Biodiversity Research

Biodiversity Conservation in the Americas: *Lessons and Policy Recommendations*

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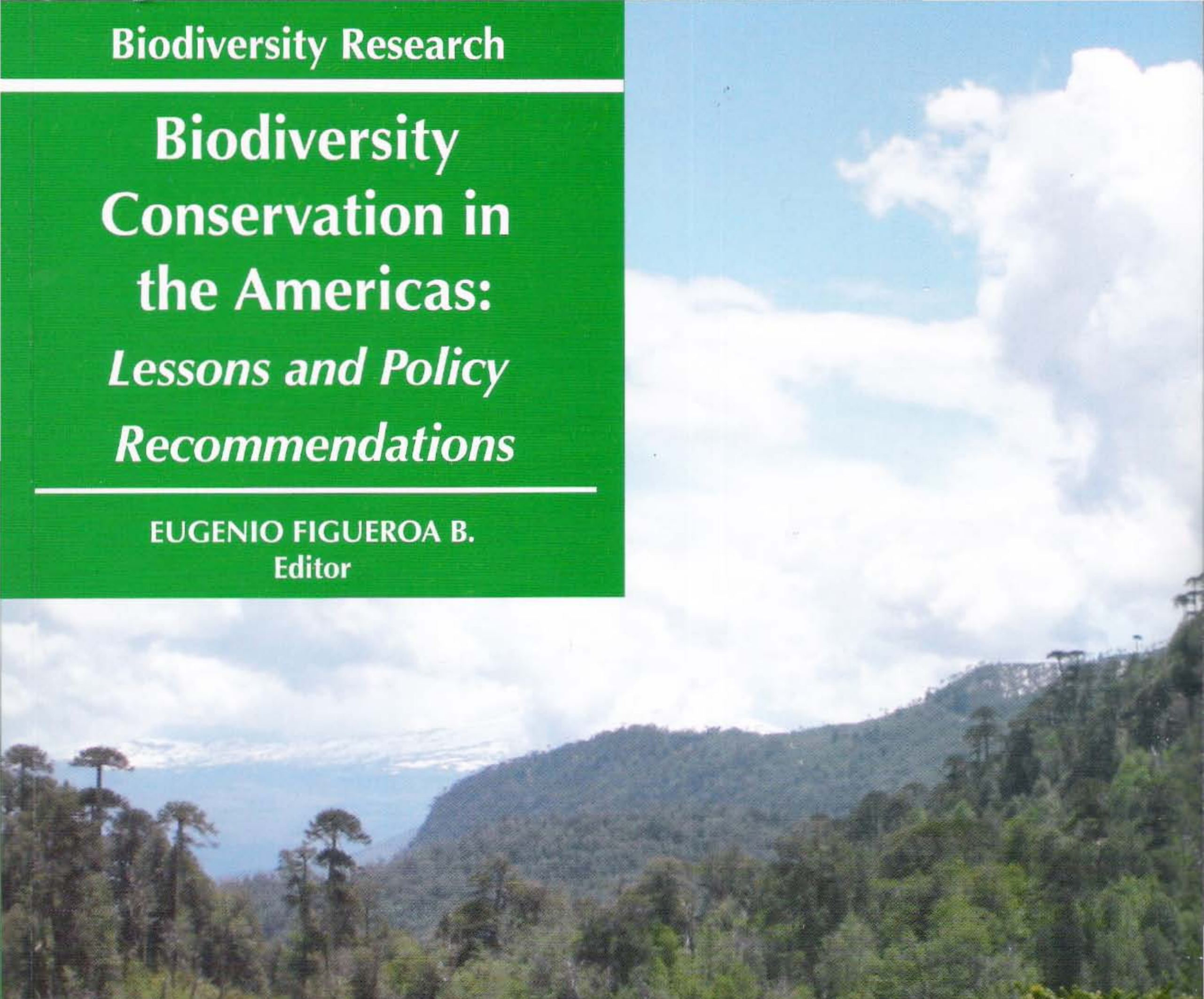
Editor



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Chapter 18

TAKING BIODIVERSITY TO SCHOOL

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1. INTRODUCTION

Let's take a trip to the past, let's go 3.5 billion years ago. The earth had been formed one billion years ago, the atmosphere lacked oxygen. Those were violent times: lighting from intense electrical storms and volcanic eruptions were common. There, at that moment, life originated: a complex association of molecules persisted longer and gradually acquired the ability to reproduce itself. That was the first step in the history of biodiversity. This extraordinary moment deeply changed the planet and its atmosphere.

During these 3.5 billion years, millions and millions of species appeared (and in many cases also disappeared). All living beings that exist (or have existed) are bound in brotherhood because they share that precious moment of the origin of life. Every organism keeps in its genetic memory the sound of the thunder that cradles life and shares that memory with the rest of biodiversity. But, at the same time, every species is a unique and precious experiment of nature.

Biodiversity refers to the variety and variability among living organisms and the ecological complexes in which they occur. Diversity can be defined as the number of different items and their relative frequency. For biological diversity, these items are organized at many levels, ranging from complete ecosystems to the chemical structures that are the molecular basis of heredity. Thus, the term encompasses different ecosystems, species, genes, and their relative abundance.

Estimates of the number of species on earth vary from 3 million to 100 million. The UN Convention on Biological Diversity says there are some 13 million

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species, of which 1.75 million have been described. A more updated figure comes from an analysis of the IUCN's 2008 Red List of Threatened Species (the issue is not addressed in the 2009 Red List) which states that 1.8 million species have been described out of an estimated 5 million to 30 million in existence.

Today that biological treasure is facing times of ruin and devastation. Biodiversity is being lost around the world in an escalating epidemic of extinctions.

Effective action to conserve and sustainably use biodiversity must be based on accurate scientific information. Biological systematics is one of the main tools that science has to map biodiversity. Biological systematics is a multidimensional scientific discipline that describes, names, classifies, and determines relationships among the earth's biota. It accomplishes these deeply interdependent tasks through surveys, inventories, collections, description of species, phylogenetic reconstruction, hierarchical classifications, monographing, and application of rules of nomenclature. All these activities, except phylogenetic reconstruction, are encompassed by the sub-discipline named taxonomy.

To impede species extinction, the first step is to know them scientifically: their systematic placement, geographic distribution, ecology, and to what degree they are vulnerable to environmental changes. Biological systematics has an important role to provide this information. Without systematic biology, ecologists and conservationists do not know which species exist within ecosystems, and cannot discover which are thriving and which are under threat of extinction. The science of systematic biology, therefore, is a vital discipline that underpins the conservation of the earth's biodiversity (House of Lords, 2002). An understanding of systematics and its role in maintaining diversity, therefore, is an important goal of biological education.

The objectives of this contribution is to justify the need of taking biodiversity to school through biological systematic, and present and evaluate two previous successful attempts to take biodiversity to school.

2. WHY TAKING BIODIVERSITY TO SCHOOL?

The major mass extinction event that we are witnessing is the most catastrophic loss species in the last 65 millions years. Most importantly, it is the first major extinction event that has been caused by a single species, *Homo sapiens*. That one species has become so efficient at reproducing itself and dominating all other forms of life that it is in the act of endangering all species, including itself.

The current rate of species extinction is many times higher than the "background" rate, which has prevailed over long periods of geologic time. The background extinction rate varies, but estimates based on the fossil record suggest that in mammals and birds, one species has been lost every 500 to 1,000 years. According to Global Environment Outlook 4, species extinction is occurring at 100 times the natural rate and is expected to accelerate to between 1,000 and 10,000 times the natural rate in the coming decades. The IUCN says that the current rate of extinction may already be as high as 10,000 times the natural rate.

The current disappearance of biodiversity has five major factors of human interference: habitat loss, overexploitation, and spread of exotic species, pollution and climate change. The five factors of interference may constitute the most obvious proximal causes of biotic attrition, but the more fundamental causes are rooted in the contemporary human condition. These more fundamental causes included among others: human population growth, poverty, anthropocentrism, cultural transitions, and failure of planning and inability of modern states to enforce laws and implement conservation policies.

The loss of biodiversity should be of concern to everyone for five basic reasons: 1) the moral responsibility to protect what are our only known living companions in the universe; 2) the esthetic rewards that human beings gain from those companions; 3) the enormous direct and indirect economic benefits that humanity has obtained from biodiversity; 4) the essential services provided by natural ecosystems, of which diverse species are the key working parts, and 5) the scientific obstacle that the loss of species produce in our capacity to understand biological phenomena and processes.

In 2002 in Johannesburg, the world's leaders agreed to achieve a significant reduction in the rate of biodiversity loss by 2010. Having reviewed all available evidence, including national reports submitted by Parties, the third edition of the Global Biodiversity Outlook released last May by the Convention on Biological Diversity concludes that the target has not been met. Moreover, the Outlook warms, the principal pressures leading to biodiversity loss are not just constant but are, in some cases, intensifying. The consequences of this collective failure, if it is not quickly corrected, will be severe for us all. Biodiversity underpins the functioning of the ecosystems on which we depend for food and fresh water, health and recreation, and protection from natural disasters. Its loss also affects us culturally and spiritually. This may be more difficult to quantify, but is nonetheless integral to our well-being.

The United Nations General Assembly proclaimed 2010 the International Year of Biodiversity to coincide with the deadline adopted by Governments in 2002 to achieve a significant reduction in the rate of loss of the diversity of species and ecosystems of the planet.

At the official launch of the International Year of Biodiversity in January 2010 in Berlin, German Chancellor Angela Merkel stated "we need a trend reversal –not at some point in the future, but immediately" and she added "our life is in Biodiversity".

In October 2010 the tenth meeting of the Conference of the Parties to the Convention on Biological Diversity (COP 10) took place in Nagoya, Aichi Prefecture in Japan. Parties met in Nagoya to negotiate a new deal on conserving biodiversity. One of the conclusions of the meeting was that the diversity of genes, species, and ecosystems continues to decline as the pressures on biodiversity remain constant or increase in intensity, mainly as a result of human action. A strategic Plan for Biodiversity 2011-2020 was then adopted to promote effective implementation of the Convention through a strategic approach. The mission of this approach is to take effective and urgent action to halt the loss of biodiversity in order to ensure that by 2020 ecosystems are resilient and continue to provide essential services, thereby securing the planet´s variety of life, and contributing to human well-being, and poverty eradication.

Current trends are bringing us closer to a number of potential tipping points that would catastrophically reduce the capacity of ecosystems to provide these essential services. The poor, who tend to be most immediately dependent on them, would suffer first and most severely. At stake are the principal objectives outlined in the Millennium Development Goals: food security, poverty eradication, and a healthier population.

The conservation of biodiversity makes a critical contribution to moderating the scale of climate change and reducing its negative impacts by making ecosystems – and therefore human societies – more resilient. It is therefore essential that the challenges related to biodiversity and climate change are tackled in a coordinated manner and given equal priority.

We need a new vision for biological diversity for a healthy planet and a sustainable future for humankind.

3. WHY BIOLOGICAL SYSTEMATICS?

Systematics was once the proud flagship of natural sciences. Charles Darwin, the founder of the theory of natural selection, working in Cirripedia (barnacles) in the 19th century and Willi Hennig, the founder of modern phylogenetic reconstruction, working in Diptera (flies) in the 20th century, were both practicing taxonomists. However, in the last 30 years taxonomy has seen a gradual loss of credibility among fellow scientists. This image problem is based on misconceptions of how taxonomy works. The view that taxonomy is a purely descriptive branch of knowledge that consists only of observations is a clear example of these misconceptions. In fact, taxonomy is a scientific discipline that requires description, but also theoretical, empirical and epistemological rigor, a hypothesis-driven approach, and field and lab expertise.

Homo sapiens is by nature a classifying animal. Our continued existence depends on our ability to recognize similarities and differences between objects and events in our physical universe and to communicate these similarities and differences linguistically. Classification systems are not unique.

Given any set of objects, the logical requirements of a classification are fulfilled by an immense array of alternative solutions. The problem is not to classify but to find reasons for choosing a particular solution. Scientifically, one classification scheme is better than another if it is more fruitful in suggesting scientific laws, and generates better explanatory hypotheses. A condition to produce a classification with explanatory power is the existence of a generative system responsible for the observed attributes. The generative system of biodiversity is biological evolution. The goals of evolutionary biology are to: 1- Discover the history of life (= phylogeny), and 2- investigate the processes that account for this history. Evolution explains, and systematics reflects the unity and diversity of species.

Furthermore, classification systems are hypotheses of order in nature (Figure 1). A taxon, the basic unit of taxonomy, is a classification system and as such is a scientific hypothesis about order in nature. Like every scientific hypothesis, a taxon goes beyond the evidence (observations) for which it purports to account. That is, a taxon has greater scientific content (e.g., predictive capability and explanatory power) than the empirical propositions it covers. This taxon-hypothesis, once its scientific content is tested and corroborated, permits scientists to study aspects of biology other than systematics (ecology, biogeography, comparative physiology, comparative morphology, genetics, conservation, etc.). The placement of genera and species in higher categories (Table 1) also is significant for its predictive value with respect to physiological and ecological attributes, because species from the same genus, or genera in the same family, tend to have similar types of life histories, growth and behavioral characteristics, physiological responses, biochemical products, and host or substrate.

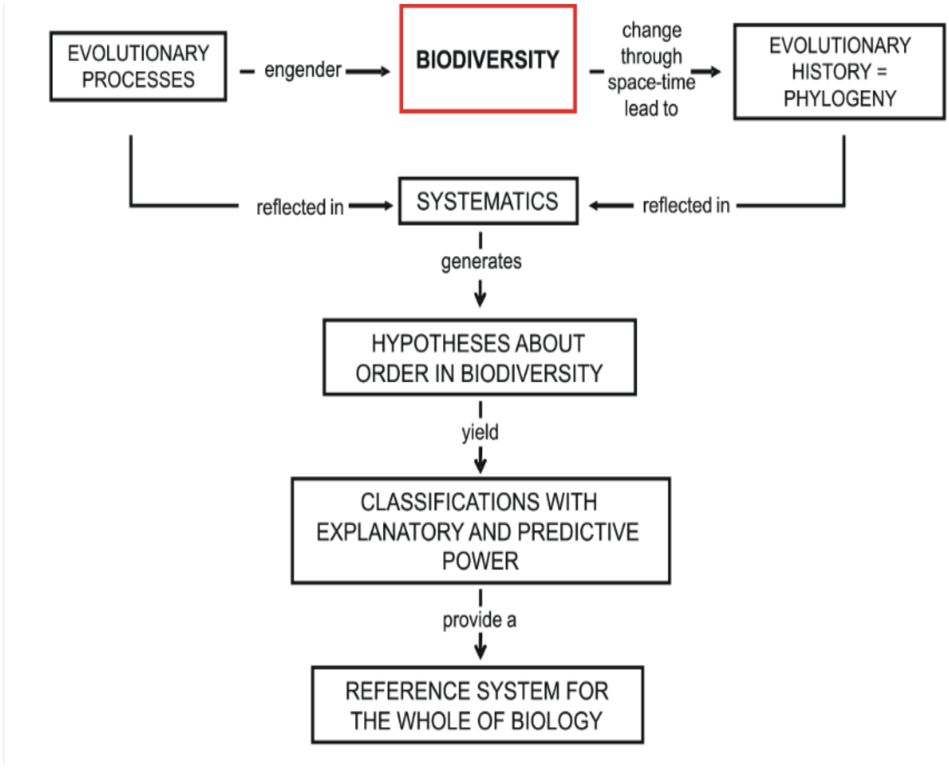

Figure 1. Concept map showing biological systematics as one of the main tools that science has to map biodiversity.

Table 1
Hierarchical system of Biological Systematics showed through an example of the human species (*Homo sapiens*).

CATEGORIES	**TAXA**
Species	*Homo sapiens*
Genus	Homo
Family	Hominidae
Order	Primates
Class	Mammalia
Phylum	Chordata
Kingdom	Animalia

Let´s take as an example the “fruit fly”, *Drosophila melanogaster*, named and described by first time by J. W. Meigen in 1830. Meigen’s hypothesis about order in nature has predictive and explanatory power that were used by geneticists, when they studied a few individuals and assumed that the results were valid for all the members (past, present, and future) of the species *Drosophila melanogaster*.

To describe and to classify all the surviving species of the world deserves to be one of the great scientific goals of the new century. In applied science, it is needed for effective conservation of natural resources, for bioprospecting, and for impact studies of environmental change. In basic science, a complete biodiversity map is a key element in the advance of ecology, including especially the understanding of ecosystem assembly and functioning.

4. WHY EDUCATION?

The problem of biodiversity poses new challenges to education systems: how can schools prepare students, tomorrow's citizens, to become more sensitive to the loss of species and to understand the role of species, especially through systematics, in maintaining biodiversity.

Koïchiro Matsuura, General Director of UNESCO in 2000 stated: “A far greater effort in education in biological diversity is needed to create world-wide public awareness of the issues at stake. Only an educated, global constituency for biodiversity can build up the pressure to ensure that we take the path to a sustainable future.”

This is a global crisis requiring an educational component among the solutions. The goals of education in democratic societies must be responsive.

Sara Michaels and colleagues stated that among the important objectives of science education is the students' introduction to the methods of science and to the habits of mind that scientific inquiry cultivates. The questions and methods of systematics provide numerous opportunities for students to encounter the nature of science-to see science as a unique and powerful form of inquiry that provides rational explanations for our observations about the natural world.

What the future holds in store for individual human beings and the world depends largely on the wisdom with which humans use science and technology. And that, in turn, depends on the character, distribution, and effectiveness of the education that people receive.

Underlying all our conclusions and recommendations is a redefinition of and a new framework for what it means to be proficient in science. This framework rests on a view of science as both a body of knowledge and an evidence-based, model-building enterprise that continually extends, refines, and revises knowledge.

This framework moves beyond a focus on the dichotomy between either content knowledge or process skills because content and process are inextricably linked in science:

1. know, use, and interpret scientific explanations of the natural world;
2. generate and evaluate scientific evidence and explanations;
3. understand the nature and development of scientific knowledge; and
4. participate productively in scientific practices and discourse.

These strands of proficiency represent learning goals for students as well as a broad framework for curriculum design. They address the knowledge and reasoning skills that students must acquire to be proficient in science and, ultimately, able to participate in society as educated citizens. They also incorporate the scientific practices in which students need to demonstrate their proficiency. The process of achieving proficiency in science involves all four strands –advances in one strand support and advances those in another.

Teaching should be consistent with the nature of scientific inquiry, this means replace rote memorization as a traditional goal of learning with an emphasis on thoughtful inquiry and decision making. This approach encourages students to view science as an ongoing, relevant process of learning, as well as a body of currently available information and theories. Students come to understand and appreciate the tentative nature of science and its continuing importance to, and impact on, their lives.

Education is an essential management tool that recognizes the central role of people in all nature conservation efforts. Indeed, although a conservation goal may be focused on a biological problem, effective conservation strategies must incorporate communication and educational programs designed to affect people's awareness, attitudes, and behaviors toward natural resources and land management.

5. PREVIOUS SUCCESSFUL ATTEMPTS TO TAKE BIODIVERSITY TO SCHOOL

5.1. Order and Diversity in the Living World: Teaching Taxonomy and Syustematics in School

Jorge Crisci and colleagues developed in 1993 a document whose objectives were:

1) Create a coherent vision of what it means to be literate in systematics in a world where biological diversity is treated as a global resource to be indexed, used and above all preserved; and in a world where systematics provides the framework for analyzing biological diversity and putting such knowledge into a more accessible form.
2) Establish a set of standards to guide the revision of the school curriculum in biological systematics.
3) Provide examples of classroom instruction that are consistent with the aforementioned standards, that address systematics and biodiversity, and that can be adapted to meet the needs of teachers and students around the world.
4) Discuss the necessity of a narrative that supports taking biodiversity to school.

Education about systematics must develop in students an appreciation for systematics as a discipline that addresses the following questions:

a. Why should we study systematics?
b. How many different groups of organisms are there on earth?
c. How can we organize this diversity so we can better understand it?
d. How do we define, name and identify organisms?
e. How can our system of organization allow us to incorporate new information?
f. How are the organisms on earth related?
g. What factors result in an increase and/or decrease in diversity and what role do humans play in the process?

Students must understand that our system of classification is a mutable human construct. Organisms do not come into the world as members of a phylum, genus or species. Humans place them in those categories-and within the context of a larger classification scheme--on the basis of current knowledge and the perspectives of those who designed the classification system to meet their needs.

As our knowledge of genetics, evolution, anatomy, development, reproduction, energetics and other disciplines expands, we must reorganize the system of classification, as evident in the expansion of the number of kingdoms from three to five within the last two decades. This is an important lesson for students because it demonstrates the dynamic nature of science and the role of multiple competing hypotheses in scientific progress. This, indeed, should be one of the most important lessons of education in taxonomy.

Toward that end, classrooms must become places where students regularly explore interesting problems using important biological tools. Our premise is that what a student learns depends to a great degree on *how* he or she has learned it.

The need for a new approach to teaching systematics. There is a clear need for curricular reform in school-based biological systematics. Such reform must address the content of the curriculum as well as approaches to instruction. The present curriculum often fails to foster biological insight, reasoning and problem solving and fails to emphasize interactive activities. Too often in the teaching of systematics, students become passive recipients of meaningless names and information rather than active participants in developing an understanding of major concepts.

An appropriate curriculum for young children that reflects this document's overall goals must involve children in the process of doing systematics. Young children are active individuals who construct, modify and integrate ideas by interacting with nature, materials and other children. Children must be encouraged to explore, describe, name, discuss, investigate, develop, construct and predict.

Active learning has many implications for systematics education. First, teachers must create an environment that encourages children to explore, name, and discuss nature and biodiversity. They need to listen carefully to children and to guide the development of their ideas accordingly. They need to make extensive and thoughtful use of the organisms around the school to foster the learning of such abstract ideas as the diversity of life and the species concept. The teacher also must sharpen children's powers of observation.

Second, the curriculum should emphasize the development of children's classificatory thinking and reasoning abilities. The curriculum must take seriously the goal of instilling in students a sense of confidence in their ability to classify, detect patterns and see classification schemes as hypotheses about nature.

Third, the curriculum should emphasize the application of systematics. If children are to view systematics as a practical, useful subject, they must understand that it can be applied to a wide variety of problems and phenomena that have some meaning for them. Children also need to understand that systematics is an integral part of biology.

Curriculum standards. Standards help to ensure quality curricula, give direction to the attainment of goals, and thereby promote educational changes and understanding of these changes. Two features are embedded in each of the standards that is identified. First, knowing systematics is "doing" systematics. Students discover or create knowledge by engaging in activities. Second, the value of information lies in the extent to which it is useful in the course of some purposeful activity.

Sample standards (ages 6-12)

The study of biodiversity at ages 6-12 should include numerous experiences with living organisms of diverse groups so that students can:

- Distinguish living from nonliving.
- Observe similarities and differences between objects and organisms.
- Develop simple classification schemes.
- Relate organisms to other organisms.
- See themselves as part of Earth's biodiversity.
- Realize that biodiversity is a vital part of our everyday life.

Focus

From the earliest grades, the curriculum should give students opportunities to focus on similarities and differences between objects. Children should begin to see that similarities are the essence of classifications. The idea of relationships can be developed intuitively through observation of similarities and differences. Children should use physical materials, pictorial displays and a variety of organisms to recognize and create classifications and relationships. This experience builds readiness for a generalized view of systematics.

A classroom can become a rich environment in which to study classification. A group of students, various furniture, shoes, pencils and selected pictures are examples of materials for classification that children can create. Classification can be as simple as a dichotomous grouping (e.g. classifying students into boys and girls), or more complex.

Sample standards (ages 13-18)

The teaching of systematics must avoid overdependence on rote memorization of names. The curriculum should include active problem-solving exercises that focus on one or more of the following suggested standards:

- Systematics as an integrated whole consisting of microtaxonomy, macrotaxonomy and nomenclature
- Ecological relationships
- Human dependence on biodiversity
- The biological species concept
- Phylogenetic systematics
- Nomenclature
- Biogeography
- Computers and systematics
- The fossil record: reconstructing the past.

Although each of the foregoing topics is a valid component of systematics in its own right, the topics should be taught as an integrated whole, not in isolation. The emphasis must shift from one dominated by memorization of names of isolated taxa to one that emphasizes major concepts and a coherent picture of order and diversity.

Teachers should employ a variety of instructional methods in classrooms to cultivate students' abilities to investigate, to construct classifications of organisms, and to make and provide arguments for establishing phylogenetic relationships. These alternative methods of instruction will require that the teacher's role shifts from dispensing information to facilitating learning-from that of director to one of catalyst and coach. The introduction of new topics such as nomenclature should be embedded in problem situations posed in an environment that encourages students to explore, formulate and test phylogenetic relationships and discuss the implications of classification schemes as hypotheses about the living world. Such an instructional setting enables students to approach the learning of biological systematics both creatively and independently and thereby strengthen their confidence and skill in doing systematics.

With the foregoing standards in mind, the CBE has identified activities that illustrate the type of experiences students should have in the classroom: activities that involve "doing" systematics, not merely reading about the nature, substance and purpose of this subdiscipline.

There are, of course, barriers to the implementation of new instruction in any area, and this is especially true for systematics, which does not enjoy a favorable reputation among most teachers and students. The best way to bring about reform is to provide instruction that directly challenges the largely negative perceptions that many students and teachers now hold about biological systematics.

We must remember that:

- Biodiversity is a global resource that needs to be preserved.
- The learning of systematics should be an active, constructive process.
- Instruction must be based on real problems that demonstrate the personal and social significance of biodiversity.

If we keep these points in mind, collectively we have a rare opportunity to provide the kind of leadership that will encourage substantive changes in the teaching of biological systematics in schools. These changes will ensure that all students possess both a suitable and a sufficient biological systematics background to be productive citizens in the next century.

5.2. Climbing the Tree of Life: Taxonomy and Phylogeny for High School Biology

Under a grant from the National Science Foundation, BSCS (Biological Sciences Curriculum Study) collaborated with the ETI, Amsterdam, and Ward´s Natural Science Establishment, Rochester, to develop and publish an interactive CD-ROM. The CD-ROM *Climbing the Tree of Life: Taxonomy and Phylogeny for High School Biology*, uses biodiversity as a vehicle to restructure and modernize the teaching of taxonomy and systematics at the high school level. Students are involved in interactive and laboratory-based investigations that allow them to use a variety of morphological, behavioral, and molecular data to construct and analyze classifications of groups of organisms, both extant and extinct. The students learn that the classifications systems are active hypotheses that represent current –and somewhat flexible- view of the history and relatedness of life on earth.

The program, developed by Kenneth Andrews and colleagues in 2002, consisted of an activity-driven, that uses high school students' interest in biodiversity and concern about its decline to introduce high school students and teachers to: (1) the principles of taxonomy and systematics; (2) the nature and methods of science; and, (3) the personal and social implications of advances in taxonomy and systematics. The concepts presented in the program supports selected national science education standards related to teaching and content, including science as inquiry, the life sciences, science and technology, science in personal and social perspectives, and the history and nature of science.

The CD-ROM consists in a series of activities:

1. *Teeming with life*. Students view and analyze an informative video about biodiversity and answer questions. They discover

several important concepts of biodiversity and the storyline for the CD-ROM´s learning activities. This activity introduces students to the CD-ROM and develops their observations skills, listening skills, video analysis skills, and conceptual understanding of biological diversity. Students participate in a writing-to-learn exercise and a teacher-guided discussion.

2. *Tube worms in hot water: Discovering and classifying life*. As members of the Biodiversity Action Team (BAT), students investigate the biodiversity of a deep-sea hydrothermal vent, discover and classify several new species, and evaluate the scientific and practical value of the organisms living near the vent. The activity develops student´s conceptual understanding of taxonomy and introduces them to the principles underlying the organization of three modern systems of classification and the taxonomic hierarchy. Students also gain experience at working collaboratively with a virtual problem-solving team.

3. *Biodiversity: Its´s all around you*. Students learn how to detect, survey, and identify the animals, plants, and fungi in their local area, then write a newspaper article that summarizes the findings. This activity develop student´s listening, observational, and writing skills, familiarity with the nature and methods of science, knowledge of the organisms that inhabit their local area, and conceptual understanding of biodiversity.

4. *Dinosaurs in your backyard? Investigating evolutionary relationships*. Students learn how to use cladistics to infer the evolutionary relationships among organisms. They then use this knowledge to evaluate the scientific accuracy of information presented in a hypothetical movie script. The activity develops student´s conceptual understanding of biological evolution, cladistics as a method for inferring the evolutionary relationships among organisms and reconstructing their evolutionary history, and how the taxonomic classification of organisms reflects their evolutionary relatedness.

5. *A whale of tale: Practical applications of taxonomy*. Students investigate allegations that meat from endangered whales is being sold as food. If substantiated, such commercial activity

would undermine international efforts to conserve endangered whale species. The activity develops students´ problem-solving, reading comprehension, and presentation skills. It also develops their conceptual understanding of taxonomic keys, molecular techniques for identifying species, and international conservation issues.

6. *Biodiversity: Its origin, loss, and conservation*. Students create a visual study guide that summarizes important information about the origin, loss, and conservation of earth´s biodiversity. The activity develops students´ reading skills; teaches them several learning tools for organizing complex content (matrices, mind maps, and concept maps); and enhances their conceptual and specific knowledge of earth´s biodiversity.

A prototype version of the CD-ROM was launched in 2002 and tested in 19 high schools located in different states of the United States of America. The results were evaluated and, on the basis of the answers of both students and teachers, modifications were implemented and a final version of the CD-ROM was produced.

Major goals. The major goals of this educational program are to:

- restructure and modernize the teaching of taxonomy and systematics in high school biology by using inquiry-oriented instructional methods;
- use students' interest in biodiversity and concern about its decline as the context for conveying major concepts in taxonomy and systematics;
- promote an understanding of taxonomy and systematics by using interactive, CD-ROM-based instructional activities that are accompanied by laboratory and field experiences;
- use taxonomy and systematics to teach students about the nature and methods of science;

- illustrate the personal and social implications of using taxonomic information to understand biodiversity, develop public policy, and solve everyday problems; and

- collect information about how effective this instructional method is in promoting a conceptual understanding of biodiversity, taxonomy, and systematics among students and teachers.

Educational goals. The program:

- improves students' conceptual understanding of taxonomy and systematics by involving them in interactive, inquiry-oriented, CD-ROM-based instructional activities. These activities will be supplemented with laboratory exercises and field experiences.

- uses biodiversity as a vehicle to improve the teaching of taxonomy and systematics.

- teaches taxonomy and systematics within an evolutionary context.

- uses biodiversity, taxonomy, and systematics to familiarize students with the nature and methods of science, and help students understand the personal and social implications of scientific discoveries.

- conveys to students a set of major concepts of biodiversity, taxonomy, and systematics that is scientifically accurate and up-to-date.

Product goals. The program is an ancillary resource for teachers to use when teaching a wide variety of topics in biology, such as evolution, genetics, and molecular biology.

This program conveys the major concepts of three topics: biodiversity, taxonomy, and systematics; the nature and methods of science; and the personal and social implications of biodiversity. Some form of teacher's guide must explain the program's place in the curriculum, its pedagogy, and its use in the classroom (Figure 2).

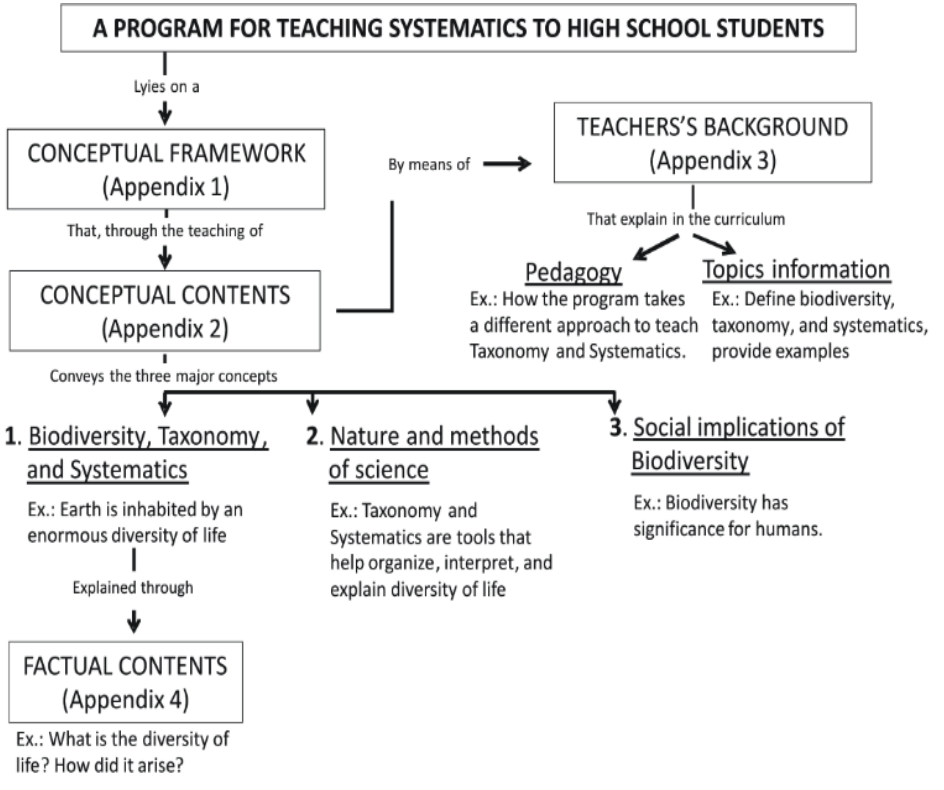

Figure 2. Concept map showing the components of a program for teaching systematics at high school level.

6. CONCLUSIONS

In considering how to conduct the schooling of our young, adults have two problems to solve. One is an engineering problem; the other, a metaphysical one. The engineering problem, as all such problems are, is essentially technical. It is the problem of the *means* by which the young will become learned. It addresses the issues of where and when things will be done, and, of course, how learning is supposed to occur. The problem is not a simple one, and any self-respecting educational project must offer some solutions to it. But to become a different person because of something you have learned –to appropriate an insight, a concept, a vision, so that your world is altered- that is a different matter. For that to happen, you need a reason. And this is the metaphysical problem.

A reason, as we use the word here, is different from a motivation. Within the context of schooling, motivation refers to a temporary psychic event in which curiosity is aroused and attention is focused. We do not mean to disparage it. But it must not be confused with a reason for being in a classroom, for listening to a teacher, for taking an examination, for doing homework, for putting up with school even if you are not motivated.

This kind of reason is somewhat abstract, not always present in one's consciousness, not at all easy to describe. And yet for all that, without it schooling does not work. For school to make sense, the young, their parents, and their teachers must have a narrative or even better several narratives. If they have none, school is pointless. Nietzsche's famous aphorism is relevant here: "He who has a *why* to live can bear with almost any *how*." This applies as much to learning as to living.

We mean by narrative a story, not any kind of story, but one that tells of origins and envisions a future, a story that constructs ideals, prescribes rules of conduct, provides a source of authority, and, above all, gives a sense of continuity and purpose. In the sense we are using the word, is the name of a great narrative, one that has sufficient credibility, complexity, and symbolic power to enable one to organize one's life around it. A comprehensive narrative about what the world is like, how things got to be the way they are, and what lies ahead.

Three narratives that singly and in concert, contain sufficient resonance and power to be taken as reasons for “Taking Biodiversity to School”:

1. Earth as our one and only home.
2. Biological evolution.
3. Bronowski’s *The Ascent of Man*.

Earth as our one and only home is the story of human beings as stewards of the earth, caretakers of a vulnerable planet. If any part of our home is poisoned, then all suffer -which is to say that the pollution of the Gulf of Mexico is not a Louisiana problem, “*Therefore*, *send not to know for whom the bell tolls*”, wrote John Donne. “*It tolls for thee*”.

Biological evolution, as a narrative, is a great and stirring account of life on earth and the human origin within it. It speaks of human frailty and invokes our sense of stewardship of biodiversity.

Jacob Bronowski’s *The Ascent of Man* is a book, a film, and a philosophy, filled with optimism and suffused with the transcendent belief that humanity’s destiny is the discovery of knowledge. Although Bronowski's emphasis is on science, he finds ample warrant to include the arts and humanities as part of our unending quest to gain a unified understanding of nature and our place in it.

Jorge Luis Borges (1899-1986), the great Argentinian poet asked himself a question whose answer reflects the whole matter of taking biodiversity to school:

> *"A small child is taken to the zoo for the first time. This child may be any one of us, to put it another way, we have been this child and have forgotten about it. In these grounds -these terrible grounds- the child sees living animals he has never before glimpsed; he sees jaguars, vultures, bisons, and -what is still stranger- giraffes. He sees for the first time the bewildering variety of the animal kingdom, and this spectacle, which might alarm or frighten him, he enjoys. He enjoys it so much that going to the zoo is one of the pleasures of childhood, or is thought to be such. How can we explain this everyday and yet mysterious event?"*

> *"The child looks at the tigers without fear because he is aware that he is the tigers and the tigers are him or, more accurately, that both he and the tigers are but forms of a single essence".*

The child unconsciously knows that we share the precious moment of the origin of life with the rest of the living beings.

Education on biodiversity should remind us of that extraordinary moment 3.5 billion years ago and nurture in our children –and us all– a sense of stewardship for our planet's biodiversity, of which we are but a small part.

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Appendix 1.
Climbing the tree of life: Taxonomy and phylogeny for high school biology. Conceptual framework of a program for teaching systematics.

Biodiversity, Taxonomy, and Systematics

1. Students will understand the terms biodiversity, taxonomy, and systematics. Biodiversity refers to variation that exists at different levels of biological organization, including the genetic, biochemical, and morphological variation that exists among individuals within a species, among different species and higher taxa, and within and among ecosystems.

   Taxonomy and systematics are the sciences we use to interpret and understand biodiversity. Biologists use different definitions for the terms taxonomy and systematics in the scientific literature. For example, some biologists use the terms synonymously, whereas others view taxonomy as part of the study of systematics. In this program, taxonomy refers to the science of classifying organisms, whereas systematics refers to the study of the evolutionary and genetic relatedness of species.

2 Students will understand that the earth is inhabited by an enormous diversity of life and that nearly all parts of the environment possess biodiversity.

3 Students will recognize that biodiversity has varied across time and space because of a variety of factors such as mutation, genetic drift, speciation, extinction, and historical events.

4 Students will understand that ecosystems are characterized in part by their biodiversity and are dynamic systems composed of organisms interacting with each other and the physical environment. These interactions form the basis for ecosystem processes such as energy flow and the cycling of materials.

5 Students will understand that individual members of natural and domesticated species vary in their characteristics, including morphology, biochemistry, and genetic makeup.

6 Students will understand that organisms can be sorted into categories on the basis of their characteristics and that the selection of characteristics depends on the reason for the sorting.

7 Students will understand that the hierarchical structure of modern taxonomic classification systems organizes information about the world's known biodiversity. The smallest natural taxonomic grouping that scientists recognize is the species, which forms the unit of genetic continuity. There are several different ways to define a species (for example, biological and typological), but the concept of a species has limited applicability for certain groups of organisms, such as the prokaryotes.

8 Students will understand that modem classification systems reflect the evolutionary history and relatedness of species.

9 Students will recognize that scientists are working to construct a phylogenetic tree (or evolutionary map) that accurately reflects the evolutionary relatedness of all life on earth. Scientists continue to refine the structure of this tree of life and make it more complete as they incorporate new information about organisms. Controversy sometimes occurs about the details of the phylogenetic tree when scientists disagree over the interpretation of new or well-established data used in constructing the tree.

10 Students will recognize that scientists use the characteristics of organisms as the basis for reconstructing the evolutionary history of the organisms.

11 Students will understand that Darwin's theory of biological evolution explains why the widely diverse species that make up the earth's biodiversity share fundamental characteristics such as DNA and metabolic pathways. According to the theory, these similarities occur because all organisms on earth are derived from a common ancestor through descent with modification.

Nature and Methods of Science

12 Students will understand that taxonomy and systematics help scientists organize, interpret, and explain the extraordinary diversity of life on earth, both extant and extinct.

13 Students will understand that the taxonomic classification systems and phylogenetic trees devised by scientists represent testable hypotheses that can be challenged and modified as new information is collected.

14 Students will recognize that the taxonomic classification of a group of organisms may vary among classification systems depending upon the assumptions of each system and the information used to classify organisms.

15 Students will understand that there are several ways to recognize a species in nature and that the taxonomic designation for a species can change as new information is collected.

16 Students will recognize that scientists use multiple lines of evidence (for example, morphological, developmental, behavioral, biochemical, and genetic evidence) to determine the phylogenetic relationships among groups of organisms.

17 Students will recognize the role that computers and electronic databases play in modem taxonomic and phylogenetic analyses. Furthermore, students will be able to search for reliable and up-to-date information about biodiversity, taxonomy, and systematics on the World Wide Web, access and use electronic databases, and communicate what they learn through E-mail and/or user groups.

Personal and Social Implications of Biodiversity

18 Students will understand that humans are part of the earth's biodiversity and recognize the interrelationships between themselves and the biodiversity around them.

19 Students will recognize that biodiversity has significance for humans and will understand the various arguments that people use to preserve biodiversity, such as aesthetic, practical, scientific, life-support, and ethical arguments.

20 Students will recognize that their ethical, political, and economic decisions can have an impact on the world's biodiversity; thus they need to make informed decisions.

Appendix 2
Climbing the tree of life: Taxonomy and phylogeny for high school biology. Conceptual Content for teaching systematics.

Biodiversity, taxonomy and systematics

21 Basic Concepts. Students will understand the terms biodiversity, taxonomy, and systematics.

Biodiversity refers to variation that exists at different levels of biological organization, including the genetic, biochemical, and morphological variation among individuals within a species, among species and higher taxa, and within and among ecosystems.

Taxonomy and systematics are the sciences we use to interpret and understand biodiversity. Taxonomy refers to the science (and art) of classifying organisms. Systematics studies the evolutionary and genetic relatedness of species.

22 Biodiversity on earth. Students will understand that the earth is inhabited by an enormous diversity of life and that nearly all parts of the environment possess biodiversity.

23 Biodiversity across time. Students will recognize that biodiversity has varied across time and space because of a variety of factors such as mutation, genetic drift, speciation, extinction, and historical events.

24 Ecosystems. Students will understand that ecosystems are characterized in part by their biodiversity and that ecosystems are dynamic systems composed of organisms interacting with each other and the physical environment. These interactions form the basis for ecosystem processes such as energy flow and the cycling of materials.

25 Individual variation. Students will understand that individual members of natural and domesticated species vary in their characteristics, including morphology, biochemistry, and genetic makeup.

26 Criteria for classification depend on purpose. Students will understand that organisms can be sorted into categories on the basis of their

characteristics and that the selection of characteristics depends on the reason for the sorting.

27 Hierarchical organization. Students will understand that the hierarchical structure of modem taxonomic classification systems organizes information about the world's known biodiversity. The smallest natural taxonomic grouping that scientists recognize is the species, which forms the unit of genetic continuity. There are several different ways to define a species (for example, biological and typological), but the species concept has limited applicability for certain groups of organisms such as the bacteria.

28 Phylogeny-based taxonomy. Students will understand how some modern taxonomic classification systems reflect the evolutionary history and relatedness of organisms. Students will recognize that scientists use the characteristics of organisms as the basis for reconstructing the evolutionary history of the organisms.

29 Constructing phylogenetic tree. Students will recognize that scientists are working to construct a phylogenetic tree that accurately reflects the evolutionary relatedness of all life on earth. Scientists continue to refine the structure of this tree of life and make it more complete as they incorporate new information about organisms. Controversy sometimes occurs when scientists disagree about how the tree should be modified in light of new information.

30 Evolution explains shared characteristics. Students will understand that Darwin's theory of biological evolution explains why the widely diverse species that make up the earth's biodiversity share fundamental characteristics such as DNA and metabolic pathways. These similarities occur because all organisms on earth are derived from a common ancestor through descent with modification.

Nature and methods of science

31 Taxonomy and systematics are tools. Students will understand that the fields of study called taxonomy and systematics help scientists organize, interpret, and explain the extraordinary diversity of life on earth, both extant and extinct.

32 Taxonomy and systematics are hypotheses. Students will understand that the taxonomic classification systems and phylogenetic trees devised by scientists represent testable hypotheses that can change as new information is collected.

33 Classification varies with assumptions. Students will recognize that the taxonomic classification of a group of organisms may vary among classification systems depending upon the assumptions of each system and the information used to classify organisms.

34 Several ways to classify. Students will recognize that there are several ways to recognize a species in nature and that the taxonomic designations for organisms can change as new information is collected.

35 Multiple lines of evidence to generate a phylogeny. Students will recognize that scientists use multiple lines of evidence (for example, morphological, developmental, behavioral, biochemical, and genetic evidence) to determine the phylogenetic relationships among groups of organisms.

36 Computers are valuable tools for storing and analyzing information about biodiversity. Students will recognize the role that computers and electronic databases play in modern taxonomic and phylogenetic analyses. Furthermore, students will be able to search for reliable and up-to-date information about biodiversity, taxonomy, and systematics on the World Wide Web, access and use electronic databases, and communicate what they learn through E-mail and/or user groups.

Personal and social implications

37 Humans are part of the world's biodiversity. Students will understand that humans are part of the earth's biodiversity and recognize the interrelationships between themselves and the biodiversity around them.

38 Significance of biodiversity for humans. Students will recognize that biodiversity has significance for humans and will understand the various arguments that people use to preserve biodiversity, such as aesthetic, practical, scientific, life-support, and ethical arguments.

39 People's decisions affect biodiversity. Students will recognize that their ethical, political, and economic decisions can have an impact on the world's biodiversity, thus they need to make informed decisions.

Appendix 3

Climbing the tree of life: Taxonomy and phylogeny for high school biology. Teacher background materials for teaching systematics.

A subcommittee of the CBE recommended that some form of teacher's guide explain the program's place in the curriculum, its pedagogy, and its use in the classroom. The guide also should provide background information on scientific content, both general and specific.

The subcommittee created guidelines for developing the teacher's guide. They recommended that the manual be user-friendly, forward looking, thorough, scientifically accurate, and up-to-date. Important concepts should be illustrated by numerous relevant examples that are graded from simple to complex.

Place in the curriculum. The teacher's guide will identify where the program fits into the high school science curriculum and how the program can be incorporated into high school biology courses. This section of the teacher's guide will

- explain why it is important for students to understand concepts pertaining to biodiversity, taxonomy, and systematics;
- explain how teachers can integrate the program into their biology courses during the school year; and
- provide an overview of the content and the structure of the program.

Pedagogy.

- explain how the program takes a different approach for teaching taxonomy and systematics;
- explain inquiry-oriented pedagogy as a way of teaching and learning and how this approach promotes open-ended investigation, critical thinking, and discussion by challenging students to construct their own understanding of the material, instead of providing easy, readily available answers;
- explain how the 5-E instructional model (engage, explore, explain, elaborate, and evaluate) was used to design the activities for the program;

- provide a sample lesson plan that illustrates some of the advantages of a using a CD-ROM-based program to teach taxonomy and systematics, compared with a more traditional approach;
- explain the importance and value of student-student and student-teacher discussion in problem solving inside and outside the classroom;
- explain how teachers can incorporate into the activities various types of writing assignments that require the use of Internet and library resources;
- explain how teachers can incorporate information from the World Wide Web into the activities; and
- discuss the national standards movement and identify which National Research Council science education standards the program addresses.

Background information.

Teachers will benefit from an overview of the topics and major concepts as well as from information pertaining to specific activities. This section of the teacher's guide will present background information that helps teachers teach the program successfully. The background information should be stratified so that teachers can distinguish between essential background information and ancillary information. Discussions of major concepts should be supplemented with content-rich information boxes that illustrate a concept with concrete examples that refer to familiar and popular organisms, such as whales and dogs. However, new and unusual organisms can sometimes be more interesting and exciting than familiar and popular organisms.

The overview of the program's topics and major concepts will

- use concept maps or flow diagrams to illustrate how the topics (biodiversity, taxonomy, and systematics) are related;

- use concept maps or flow diagrams to illustrate how the major concepts are related; and

- suggest reference materials that provide more detailed information about the topics, such as books (for example, E.O. Wilson's books), magazines, and CDs (for example, ETI's extensive collection of biodiversity CDs).

The background information pertaining to the history, nature, and methods of science will

- explain that science is a dynamic way of learning about the natural world and that our scientific understanding typically progresses by refining our understanding, whereas the core principles remain intact; and

- explain that controversy and debate are a part of science and contribute to the advancement of scientific knowledge; teachers should not, however, overemphasize controversy because students need to realize that there is widespread agreement among scientists on most of the concepts presented in the program.

The background information pertaining to biodiversity will

- define the various types of biodiversity and provide relevant examples;

- discuss humanity's interest in biodiversity and why humans value biodiversity (for example, its utilitarian value as a source of food and medicines, its aesthetic value as source of beauty and inspiration, and its scientific value);

- describe the various ways that scientists measure biodiversity and provide examples;

- provide up-to-date information about biodiversity such as the number of described species and the number of species thought to exist;

- describe how travel and technology have advanced humanity's knowledge about the world's biodiversity and include a review of ecosystems (for example, ecosystem characteristics and balanced versus imbalanced ecosystems) and a discussion about the biodiversity of various ecosystems and remote environments;

- explain how biodiversity has changed across time, including changes in the prominence of different species during geological history;
- discuss how Darwinian evolution gives rise to biodiversity;
- discuss variation and speciation using examples that refer to familiar organisms;
- describe the purpose and challenges of the Human Genome Project and the difficulty of obtaining such information for all the world's species; and
- provide an overview of humanity's role in promoting species extinction and species preservation.

The background information pertaining to taxonomy will

- define the subject matter of taxonomy and provide relevant examples;
- explain that taxonomy and systematics derive their insights from analyzing the characteristics of organisms and that scientists once analyzed morphological characteristics only, but today they analyze a wide variety of characteristics including behavior, molecules, and genes;
- explain that people classify organisms for convenience because it helps them organize and make sense of the vast amount of information about biodiversity, but that each system is devised for a purpose and there is no perfect classification system;
- explain how scientists use parsimony as a tool and a philosophy in classification;
- discuss the importance of naming organisms and the importance of knowing an organism's habitat and niche to understand it completely;
- explain the strengths and limitations of the biological species concept, including the difficulty of applying the concept to species that readily exchange genes (for example, bacteria);

- give a historical overview of how classification systems and phylogenies have changed through history as scientists have learned more about biodiversity (for example, Darwin was uncertain how plants and animals were related evolutionarily, but today we better understand the evolutionary history of plants and animals); and

- summarize the controversy concerning the five kingdoms versus the three domain systems of classification.

The background information pertaining to systematics will

- define the subject matter of systematics and provide relevant examples;

- explain how systematics pervades all aspects of biology (including molecular biology) in such profound ways that it will shape the future of biology;

- explain how scientists know that all life on earth is related (for example, all forms of life have DNA as their genetic material) and why this concept is central to our understanding of biodiversity, systematics, and taxonomy;

- discuss in detail biological evolution by natural selection, phylogeny, and the implications of the theory of evolution for classification;

- discuss the value of a gene-centered perspective for understanding evolution;

- discuss populations, variation within a species, the different definitions of species, the mechanisms of speciation, the role of sexual reproduction, and microevolution and macroevolution;

- explain the importance of thinking historically, discuss "tree thinking," and use examples to illustrate how scientists use character analysis to construct and interpret phylogenetic trees;

- explain that whatever characteristics we use to reconstruct the phylogenetic history of organisms, such analyses have certain strengths and limitations (for example, convergence complicates morphological analysis, whereas gene-sharing and chimeras complicate sequence analysis);

- explain that information about parts of organisms (for example, gene sequences or molecules) as well as information about the whole organism can be used to reconstruct phylogenetic relationships, and that each approach has advantages and disadvantages;

- explain the power of using DNA sequence data to reconstruct phylogenetic histories;

- discuss the significance of mitochondrial DNA, the origin of mitochondria, and the importance of chimeric genes in the study of systematics;

- explain why homology and analogy (as applied to both morphological characteristics and genes) are important for understanding biodiversity, taxonomy, and systematics;

- explain convergence and provide examples (for example, flower shape); and

- use a balanced, historical approach that focuses on the nature and history of science to explain how cladistics and evolutionary taxonomy differ as techniques for analyzing the relatedness of organisms.

Appendix 4
Climbing the tree of life: Taxonomy and phylogeny for high school biology. Factual content of the program for teaching systematics.

1. What is the diversity of life?
   Diversity is the cornucopia of species on earth (the millions of distinct species that represent discontinuities in variation).
   It is the assembly of species into functional ecosystems.
   It is the tree of life (that is, all species are related phylogenetically).

2. How did this diversity arise?
   Diversity arose through speciation (the splitting of lineages).
   Speciation is a population-level process involving the statistical divergence between gene pools. Sexual reproduction gives coherence to the gene pools of most eukaryotes.
   Daughter species share essentially identical evolutionary histories. The same is true for higher taxa that result from repeated speciation.
   Homologies result from descent with modification.

3. How are phylogenetic relationships inferred?
   Phylogenetic relationships are inferred through the study of homologous structures or genes (if studying genes, distinguish between orthologous and paralogous genes).
   Study synapomorphies using parsimony methods and study similarities using distance methods.
   Identify the phylogenetic tree that is most consistent with the data. It often is necessary to infer ancestral character states (paleontology without fossils).
   For some data (for example, DNA sequences), differences can be used to estimate times of divergence (lineage splitting).

4. How is this diversity distributed in space and time?
   Related lineages often occur near each other in time and geographic proximity.
   Species that are related to the ancestors of living taxa are found in the fossil record.
   There have been dramatic increases and decreases in biodiversity during the history of the earth. Biogeographic and fossil evidence can be used to calibrate molecular clocks.

5. How are species classified?

   Species are classified primarily by common descent, which is not always reflected in their overall similarity.

   A hierarchical classification system reflects major events in the history of life.

   The theory and practice of classification have changed during the last century due to the acquisition of better data, new techniques for inferring phylogenetic relationships, and the cladistics-based philosophy of classification.

6. What is the future of biodiversity?

   New species are discovered every year.

   Systematics research often is essential for identifying new species.

   Human activity is currently causing a mass extinction comparable to mass extinctions observed in the fossil record.

   Systematics research allows us to understand extinction and quantify it.

   Comparative studies and systematics research are transforming all of biology, including molecular biology, genetics, and the medical sciences.