the 21st century must include a diverse set of instructional strategies. The Criteria for Instruction in Biology Teaching should include:

1. The humane integration of living organisms, including vertebrates, into all levels of biology instruction.
2. An emphasis on short- and long-term laboratory/fieldwork, both experiential and experimental, directed towards:
   a) Concept and skills development, including the psychomotor component of field studies and laboratory activities
   b) Creative and critical thinking relevant to current problems and solutions
   c) Encouragement of leisure time activities related to the study and well-being of living systems (the biota).
3. Activities that require students, individually and collectively, to acquire, use, interpret, analyze and evaluate data.
4. Group and individualized instruction based on current research in learning theory and cognitive psychology to optimize the learning process for all student populations.
5. The systematic use of mathematics, statistics and computers in the learning and problem solving process.
6. The application of an eclectic teaching-learning strategy that would lead students to use such reasoning processes as:
   a) Divergent/convergent thinking
   b) Inductive/deductive thinking
   c) Metaphoric thinking.
7. The implementation of indepth studies of major issues to stimulate discussion of open-ended questions through the use of various small-group techniques.
8. A fully-equipped and supplied facility to support program activities.
9. A shift away from major dependence on textbooks and workbooks to place more emphasis on:
   a) Community resources (natural and/or modified environment in the home, museums, zoos, aquaria, libraries; inviting guest speakers from institutions of higher learning, business and industry)
   b) Up-to-date literature for informed citizens
   c) Print and nonprint multi-media formats (videodiscs, computer-assisted instruction, learning centers and educational television)
   d) Active participation toward a solution for biologically-related issues in the global society.

Students should be provided with the opportunity to study realistic problems and develop workable solutions to those problems. For example, an indepth study of an ecosystem such as the Chesapeake Bay (Wright 1985) would not only involve the study of its ecology, but the historical, political, economical and social factors that have influenced its use, misuse and management. The insights developed would broaden student perspectives about solving biologically-related problems in the "real" world. An exemplary program in biology must encourage decision making about holistic issues, whether it involves an estuary, a forest, a watershed, green space or air quality.

IV. Criteria for Evaluation

The fourth subsection in the Criteria for Excellence in Biology is the Criteria for Evaluation. A program of excellence in biology must be continually evaluated and data from the evaluations used to confirm the worthiness and validity of the program components. In evaluating the program, three major features must be examined:

1. Program components that:
   a) Provide internal and external feedback for program revision in curriculum, instruction and staffing
   b) Provide feedback for program impact outside of school.
2. A program that incorporates evaluation strategies for instructional staffing components and which adopts idealized instructional staffing criteria (as outlined in Section V).

The evaluation process should provide a continual review of the professional activities of the staff members since this is viewed as an important component of the idealized situation.

3. Evaluation strategies that monitor student components which:
   a) Measure student attainment of the schools' program objectives based on the idealized criteria of goals, curriculum and instruction
   b) Measure student performance using oral and written reports, lab assignments and other objective and subjective measures
   c) Measure student attitude change
   d) Measure cognitive level change
   e) Measure psychomotor skills (laboratory skills)
   f) Provide for feedback and self-evaluation.

V. Criteria for Instructional Staff in Biology Teaching

The fifth and terminal subsection in the Criteria for Excellence in Biology is the Criteria for Instructional

Staff in Biology Teaching. The instructional staff plays a vital role in this type of program. The professional background and self-development of the instructor(s), enrichment of instructor-student academic/intellectual relationships, and a school system that supports professional and personal growth are all key components of an exemplary program.

The major characteristics of each component are outlined below:

1. Professional Background and Self-Development Characteristics:
   a) Demonstrate ability to work effectively with biologically-related societal issues through an integration of diverse ideas from the sciences, technology and the humanities
   b) Promote an active involvement in improving the teaching of biology through participation in professional conferences/meetings, community activities and publication of innovative ideas.
2. Instructor-Student Relationships:

Because the purpose of teaching is to assist the student in doing, not telling, the exemplary instructor must not become a depository of facts but rather a dynamic resource of ideas that students can use in exploring solutions for social problems with no final answers. The skill to work with ambiguity and to exchange information in discussions is essential. The following characteristics identify the relationship that the instructor must mentor and nurture with students.

The instructor must:

   a) Be willing to examine all options proposed by students as they relate to the topic being discussed
   b) Allow students to arrive at conclusions to problems without biasing them with his or her own beliefs
   c) Foster students to work together cooperatively in the resolution of problems and issues
   d) Enhance positive attitudes in students toward continued learning in science
   e) Use both interdisciplinary perspectives and community resource persons
   f) Tolerate conflicting interpretations, stimulate healthy discussion, encourage the continuity of ideas not forcing closure and respect students
   g) Encourage the use of group dynamics in the classroom as a model for broader societal issues and specifically relate biology to bio-social matters of concern and importance
   h) Know about biology-related careers and maintain contacts with working biologists and other community resources
   i) Provide objectives, content, and instructional and learning strategies that are appropriate to the students' stages of mental, moral and physical development.

3. Support from the School System:

For a school system to maintain an exemplary program it must encourage and support (facilitate) teachers' attendance and participation in professional events and personal growth activities. This extension will enhance the teachers' awareness of current issues in biology and education, which they will then disseminate to their students by subscribing to activities that promote Promethean involvement.

Summary

A biology program of excellence for the 21st century must be prepared to incorporate a twofold holistic focus that views biological knowledge, first, as an instrument to examine science as a process. This process includes not only the history of how that knowledge has developed but also how the process is used in identifying problems and the solutions to tackle issues related to the biosphere-society-individual continuum. Secondly, the biological knowledge is used to examine the unique role of human existence within the biosphere and society. Students must recognize their role and responsibilities in preserving the biosphere from individual, national and international perspectives, and develop the knowledge to intelligently sort through available options to maintain quality ecosystems in the biosphere.

Secondary students, particularly in a democracy, need to develop social and political skills (e.g. debating) that will encourage them to be not only concerned about major ecological issues, but equipped to act as advocates at the local or a broader level. Further, attention must be paid to how biological knowledge can be used to understand and solve current social problems. By making personal and societal needs the primary focus of biology (holistic approach), students will, hopefully, develop the attitudes and social and intellectual skills to confront science-related personal and societal problems and arrive at meaningful decisions that will trigger suitable action(s).

Finally, an exemplary biology instructor should be erudite in his/her specialty, must possess a broader working knowledge of other specialties that affect the biotic and abiotic environments and must model the characteristics of a scientifically literate citizen.

It is our hope that readers will accept these criteria in the spirit they are intended. The teaching of biology and supporting curricula are very complex packages. The views expressed here are an attempt to crystallize the issues. The major objective in such an attempt is to stimulate biology teachers to rethink

why, what, how and when they teach. We firmly believe that students participating in programs as outlined above will develop the insights and skills necessary to function as contributing adults in a democratic, secular society facing significant change in the 21st century.

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