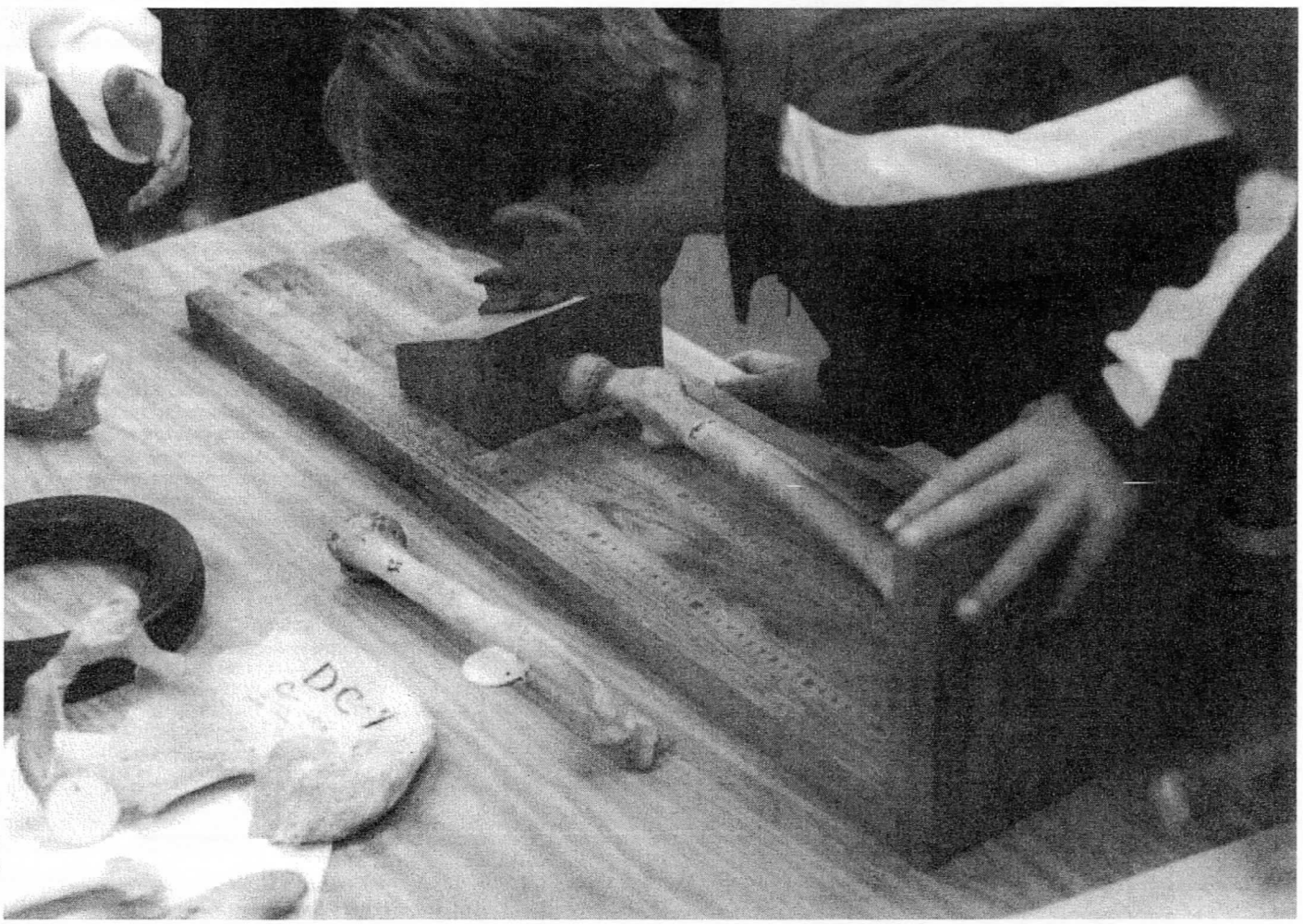
REPORTS OF THE NATIONAL CENTER FOR SCIENCE EDUCATION

DEFENDING THE TEACHING OF EVOLUTION IN THE PUBLIC SCHOOLS

Volume 21, Numbers 1–2 JAN–APR, 2001

CONTINUES *NCSE REPORTS* & *CREATION/EVOLUTION*



Photograph: AJ Petto

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Cover: Grade 6 students explore variation in the human skeleton; photograph by Andrew Petto.

FROM THE EDITOR

Science education standards and benchmarks published in the mid-1990s reiterated the focus and themes of post-Sputnik science education reforms initiated 4 decades ago. These include having students participate in active exploration of science using the materials and methods of practicing scientists. Perhaps one of the most resilient and enduring leaders of that effort is the Biological Sciences Curriculum Study (BSCS), which, among other things, placed evolution firmly at the root of all life-sciences instruction. One reaction to these reforms, of course, was the "creation science" movement that culminated in several decisions by the federal and state courts rejecting the fairness and equal-time claims as having neither legal nor scientific validity (*see* Eight Significant Court Decisions *at <http://www.ncseweb.org/resources/articles/3675_eight_significant_court_decisi_2_15_2001.asp>*).

In the early 21st century, other voices have joined BSCS and NCSE to renew and strengthen the commitment to evolution education. Educational, scientific, religious, and civic organizations recognize that evolution is the theoretical foundation of the biological sciences. These organizations acknowledge that evolution is also supported by the work of scientists in many scientific fields and should be a central theme in modern science education (*see* Voices for Evolution *at http://www.ncseweb.org/article.asp?category=7*). With the increased support for evolution, however, has come an increase in agitation against evolution education.

The catch phrases have evolved, as it were. Although the newer anti-evolutionary slogans are a call to prohibit "viewpoint discrimination", we can easily locate their ancestral roots in the failed "fair treatment" arguments. This strategy argues that an idea embraced primarily by nonscientists as an "alternative" to evolutionary theory should be allowed to bypass the normal route through which scientific ideas make their way into the classroom — by proving themselves in the professional (that is, peer-reviewed) literature. However, scientific ideas should make their way into the textbooks only when they have passed this test and represent the consensus of modern scientists.

Teaching evolution

In this issue we revisit the theme of our very first issue in the new format — education. We have received so many good submissions on this theme that we will present them in a special double issue. NCSE member Bob Cooper has been thinking about how to teach evolution for a long time and was interested in the inaugural essay by Contributing Editor Brian Alters on teaching students to believe evolution. Bob agrees that we should expect students to embrace evolution as they do electrons, but has some concerns about how we reach that goal.

In a practical examination of what students really think about evolution and what classroom strategies might be needed, James Wilson reports on student attitudes and beliefs in his biology classes. Randy Moore presents some sobering thoughts on the impact of state science education standards. Do standards that include strong support for evolution education ensure that evolution will receive adequate classroom coverage? There is evidence to the contrary.

Steve Randak writes from Indiana about a student-led action to teach creationism as a "scientific" alternative to evolution in the classroom. The student action received quite a bit of support among the faculty — even among some science faculty, as Moore would have anticipated based on his review. And Brandon Seger, a high-school student from California, writes of his experiences *learning* evolution in biology class.

What is evolution?

Most critiques of evolution, of course, are aimed at misrepresentations or caricatures of modern evolutionary biology. In a recent posting to its web site case, the Discovery Institute limited its critique of evolutionary theory to "Darwinism" and the idea that "random mutation and natural selection" alone are sufficient to account for the complexity of life (*see <http://www.reviewevolution.com/press/pressRelease_100Scientists.php>*). NCSE readers know that there is a lot more to evolution than "mere Darwinism", so John Wilkins has provided a guided tour of the history of the term "evolution" and the ways in which it is used today in biological science.

The meaning of evolution pops up in the news, too. Art Hobson reports on education standards in Arkansas, and Jeff Shallit gives us his impressions of a conference on "Intelligent Design" held at Calvin College. We also reprint the response of the American Geophysical Institute to the so-called Santorum Amendment (*see Eric Meikle's "Senseless in the Senate" in* RNCSE *2000 Nov-Dec; 20 [6]: 4*). At press time, the AGI response had been co-signed by the presidents of about 100 professional scientific and research organizations in the US.

Welcome to Skip Evans

Please welcome Skip Evans as NCSE's new Network Project Director. Some *RNCSE* readers will remember Skip's report on Ken Ham's visit to Atlanta. Since then, Skip put a few miles on his odometer before arriving in the Bay Area. Skip has been an active member of NCSE since 1996, and now we are very happy to have Skip on board full-time.

RNCSE 21 (1-2) was printed in December 2001.

NEWS

Calvin College Hosts "Design" Conference

Jeffrey Shallit

As a part of its Seminars in Christian Scholarship series, Calvin College hosted a conference entitled "Design, Self-Organization, and the Integrity of Creation" on May 24–26, 2001. The featured speakers included Paul Nelson, Stephen Meyer, William Dembski, and Jonathan Wells (for the complete conference program, see <http://www.calvin.edu/fss/dembschd.htm>). In response to the presentations at the conference, I offer some observations and a few impressions.

The two most notable aspects of the conference for me were how little the members of the intelligent design (ID) movement have been able to accomplish scientifically in the 5 years since the publication of Michael Behe's *Darwin's Black Box* and how much they have been able to accomplish politically. Not since cold fusion has there been so much hullabaloo with so little scientific output.

Strategies for promoting "Intelligent Design"

ID proponents use several strategies to get around this hard truth. One strategy, exemplified by Paul Nelson's talk, consists of combing the existing scientific literature for explanatory gaps and then claiming that ID fills them. Nelson claimed that one gap is the existence of a variant genetic code in *Tetrahymena*, where the codes for glutamine and stop differ from the ordinary codes. Nelson objected to scientists' explanation of how this difference could have evolved and said that ID was a better explanation. But how much of an explanation is it and why is it better? Nelson provided neither specific criteria that would allow a standardized approach to ascertaining the superiority of design arguments nor any broader criteria that could be generalized from this specific case.

The entertaining presentation of Jed Macosko of the University of California-Berkeley illustrated a second strategy — present complex data followed by oversimplified and misleading questions. Macosko focused mostly on showing videos created by other researchers that portrayed complex biological systems and then asked, "Chance or design?" Of course, the question itself is tendentious, because no evolutionary biologist would argue that chance alone is responsible for complicated systems such as ribosomes or that design is the only alternative to chance.

A third strategy to promote ID was exemplified by the talk of Scott Minnich, a microbiologist at the University of Idaho. One of the few speakers who actually discussed his own original scientific research in any detail, he talked about the flagellum and virulence in *Yersinia enterocolitica*. He argued that his use of intelligent design as a heuristic allowed him to get to the answers faster than other researchers. However, it was unclear exactly what role ID played in Minnich's research and how it produced this expeditious result.

The last strategy to promote ID employed at the conference was to use outright misrepresentation in an attempt to cast doubt on evolution. This strategy was used by Jonathan Wells, who claimed at one point in his presentation that the evidence in Darwin's *On the Origin of Species* (first published in 1859) was based in part on Haeckel's 1868 drawings. Even before a sympathetic crowd, this strange claim prompted some doubt from the audience and Wells was forced to retract it. He also claimed that common descent predicts that "major differences would appear last", and since this is not what we see in nature, common descent is falsified. Of course, common descent makes no such prediction.

ID's elusive research record

The lack of published scientific evidence supporting ID is in stark contrast to the immodest claims made for it. For example, philosopher Rob Koons introduced mathematician-theologian William Dembski as the "Isaac Newton of information theory", despite the fact that Dembski has not published a single paper on the subject in a peer-reviewed mathematical journal (Dembski's only published paper in such a journal was on probability, back in 1990). Despite the conspicuous dearth of papers published in scientific journals on ID, Paul Nelson claimed that "data in support of intelligent design are pouring in", and philosopher Bruce Gordon claimed that his interpretation of quantum mechanics would result in the destruction of naturalism.

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The lack of scientific success may account for the large chips on the shoulders of ID advocates. In talks and discussions, I heard repeatedly about how the "scientific establishment" was arrayed against ID proponents, that their work was being "suppressed", and so forth. The possibility that ID research was either nonexistent or of poor quality was never entertained. Yet some presentations were remarkable for their lack of scholarship and awareness of current literature.

JUST "GOOD SCIENCE"?

There is not much doubt that the primary motivations behind ID are political and religious, not scientific.The Discovery Institute (DI) was a prominent presence, selling books by anti-evolutionist authors such as Phillip Johnson and David Berlinski. (At least four of the speakers have their institutional home at the DI.) DI literature was widely available, including a very carefully worded statement encouraging the teaching of "the full range of scientific evidence" about origins. But in another brochure, they were less circumspect about their concerns:

> This materialistic conception of human nature ultimately infected almost every area of Western thought and culture. ... Materialistic thinking undermined belief in personal responsibility. ... Materialists also devised utopian political schemes. Thinking they could manipulate people like mathematical variables, social theorists advocated coercive government programs that promised heaven on earth, but often produced the opposite — oppression and genocide.

One of the few speakers to exercise a cautionary tone was Calvin College philosopher Del Ratzsch, who gave the banquet address, "Design: Looking Back to the Future". Ratzsch discussed why design as a scientific paradigm was abandoned 150 years ago, questioned the explanatory power of design, and warned that there is no rigorous analysis in the ID community of what design is. When his talk concluded, there was a distinct and uncomfortable silence in the room.

This conference convinced me that ID remains almost entirely hype. Until some serious scientific evidence is adduced in its favor, its influence on the scientific community is likely to be minimal. With monetary resources and political clout, however, its influence on the general public will be more substantial.

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Position Statement: Teaching Human Evolution in the High-School Classroom

Tennessee Darwin Coalition
September 12, 2001

It has recently come to our attention that, with the inclusion of the Gateway standards in the Tennessee high-school biology curriculum, which require the coverage of evolutionary principles, many teachers are choosing to exclude human-related examples. We support and applaud the effort that administrators have made to ensure the inclusion of evolution in the curriculum of high schools across the state. However, while we are sensitive to the fact that broaching this topic may be difficult for many individuals because of cultural beliefs or religious convictions, we find the exclusion of human evolution to be incompatible with the goal of integrating evolution throughout the biology curriculum. We are further disappointed because there are excellent examples from humans and closely related lineages that uniquely illustrate many evolutionary principles. Many students would find the discussion of these topics both relevant and intriguing, and their inclusion would help students appreciate relationships between ourselves and other organisms living on this planet. These points are outlined in more detail below:

1) Exclusion of human examples is incompatible with an accurate presentation in the curriculum of key ideas in biology. Discussion of evolution in a topical framework is inadequate. Instead all topics in biology should be presented with a historical perspective. This approach makes the discussion of our historical relationships to other organisms inevitable. For example, all subjects in biology are enhanced by an evolutionary context — from molecular biology (such as the universal nature of the genetic code) and cellular biology (such as the origin of mitochondria) to developmental biology (such as similarity in early embryonic development among mammals) and the discussion of whole organisms (such as homologies ... in the anatomy of appendages in birds, bats, whales, and so on). Discussion of biology in an evolutionary framework would not only be more accurate, but would also render the subject matter intrinsically more interesting to students.

2) Examples from human evolution uniquely illustrate many evolutionary principles. In humans and closely related species we have a relatively complete and well-documented database supporting evolutionary relationships.This is particularly true for a range of molecular and DNA-sequence analyses that have been completed for humans and other primates

EVOLUTION

WGBH Educational Foundation, Boston, and Clear Blue Sky Productions, Seattle.

Reviewed by Timothy H Goldsmith, Yale University

If I were to give a prize for the single best idea anybody ever had, I'd give it to Darwin for the idea of natural selection. Ahead of Newton, ahead of Einstein, because his idea unites the two most disparate features of our universe: the world of purposeless, meaningless matter in motion on the one side, and the world of meaning and purpose and design on the other. He understood that what he was proposing was a truly revolutionary idea.

These words are spoken early in the television production *Evolution*, which aired on the Public Broadcasting System in the United States in September 2001. With them, the philosopher Daniel Dennett captures eloquently the power and the beauty of evolutionary theory and at the same time identifies the intellectual dilemma faced by those who lodge their understanding of nature in a literal reading of scriptures. In view of the guerrilla warfare over the teaching of evolution that is taking place in school boards and state legislatures around the United States, the appearance of this series is both timely and useful.

Many of the arguments presented by the anti-evolutionists as "evidence" — those that go beyond the desire to see science accommodate the unobservable and the unmeasurable — are hollow echoes from the 19th century. For example, the incompleteness of the fossil record and the alleged perfection of the human eye are regularly trundled out as if understanding of evolution has remained frozen since the publication of *One the Origin of Species* in 1859. For viewers interested in the history of ideas and the scope of contemporary evolutionary theory, the seven episodes of PBS's *Evolution* provide diverse and fascinating examples of how rapidly our understanding of this important natural process is growing. For example, recent discoveries of transitional forms in the evolution of whales illustrate how paleontology continues to provide confirmation of the Darwinian concept of descent with modification.

Since Darwin's day the catalog of simple eyes of invertebrates has expanded greatly. These are not transitional forms to the vertebrate eye, but they show that eyes of varying degrees of complexity have arisen scores of times. Recent computer models validate how easy this is. Starting with a small sheet of light-sensitive cells and conservative assumptions about incremental changes, optically respectable eyes with spherical lenses can evolve in a few hundred thousand generations, ample time for evolution. At the molecular level, the recent research on a family of genes that control the expression of still other genes during the embryological development of animals as different as mammals and insects reveals an underlying order to diverse body plans that was unanticipated a generation ago. Although much remains to be discovered, neither macroevolution nor the Cambrian explosion are as mysterious as the anti-evolutionists would have us believe.

The series begins with a segment on Darwin himself. In this episode, the writers have used Darwin's older brother Erasmus as a kind of foil: a contrast to Charles's caution and a vehicle for revealing the development of his ideas about natural selection. This approach works well, and the resulting picture of the naturalist is accurate in its important details. Those familiar with the Richmond portrait of Darwin as a young man may feel that on the screen he appears a bit hefty, and they may be disconcerted by his failure to age during the following 30 years. But I quibble.

Subsequent episodes share the interrelations of organisms as an overarching theme. One explores the significance of extinction. Perhaps 99% of all species that have ever existed have gone extinct, which is hardly evidence for intelligent design. The mean lifetime of a species is estimated to

DO YOU BELIEVE IN ... PHYSICS?

Without being highly educated in physics, we can only read summaries of the theory [of relativity], accept the points on *faith*, and then successfully repeat to others what we have learned. But the theory of relativity is not unique in this regard. All of us are capable of understanding far more than we do; we just don't have the time to educate ourselves in every field.

[*This reply appeared in the "Ask Marilyn" column by Marilyn vos Savant in the September 9, 2001 issue of* Parade *magazine, page 7.*]

August 2001 Joint Letter from Scientific and Education Leaders on Evolution in HR1

[*In* RNCSE *20.6, Eric Meikle reported on the so-called Santorum Amendment to the Elementary and Secondary Education Act authorization bill. Since there was no similar amendment in the House of Representatives, the House-Senate Conference Committee will need to reconsider it when it meets to reconcile the two versions of the bill. In response to this amendment, almost 100 scientific and educational organizations joined together to inform the chairs of the Conference Committee of the dangers of and problems with this innocuous-sounding resolution.*]

The Honorable John Boehner
Chairman, Committee on
Education & the Workforce
US House of Representatives
Washington DC 20515

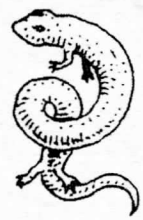
The Honorable Edward M
Kennedy
Chairman,Committee on Health,
Education, Labor & Pensions
US Senate
Washington DC 20510

Dear Conference
Committee Chairmen:

The undersigned scientific and educational organizations urge the Conference Committee to remove Section 1022 from the Senate-passed version of HR1. This Sense of the Senate resolution introduced by Senator Santorum sets a precedent of congressional involvement in the teaching of evolution, an issue that until now has been debated at state and local levels. Given the significance of such a precedent, we do not feel that adequate consideration was given to the amendment's implications before its adoption.

Those implications have become increasingly apparent in recent weeks as anti-evolution groups have hailed the amendment's passage as a major victory. The Senate vote is being portrayed as a vindication of the 1999 decision by the Kansas Board of Education to eliminate evolution from state tests. Yet Kansas citizens recognized that the board's decision weakened science education in their state, and they repudiated the school board vote in the following year's elections. Today, Kansas has some of the best science education standards in the country.

As written, the apparently innocuous statements in this resolution mask an anti-evolution agenda that repeatedly has been rejected by the courts. The resolution singles out biological evolution as a controversial subject but is deliberately ambiguous about the nature of the controversy. Evolutionary theory ranks with Einstein's theory of relativity as one of modern science's most robust, generally accepted, thoroughly tested and broadly applicable concepts. From the standpoint of science, there is no controversy. If the point of the resolution is to encourage teaching about political controversy surrounding scientific topics, then evolution is just one of a legion of issues that are the subject of political debate. It should not be singled out.



Confusing political with scientific controversy on the topic of biological evolution will weaken science education. Thank you for considering our request to remove this resolution and for your lasting commitment to ensuring that students in the nation's public schools receive the best science education possible.

[*The text of the letter and the current list of scientific and educational organizations supporting it can be found on the American Geophysical Institute's web page: <http://www.agiweb.org/gap/legis107/evolutionletter.html>*].

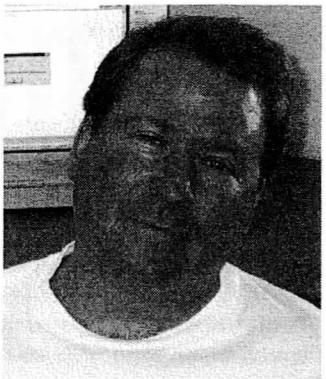
UPDATES

Indiana, Lafayette: On August 13, 2001, the Lafayette School Corporation board was asked by Jefferson High School chemistry teacher Dan Clark to remove a formal reprimand placed in his personnel file by the district's superintendent the previous September. The reprimand accused the teacher "of teaching religion through creationism in a classroom setting", according to a Lafayette *Journal and Courier* account. Supporters of the teacher who spoke at the meeting reportedly claimed that other science teachers at the high school "blatantly use religious references in their classrooms and teach evolution as fact". Board members did not deal with Clark's request at the meeting, after being advised by the district's attorney that it would be "out of order" for them to do so at that time. On August 16, the *Journal and Courier* reported that Clark had resigned and taken a position in another Indiana school district.

Michigan: As of September 2001, the Education Committee of the Michigan House of Representatives had not held hearings on two "intelligent design" bills introduced before the legislature's summer recess (*see* RNCSE *2000; 20 [5]: 10*). At press time it was not known when or if any action will be taken on these bills during this session. These are the last of this year's many pieces of state legislation regarding evolution education still pending. See the previous few issues of *RNCSE* for information about proposed legislation in Arkansas, Georgia, Indiana, Louisiana, Montana, Washington, and West Virginia.

[*NCSE thanks Gregory Forbes for information used in this article.*]

NCSE NEWS



Meet NCSE's New Network Project Director

Skip Evans
Network Project Director

My road to the National Center for Science Education is a meandering one. I grew up in Orlando, Florida, and I suppose my formative years would have been the late 70s and early 80s. Anyone interested in what my early years were like should rent the Richard Linklater movie *Dazed and Confused.* I was the little brother that was always being harassed by the older guys.

I learned the nuts and bolts of grassroots activism with a local group called Central Floridians Against Censorship, created in 1988 largely due to the controversy surrounding the film *The Last Temptation of Christ.* Since I made my living then as a computer programmer, I was a natural for tasks such as maintaining our membership database and handling the desktop publishing duties of laying out our newsletters and flyers. I also learned to articulate our group's position to the media and to speak publicly before civic groups.

I left Florida in 1995 and headed to Atlanta, and in that same year got a chance to meet one of the people I most admire, Barry Lynn, of Americans United for Separation of Church and State. Disappointed that the local AU chapter was dormant to the point of not really existing, I helped to restart the chapter, and within a couple of months there was again a strong voice for church/state separation in the Atlanta area. In that organization, I networked with other progressive groups, informing them of AU/Atlanta's availability as a resource, and organized events that brought diverse groups together. I developed a strong working relationship with the national office and enjoyed the resources and opportunities that come with working with a national organization.

After a brief stint in New York City, my work as a programmer brought me, temporarily at first, to the West Coast and to NCSE's backyard. I had to get in touch with the gang and let them know I was available for volunteering. I visited the office a few times, did some minor web work one afternoon, and got to meet Robert Pennock at Genie Scott's place over dinner one night.

Programming in the dot.com world was becoming difficult to stomach, and when I had had a particularly bad day and found myself in front of the bus station, I took it as an omen. Thirty minutes later I was on a bus heading east. I ended up eventually on St George Island, just southwest of Tallahassee, Florida, in the Gulf of Mexico. My sister has lived there for about 10 years, and I decided to take her up on a longstanding offer to hang out there and think about what I wanted to do next. The island had the basic requirements of a sound and happy life — a beach and a pool table — but ultimately it proved to be too quiet a place for me.

As the days on the island passed and I pondered my future, I got the idea to go to Bulgaria, where I have friends, to open an English school. But as I was kicking this idea around in my head, I remembered an e-mail from Genie Scott, advertising the position of Network Project Director, which Molleen Matsumura had just left. I fired off a message asking if the position was still open. To my surprise it was, for just one more day. I had a decision to make. I could run away to Eastern Europe and begin an around-the-world odyssey, or I could make a lifelong ambition come true and become a professional activist. Well, since you are reading this, you know which one I chose.

I think that the work of the National Center for Science Education is of vital importance to our country. The continuing search for scientific knowledge of who we are and where we came from cannot be abandoned because some regard its implications as theologically difficult. The excitement and awe that science instills in us as it uncovers our past must be available to all students in an open, honest, and religiously neutral classroom setting. If I can contribute to that, then NCSE is the best place for me to be.

[*E-mail Skip at evans@ncseweb.org.*]

NCSE Supporter Tim White Honored

On August 17, 2001, NCSE received word that NCSE Supporter and University of California-Berkeley professor Tim White was featured as one of "America's Best in Science and Medicine" in a special feature in *Time* magazine. NCSE Supporter and Chair of the UC-Berkeley Department of Integrative Biology Marvalee Wake wrote: "Congratulations, Tim! It's nice to see that the nation and the world are learning what we already knew about you." Andrea Dorfman's profile of White, which describes him as "one of the world's leading collectors and interpreters of hominid fossils", may be found at <http://www.cnn.com/SPECIALS/2001/americasbest/science.medicine/pro.twhite.html>.

Pseudoscientific Beliefs Among College Students

James A Wilson
Department of Zoology, Oklahoma State University

INTRODUCTION

As an undergraduate in biological science, I became interested in evolution, and I became extremely interested in the creation/evolution "debate" as I continued my education. I also developed an interest in how scientific illiteracy sustains the public's belief in various pseudoscientific claims. My interest changed to astonishment when I began to realize how little people actually know about science.

Teaching a college biology class for non-majors gave me an opportunity to explore this issue in depth. I administered a questionnaire modified from Harrold and Eve (1995) to measure students' pseudoscientific beliefs (*see Appendix 1*) and to compare these students with those planning to pursue further studies in biology. Although informative, certain questions asked by Harrold and Eve — about students' grade point average, parents' income and education, and religious affiliation — were excluded to avoid any potential legal problems. I administered the survey to students in non-major biology classes and introductory (major) zoology courses at a California state university and a local community college. By including both science majors and non-science majors, and both four-year university students and two-year college students, I felt that my survey captured an accurate sample of the student community.

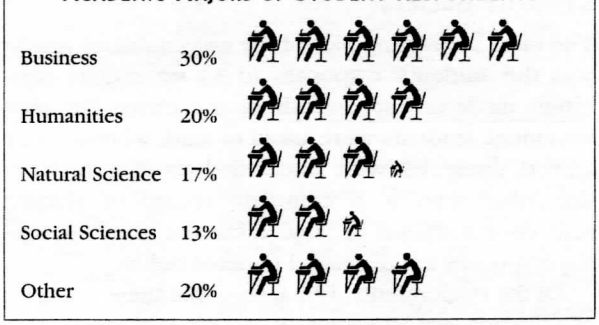
Students completed 181 questionnaires between 1996 and 1998. The survey was administered on the first day of class to reduce the possibility of students' trying to answer the way I expected. Students were told that the survey had no bearing on their grades and was not part of the official class. They were instructed not to put their names on the paper and when finished to deposit the survey in an envelope so I would have no idea of which paper belonged to whom.

Students' response to the survey ranged from indifference to caution, with some students staying after class to interrogate me about my beliefs. I was surprised by some of the answers that I received — not only the answers that were marked on the form, but also from comments written in the margins. The information I obtained from the survey gave me some insight into the scientific views of the student body and thus was very useful in my teaching. (For example, I used students' answers to figure out how to spark their interest in the science that I was about to teach them.)

STUDENT BACKGROUND

Students were asked to indicate their age, sex, academic standing, major, their home US state or foreign country, and the size of the community in which they were raised. Results of the background questions showed that 80% of the students were 22 years old or younger, 19% 23–29, and 1% over 30 (Table 1a). Most incoming freshmen are encouraged to satisfy the biology requirement during their first semester. In fact, 67% of the students were freshmen or sophomores, 18% juniors, and the remaining 15% were seniors, some of whom wrote that they had "put off taking biology as long as possible" (Table 1b). Of the respondents, 61% were female.

FIGURE 1
ACADEMIC MAJORS OF STUDENT RESPONDENTS



Students reported these academic majors (Figure 1): Business (30%), Humanities (20%), Natural Science (17%), and Social/Behavioral Science (13%). Students were mostly raised in the United States (78%), followed by Asia (16%) and other regions (5%). Of those

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raised in the US, California (93%) was the most common state, and most respondents grew up in large cities of over 50 000 people (82%).

When asked about their science and literary background, 51% of the respondents indicated that they read 0-2 books per year outside of classes; 20% reported reading more than 10 books per year beyond those required in their classes. When questioned about their high school evolution education, 30% responded that their instruction included both evolution and creation, for 46% it included evolution but no creation, and for 24% it included no evolution at all (Table 1c). When asked to mark the statement that best fit their understanding of evolution, 41% chose "evolution involved a purposeful striving toward higher life forms (steady progress from microbes to man)", 26% chose "evolution occurred because the strong eventually eliminated the weak", 21% chose "man evolved from an ape-like ancestor", and 12% chose "evolution occurred because differing individuals left different numbers of offspring" (Table 1d).

In response to the question about whether evolution has a scientific foundation, 28% agreed that evolution is scientific and its hypotheses can be tested, while 20% said evolution is scientific but its hypotheses cannot be tested. Another 16% responded that evolution was not scientific because we can never be sure of the past, 18% that evolution is based on speculation, and 18% that evolution is unscientific simply because it goes against their convictions. This is the question that received the most spontaneous written comments. These included: "I don't believe in evolution", "Evolution is a joke", "I don't agree with evolution", and some attempts to quote from the Bible.

Student Beliefs

The most interesting part of the questionnaire results was the students' responses to 33 statements commonly made in popular culture and media. For each statement, students were asked to mark whether they agreed, disagreed, were undecided about it, or were unfamiliar with it. A complete record of student responses is shown in Table 2, but the most interesting responses are discussed in detail below.

Of the respondents, 47% agreed that there was a lot of evidence against evolution — only 39% agreed that evolution correctly explains the patterns of life on earth. Non-biological evolution seemed easier to accept: most students agreed that the earth is very old. However, the relatively recent emergence of modern humans about 200 000 - 50 000 years ago (Klein 1989) was not well known among students (33% agreed, 30% disagreed, and 30% were undecided). Furthermore, 27% of the students agreed that dinosaurs and humans lived together, and another 25% were undecided. However, about half the students did know that humans, whenever we evolved, did not emerge in North America and then migrate to the rest of the world.

Despite numerous popular television shows that focus on strange creatures and "unexplained" mysteries, it seems that students were not so quick to believe in such things as we might fear. Statements asserting the existence of the "Mummy's Curse" that killed explorers in Egypt (15% agreement), Bigfoot (18% agreement), the Loch Ness monster (22% agreement), and the Bermuda Triangle (26% agreement) were not as commonly accepted as the existence of UFOs, evidence against evolution, and psychic powers. However, the fact that as many as 15-26% of the respondents reported that they believe in paranormal phenomena does raise questions.

The most common of the pseudoscientific claims in the media concern extraterrestrials and UFOs. Although respondents apparently did not believe that aliens built ancient monuments such as the Pyramids (only 11% agreed), 35% did agree that UFOs are real alien spacecraft. The king of all the UFO stories is the so-called Roswell incident, and 38% of the students believed that the US government is aware of but denying the existence of an alien spacecraft that crashed near Roswell, New Mexico.

Of all the advocates whose pseudoscientific claims were included in this survey, none will be more pleased by the results than psychics. Almost half (43%) of the respondents agreed that psychics can correctly predict the future. On the other hand, students did not put much stock in newspaper astrological forecasts — only 15% agreed that they correctly predict the future. Almost half of the respondents (42%) believe that it is possible to communicate with the dead, and 36% believe that black magic exists.

Finally, the questions on creation provided some of the most surprising results of the survey. A large percentage of the respondents (55%) believed that Adam and Eve were the first two humans. Adam and Eve would be a great launching point for the discussion of genetic bottlenecking, recessive gene disorders, and

STUDENT PROFILE

TABLE 1A AGE DISTRIBUTION OF STUDENTS

Age	< 22 years	23-29 years	> 30 years
Percent of Students	80%	19%	1%

TABLE 1B COLLEGE EXPERIENCE OF STUDENTS

Years in College	1 or 2 Years	3 Years	4 Years
Percent of Students	67%	18%	15%

TABLE 1C HIGH-SCHOOL EVOLUTION INSTRUCTION

Evolution in School	Evolution Only	Evolution and Creationism	No Evolution at all
Percent of Students	46%	30%	24%

TABLE 1D STUDENT KNOWLEDGE OF EVOLUTION

Concept	Differential Reproduction	Humans had ape-like ancestor	Purposeful striving toward "higher" life forms	"The strong survive"
Percent of Students Agreeing	12%	21%	41%	26%

anatomy (did they have navels?). About half of the respondents agreed that humans evolved through God's will, whereas 56% agreed that there was actually a flood that covered the earth.

Discussion

Effective science education should help students learn the process and practice of science (NRC 1998) However, it seems that science educators have their work cut out for them. Recent polls show that belief in the extranatural on the rise (Nisbet 1998). Polls taken in 1976 and 1997 indicate that belief in paranormal activity has increased dramatically. Belief scores rose between the 1976 and 1997 polls by 40% for spiritualism, by 35% for faith healing, by 30% for astrology, by 6% for UFOs, by 16% for reincarnation, and by 10% for fortune telling. (With respect to belief in astrology, UFOs, and reincarnation, the results of the 1997 survey [Nisbet 1998] are similar to the survey reported here.) Anderson (1998) reports that according to a 1996 survey, 49% of Americans believe that the government is concealing UFO visitations to earth; 38% of students in my survey agreed.

Carl Sagan (1995) also reports some dismal statistics about the status of scientific literacy in the United States. Sagan states that up to 95% of Americans may be scientifically illiterate. He reports polls showing that 63% of Americans did not know that dinosaurs and humans never lived together, 57% did not know that electrons are smaller than atoms, 75% were unaware that antibiotics only work against bacteria and not viruses, and 50% did not know that the earth revolves around the sun once every year (Sagan 1995). These are all basic facts in geology, chemistry, microbiology, and astronomy — what a scientifically literate citizen would be expected to know. When it comes to evolution, only 9% of Americans accept evolution without any divine intervention (when the possibility of divine action is offered in the survey), but 45% accept evolution when no mention of divine action was made.

The responses to the beliefs section of the survey indicates the general level of scientific literacy students acquire in K–12 education. Unfortunately, there seems to be quite a lot of room for improvement in our science education. Fifty percent of the students surveyed in my classes claimed that they understand what the scientific method is; however, it is difficult to reconcile those optimistic self-assessments with their answers on the questionnaire. After engaging the students in numerous explanations and analogies, I began to realize that, in fact, they do *not* understand the scientific method. Understanding how scientists test and verify their hypotheses is probably the most important topic for non-science majors to understand. By understanding how evolutionary concepts are discovered and tested, students might be enabled to understand why evolution is not "just a theory". Having a good foundational understanding of how science works might make subjects like evolution less personal to students and therefore easier to integrate within their worldviews. This would in turn open students to the overwhelming scientific evidence for evolution.

Anderson (1998) claims that one reason people may be less motivated to learn science is that the nature of science has changed. Science has moved away from topics that can be seen in everyday experiences to topics that are difficult or impossible to observe. Subjects such as evolution and quantum physics have no counterpart in daily life with which people can identify. Consequently, the time and effort required to understand these scientific ideas serves to distance science from people. Because they lack the scientific background to understand contemporary scientific theories and concepts, people mostly accept them essentially on faith alone, which leads to the misconception that science is merely a religion in itself.

The continuing trend of science's developing more detailed and obscure theories, coupled with the inadequacy of the science education of the average US citizen, creates a void in people's understanding of the world. This void creates a place for pseudoscience, allowing ideas that can be scientifically dismissed as impossible or at least highly improbable to survive. As Cooper points out (*see p 14*), replacing pseudoscientific beliefs with real scientific knowledge can be a challenge for the science educator.

The good news, however, is that the responses to the survey substantially aided me in my teaching. I used the responses to drive classroom discussion about various topics in biology. For example, questions pertaining to alien encounters and UFOs were used to talk about reproduction. Since aliens seem so interested in human reproduction, I discussed all of the different ways that life forms reproduce on earth (budding, fission, biparentalism, and so on) and which methods were possible for a multicellular alien being. We also discussed the repercussions of giving birth to a baby with such a large head while having a small pelvis (as aliens are often depicted).

Thus pseudoscience can find a place in the science classroom — it can be used to educate people in real science and debunk bogus claims at the same time. I found that students were much more interested in what I had to say if we were talking about their survey results. Trocco (1998) also suggests that pseudoscience is a good instructional tool as long as it is kept in line with real science. I also found that I had more fun teaching when we talked about aliens, psychics, and Bigfoot in conjunction with reproduction, statistics, and habitat requirements for large mammals. In addition to their making classes more enjoyable and interesting, teachers will be directly confronting pseudoscientific claims in the classroom and helping students discover why subjects such as those presented in the survey are inconsistent with scientific knowledge.

Conclusions

Although creationism and other religious topics have been banished from science classrooms, the survey indicates that there is still a significant residual religious resistance to evolutionary ideas. Even though the overwhelming majority of the respondents came directly from nearby public high schools, fully one-third of them answered that they were taught both creation and evolution in high school, and one-quarter of them reported not being taught evolution at all. Something is preventing teachers from talking about evolution, even though in many schools evolution is part of the mandated curriculum. Whether the cause is religious or social or political, teachers may feel pressured to avoid such touchy and "controversial" subjects. The results of this survey warn us that this void in science education can be occupied by pseudoscientific beliefs.

In his book *The Demon-Haunted World* (1995), Carl Sagan warned, "We've arranged a global civilization in which most crucial elements profoundly depend on science and technology. We have also arranged things so that almost no one understands science and technology. This is a prescription for disaster. We might get away with it for a while, but sooner or later this combustible mixture of ignorance and power is going to blow up in our faces." If we do not succeed in improving scientific literacy in our science classrooms, then we cannot expect that pseudoscientific beliefs will not continue to grow in acceptance. In many classrooms, teachers avoid engaging students' pseudoscientific beliefs, hoping instead simply to

TABLE 2 STUDENT UNDERSTANDING OF CONTEMPORARY SCIENCE

Statement	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	Undecided	Never Heard of It
The world is between 4 and 5 billion years old.	20	41	7	10	20	2
Aliens from other worlds are responsible for ancient monuments like the pyramids, which primitive people could not have built.	2	9	11	55	12	12
America was visited by Europeans long before Columbus or the Vikings.	16	25	10	14	22	12
An ancient curse on the tomb of the Egyptian pharaoh King Tut killed people.	4	11	11	33	18	23
The Loch Ness Monster exists only in people's imagination.	31	23	13	9	15	10
UFOs are alien spacecraft from other planets.	20	15	15	25	20	3
Humanity came to be through evolution, which was controlled by God.	30	32	7	22	8	2
There is intelligent life somewhere out there in the universe.	34	28	9	8	20	2
Adam and Eve were the first humans.	43	12	8	20	14	4
Time travel into the past is possible.	5	10	12	48	20	5
There is a lot of evidence against evolution.	22	25	16	13	18	5
Science has done more good than bad for the world.	24	31	17	12	15	2
Bigfoot is a real creature roaming the woods in the American Northwest (Oregon, Washington).	5	13	13	40	26	3
Reincarnation really happens.	10	19	9	37	21	4
Human beings that are biologically modern like they are today have been around for about 40 000 years.	11	22	12	18	30	7
Black magic really exists.	13	23	13	20	23	8
It is impossible to communicate with the dead.	17	17	20	22	21	3
Some people can predict future events using psychic powers.	10	33	16	23	15	3
Claims that there is some mysterious force controlling the Bermuda Triangle are untrue.	15	15	17	9	38	7
The lost continent of Atlantis was the home of an ancient civilization.	9	18	12	8	29	25
The theory of evolution correctly explains the development of life.	11	28	11	25	22	4
Aliens from other worlds visited earth in the past.	9	15	9	33	24	9
Dinosaurs and humans lived at the same time in the past.	9	18	111	33	25	3
Our government is hiding information about crashed alien spacecraft.	16	22	10	21	22	9
Humans first evolved in North America and spread across the world.	5	7	11	39	29	9
Astrology is an accurate predictor of the future.	4	11	16	38	22	9
Cars capable of high gas mileage (over 100 miles per gallon) are possible, but oil companies are preventing this.	22	17	12	6	24	20
There was a great worldwide flood on the earth.	39	17	10	5	19	10
Science makes our way of life change too fast.	14	27	24	14	19	2
Most scientists are not religious.	13	27	24	14	19	2
There are ghosts inhabiting the world.	14	21	17	18	25	5
I have a clear understanding of the meaning of scientific study.	15	35	19	7	20	4
The seasons are made because the earth is closer to the sun during summer and farther away in winter.	34	17	9	16	21	3

replace these ideas with "correct" information. The experiences in my own classroom show that we must bring pseudoscientific beliefs to the surface and explore them in order for students to understand what is wrong with them and, ultimately, to reject them.

Acknowledgments

I would like to thank Ian Mackenzie for introducing me to the survey that was used in this article and for providing his excellent critical mind for discussions about evolution and critical thinking during those long shifts on the Pirates of the Caribbean.

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APPENDIX I STUDENT QUESTIONNAIRE

Do Not Write Your Name on this Paper

1. Age: **a.** 22 or under **b.** 23-29 **c.** 30-39 **d.** 40 or over

2. Class Standing: **a.** Freshman **b.** Sophomore **c.** Junior **d.** Senior **e.** Graduate

3. Sex: **a.** Male **b.** Female

4. Area of Academic Major:

a. Anthropology **b.** Other Social/Behavioral Science (Political Science, Sociology, Social Work, Urban Studies, Criminal Justice, Psychology)
c. Humanities (Art, English, Foreign Language, Philosophy, History, Music, Journalism, Communications, Kinesiology, Theater) **d.** Engineering, Computer Science
e. Business **f.** Architecture, Environmental Design **g.** Natural/Physical Science (Biology, Chemistry, Geology, Physics, Math) **h.** Other

5. Outside of Class Requirements, how many books do you read per year?

a. 0-2 **b.** 3-10 **c.** over 10

6. Circle any of the following subjects that you have had college-level courses in:

a. Anthropology **b.** Archaeology **c.** Astronomy **d.** Biology **e.** Chemistry or Physics **f.** Geology **g.** History **h.** Logic **i.** Psychology **j.** Religious Studies

7. Where did you grow up, mostly?

a. In the country (rural) **b.** Small town/city (below 50 000 people)
c. Medium-sized city (50 000 - 500 000 people) **d.** Metropolitan area (above 500 000 people)

8. What country or region did you grow up in?

a. USA **b.** Britain **c.** Europe (except Britain) **d.** Africa **e.** Asia **f.** Middle East **g.** Canada **h.** Latin America **i.** Other

9. If you grew up in America, what region?

a. Texas **b.** California **c.** Pacific West (Washington, Oregon, Alaska, Hawaii) **d.** Mountain (Montana, Idaho, Wyoming, Nevada, Utah, Colorado, Arizona, New Mexico)
e. West North Central (North Dakota, South Dakota, Iowa, Nebraska, Kansas, Missouri, Minnesota)
f. South Central (Oklahoma, Arkansas, Louisiana, Mississippi, Alabama, Tennessee, Kentucky)
g. South Atlantic (Florida, North and South Carolina, Georgia, Virginia, West Virginia, Maryland, Delaware) **h.** Middle Atlantic (New Jersey, New York, Pennsylvania)
i. East North Central (Wisconsin, Illinois, Ohio, Indiana, Michigan) **j.** New England (Maine, Vermont, New Hampshire, Massachusetts, Rhode Island, Connecticut)

10. Were you taught about evolution in your high school biology course?

a. Yes, and creation was taught along with it. **b.** Yes, and creation was NOT taught along with it. **c.** No

11. Which of the following best agrees with your conception of the modern theory of evolution?

a. Man evolved from an apelike ancestor in Africa. **b.** Evolution occurred because of differing individual organisms left different numbers of offspring.
c. Evolution involved a purposeful striving toward higher life forms (steady progress from microbes to man).
d. Evolution occurred because the strong eventually eliminated the weak.

12. Do you think the modern theory of evolution has a valid scientific foundation?

a. Yes, because it is possible to test many hypotheses of evolutionary theory. **b.** Yes, even though we can never test many hypotheses of evolutionary theory.
c. No, because we can never be sure about the events of the past. **d.** No, because evolutionary theory is based mainly on speculation, not hard scientific facts.
e. No, because it goes against my convictions.

15. Circle the letter that corresponds to the following statements that most clearly describes your belief about the statements below.

A Agree strongly **B** Agree somewhat **C** Disagree somewhat **D** Disagree strongly **E** Undecided **F** Never heard of it

a. The world is between 4 and 5 billion years old.	A	B	C	D	E	F
b. Aliens from other worlds are responsible for ancient monuments like the pyramids, which primitive people could not have built.	A	B	C	D	E	F
c. America was visited by Europeans long before Columbus or the Vikings.	A	B	C	D	E	F
d. An ancient curse on the tomb of the Egyptian pharaoh King Tut killed people.	A	B	C	D	E	F
e. The Loch Ness Monster exists only in people's imagination.	A	B	C	D	E	F
f. UFOs are alien spacecraft from other planets.	A	B	C	D	E	F
g. Humanity came to be through evolution, which was controlled by God.	A	B	C	D	E	F
h. There is intelligent life somewhere out there in the universe.	A	B	C	D	E	F
i. Adam and Eve were the first humans.	A	B	C	D	E	F
j. Time travel into the past is possible.	A	B	C	D	E	F
k. There is a lot of evidence against evolution.	A	B	C	D	E	F
l. Science has done more good than bad for the world.	A	B	C	D	E	F
m. Bigfoot is a real creature roaming the woods in the American Northwest (Oregon, Washington).	A	B	C	D	E	F
n. Reincarnation really happens.	A	B	C	D	E	F
o. Human beings that are biologically modern like they are today have been around for about 40 000 years.	A	B	C	D	E	F
p. Black magic really exists.	A	B	C	D	E	F
q. It is impossible to communicate with the dead.	A	B	C	D	E	F
r. Some people can predict future events using psychic powers.	A	B	C	D	E	F
s. Claims that there is some mysterious force controlling the Bermuda Triangle are untrue.	A	B	C	D	E	F
t. The lost continent of Atlantis was the home of an ancient civilization.	A	B	C	D	E	F
u. The theory of evolution correctly explains the development of life.	A	B	C	D	E	F
v. Aliens from other worlds visited earth in the past.	A	B	C	D	E	F
w. Dinosaurs and humans lived at the same time in the past.	A	B	C	D	E	F
x. Our government is hiding information about crashed alien spacecraft.	A	B	C	D	E	F
y. Humans first evolved in North America and spread across the world.	A	B	C	D	E	F
z. Astrology is an accurate predictor of the future.	A	B	C	D	E	F
aa. Cars capable of high gas mileage (over 100 miles per gallon) are possible, but oil companies are preventing this.	A	B	C	D	E	F
bb. There was a great worldwide flood on the earth.	A	B	C	D	E	F
cc. Science makes our way of life change too fast.	A	B	C	D	E	F
dd. Most scientists are not religious.	A	B	C	D	E	F
ee. There are ghosts inhabiting the world.	A	B	C	D	E	F
ff. I have a clear understanding of the meaning of scientific study.	A	B	C	D	E	F
gg. The seasons are made because the earth is closer to the sun during summer and farther away in winter.	A	B	C	D	E	F

The Goal of Evolution Instruction: Should We Aim for Belief or Scientific Literacy?

Robert A Cooper

In the inaugural issue of *RNCSE,* Alters (1997) proposed that the goal of evolution education should be to teach students to *believe* in evolution. He argued that educators have resisted teaching evolution with the goal of student belief on the basis of five misconceptions. These are (Alters 1997: 16):

1) "belief" means little more than personal convictions — no empirical evidence;
2) "belief" is never a goal in public education;
3) evolution has little empirical evidence;
4) belief cannot be assessed, therefore it does not belong as an educational goal;
5) teaching evolution with belief as a goal is tantamount to proselytizing students

Although he offers sound arguments to refute misconceptions (2) and (4), Alters's analyses of misconceptions (1), (3), and (5) need further examination. The issues regarding the teaching of evolution in public schools with diverse populations are much more complex. We must avoid the temptation to teach evolution in a didactic, authoritarian manner regardless of the nature of the student population and their prior beliefs — an approach that would be detrimental to the goal of scientific literacy for all (American Association for the Advancement of Science 1990). It is time to revisit these issues and explore them in the context of current efforts in science education reform and what we know about how students learn. A thorough analysis of the situation with an eye toward making instructional recommendations must take into account what we have learned from research into students' pre-instructional beliefs and worldviews.

USE OF THE WORD "BELIEF"

In his discussion of the first misconception, Alters contended that the words "believe" and "accept" are essentially synonymous and are used interchangeably by both scientists and Protestant ministers. He also acknowledged that the word "believe" is more often associated with nonscientific uses in the vernacular but dismissed this distinction as unimportant. However, the distinction between the words "believe" and "accept" should not be merely dismissed as semantics in the context of teaching about evolution.

The choice of words teachers use when discussing evolutionary theories and the evidence that supports them may be crucial to the students' interpretation of the teacher's instructional intent. The use of the word "belief" often carries with it connotations of acceptance based only on faith or personal opinion. When the subject of evolution is raised, students frequently ask teachers whether they believe in evolution or not. A teacher who simply responds in the affirmative may inadvertently convey an inaccurate view of evolution and the nature of science. Whether intended or not, students may have the impression that the teacher is proselytizing for evolution. It is essential that students understand that acceptance of beliefs in science, unlike in religion, is based upon reliable empirical evidence and sound arguments. The use of the word "believe" by scientists and Protestant ministers may convey vastly different messages depending on the context in which these words are used, and students must be made aware of this distinction.

As Alters correctly pointed out, "What is of importance is on which data and arguments one bases a particular belief or acceptance" (1997: 15). Yet teachers cannot and should not dismiss the different interpretations students may have of the words "believe" and "accept". Consequently, teachers should avoid the careless use of the word "believe" when teaching about evolution and be certain that students are aware that a scientist's "belief" in evolution stems from the examination of, and the acceptance of, the empirical evidence and arguments supporting evolutionary theory. Smith endorses this view when he wrote:

> Although the distinction between believing and accepting may be a subtle one for many, it is crucial to understanding the nature of science; moreover, drawing carefully the distinction between belief (or faith) in the absence of

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objective evidence and acceptance that is based on evidence provides an excellent opportunity for helping students understand what science is (1994: 595).

Evolution has little Empirical Evidence

Another misconception addressed by Alters is that theories of evolution are supported by little or no empirical evidence. Alters contended that the lack-of-evidence "misconception is generally held by non-biology majors who simply have not been introduced to the voluminous amount of data that support evolution, and/or do not themselves believe evolution occurred" (1997: 16). He echoed the view common to professional scientists that this situation could be remedied simply by teaching evolution as fact.

In fact, this misconception is much more widespread and complex than most of us imagine, and the suggestion that teachers simply teach evolution as fact is unlikely to remedy the situation. The misconception that there is little evidence to support evolution is typically at the root of arguments for equal time for creationism in the classroom, and the wide appeal of such arguments is apparent in the results of a recent Gallup poll, which found that 68% of Americans advocate the teaching of creationism along with evolution in public schools (Gallup News Service 2001). Significant percentages of the American population also prefer the biblical account of creation to evolution, suggesting that religious beliefs are frequently at the root of the lack-of-evidence claims. The situation is clearly much more complex than the fact that students simply have not been exposed to the evidence. Instructional recommendations for dealing with evolution in such a climate must go further than simply recommending that evolution be taught as fact.

There are essentially three problems that arise from such an approach. First, in many instances, science teachers who see evolution as conflicting with their religious beliefs may not present evolution accurately, if they present it at all. Even if the teacher's religious beliefs are not an issue, many science teachers simply have a poor understanding of the factual basis of evolutionary theory (Eve and Dunn 1990; Osif 1997) and many others apparently avoid evolution or de-emphasize it because they fear potential conflict (Scharmann 1993). Some of the problem may be in the scant instruction in evolution that teachers-in-training receive, so they know or understand the subject poorly themselves. Practicing teachers may also need periodic updates on the mass of new scientific discoveries and information that validate evolution.

Second, even when teachers understand evolution and teach it well, students frequently hold misconceptions about evolution that employ teleological and Lamarckian concepts (Jensen and Finley 1997). There is ample evidence in the science education and cognitive psychology literature that pre-instructional beliefs like these are remarkably resistant to change. For instruction to be successful, it must go beyond simply teaching evolution as fact (Chinn and Brewer 1993). Good evolution instruction must engage students in inquiry and provide activities that tend to promote conceptual change (Jensen and Finley 1995; Nickels and others 1996).

Finally, evolutionary theories intersect with deeply held beliefs that constitute students' worldviews (Cobern 1991). Implying that simple exposure to the evidence for evolution will result in conceptual change in students assumes that all students already accept the basic assumptions of a scientifically compatible worldview. On the contrary, students come to class with a wide variety of worldviews — many that are inconsistent with the basic assumptions of a scientifically-compatible one. Despite the fact that evolution receives support from a wealth of data in many different disciplines, the evidence for evolution is not the issue for these students. Because of their worldviews, they simply do not believe evolutionary explanations, and since they do not consider evolutionary accounts believable, their interpretation of instructional goals will differ from that of the teacher. Their perception will likely be that a teacher who presents evolution in a didactic, authoritarian manner is proselytizing for evolution.

[It] is clearly much more complex than the fact that students have not been exposed to the evidence.

Taking these differences in worldview into account, Cobern argues that "The acquisition of a scientific viewpoint is not at heart an epistemological issue, nor is it a simple matter of conceptual change" (1991: 179). Thus, establishing an instructional environment for these students that is conducive to learning requires an approach that is akin to "foreign relations" (Hills 1989: 183; Cobern 1995).

Teaching Evolution as Fact is Proselytizing

It is possible that teachers are prevented from teaching students to believe in evolution because of a concern that teachers who teach evolution as fact *are* proselytizing. Alters argued, "Teachers are not proselytizing students when they attempt to change students' belief from 'arsenic is healthy to ingest' to 'arsenic is dangerous to ingest.' Likewise, teachers are not proselytizing when they attempt to have students believe in the scientific fact of evolution" (1997: 16). Indeed, the US Court of Appeals in *Florey v Sioux Falls School District* (1980) ruled, in effect, that while the fact of evolution may offend some students and parents, the offense is unintended and unavoidable.

This approach may address the legal and constitutional issues, but it avoids educational issues for students whose worldviews are incompatible with science. A didactic and authoritarian approach has little chance of achieving the goal of student belief. Besides alienating students, the teacher's example is likely to foster misconceptions both about evolution and the

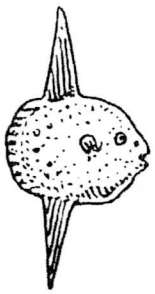
nature of science. Cobern similarly criticizes this approach:

> The challenge here is disbelief — many students simply do not believe evolutionary accounts of origins. By neglecting this legitimate student concern, the teacher tacitly takes an authoritarian and dogmatic stance with the result that the beliefs of many students, if not most, remain unchanged. Moreover, students also resist conceptual change, and hence their understanding of evolution remains inadequate (1994: 585).

When a teacher presupposes that all students will accept from the outset the assumptions underlying a scientifically compatible worldview, those assumptions become part of what has been referred to as the "hidden curriculum". Kilbourn argues that such an approach circumvents student choice since their awareness that there are other ways to view the world can be blocked. He contended that "such teaching is a morally questionable practice" (1980: 42). In any event, it is highly probable that such an approach will serve only to foster misunderstanding of evolution and nature of science.

Evolution and the Nature of Science

The failure of many students to understand and accept the fact of evolution is often a consequence of the naïve views they hold of the nature of science, which may be largely a result of the way science is presented in textbooks and in classroom discourse (Toumey 1996; McComas 1998). Many students believe that the business of science is to discover knowledge using a special method that leads to fundamental, unchanging truths that must be accepted with certainty by the scientific community (McComas 1998). In the public eye, the prestige and authority of science buttress scientific conclusions "because science is widely believed to transcend the social forces that obviously shape other human institutions, such as politics or religion. Science is believed to be, in a word, 'objective'" (Toumey 1996: 6).



According to this naïve view, the key to the unique success of science at producing true knowledge is "The Scientific Method", which, on the standard account, involves formulating hypotheses, making predictions, and then going into the laboratory to perform the crucial experiment (Gould 1980). In this parody of scientific methods, if a hypothesis passes the test set up by the crucial experiment, that is, if it is confirmed by direct observation, then it is "proven" and it is considered a fact or a law and it is true for all time.

In contrast, the work of many evolutionary biologists involves the reconstruction of the past. The methods they use do not conform to the standard view of "The Scientific Method". Although they cannot replay the past in order to experiment on and make direct observations of the events, there are methods for reconstructing the past history of life on earth (Cooper in press). The methods and patterns of reasoning resemble those that forensic scientists use to reconstruct a crime scene. Just as forensic scientists can reach conclusions that are reliable enough to convict a suspect of a crime, evolutionary biologists can establish reliable knowledge of the earth's past. Unfortunately, since most nonscientists, largely as a result of their science education in school, place a high priority on direct observation of events that occur during controlled experiments, they question the validity of the historical reconstruction of the past on the grounds that no one was there to see it happen. These critics frequently contend, for example, that since no one actually saw humans evolve from their ancestors, this conclusion may not be true, and, therefore, it is acceptable to believe whatever one wants about human origins.

Because evolutionary biologists employ different approaches to problem solving, "creation scientists" (Morris 1974) and, more recently, proponents of "Intelligent Design" (Johnson 1991) have attempted to characterize evolutionary biology as a philosophy of naturalism rather than a science. Both groups claim that creationism and evolution can be placed on an equal footing with regard to empirical support; therefore, a balanced and fair treatment should give equal time to both sides of the issue.

To a public that misunderstands science, arguments for equal time in the curriculum seem entirely fair and democratic. Any approach to evolution education based chiefly on a claim to scientific authority puts teachers in a weak position to defend against equal time arguments (Cooper 1996) and will lend credence to the misrepresentation of evolution as a philosophy of naturalism. Teachers need to avoid authoritarian instructional approaches that disguise the processes that generate scientific knowledge and give the appearance that they are proselytizing. Such didactic and authoritarian approaches to instruction tend only to reinforce misunderstandings of science.

The only way to confront misunderstandings of evolution and the nature of science is to help students achieve a better understanding of the inquiry methods actually employed by scientists. The NRC's *National Science Education Standards* characterized scientific inquiry as the "*diverse* ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (NRC 1996: 23, emphasis added), clearly rejecting the myth of *the* Scientific Method. Students' understanding of scientific inquiry must also include methods of historical reconstruction. Gould (1986) argues that historical sciences such as evolutionary biology require a different, though no less rigorous, method in order to reconstruct history. In Gould's view, the elucidation of this historical method was one of Darwin's greatest achievements. In addition to establishing the fact that all life was related by common descent and providing

a mechanism for evolution, Darwin also freed the discipline from metaphysical speculation and put it on a firm, empirical base. By first teaching students about scientific methods and the nature of scientific knowledge, biology teachers can provide a framework that will enable students to appreciate evolution as the powerful and unifying theoretical perspective that it is.

Approaches to evolution instruction

How should teachers approach the topic of evolution? Clearly, if we are going to teach students successfully about evolution and have them recognize and accept it as a well-supported scientific theory, then we need to address the widely-held misconceptions students harbor about evolution and the nature of science. One suggestion is to assess students' prior beliefs and modes of thought as a first step in any unit on evolution (Bishop and Anderson 1986, 1990; Nelson 1989; Scharmann 1993; Cobern 1994; Smith 1994; Jensen and Finley 1997). Among these, Cobern (1991, 1994) provides the most thorough treatment of worldview considerations and the potential difficulties that may arise when instruction conflicts with worldview. He cautions that the approach to teaching about evolution should not be *scientistic* — that is, teachers should avoid adopting a view that the scope of scientific authority is unlimited and beyond reproach (Duschl 1988: 52) or that "science provides the *one* reliable source of objective knowledge" (Cobern 1994: 585). Cobern recommends beginning instruction in evolution with a classroom dialogue that is informed with the knowledge of the cultural history of Darwinism.

Smith (1994) contends that any classroom discussion that precedes the teaching of evolution, and thus sets the stage for an understanding of evolution as science, should deal with the nature of science and how it differs from religion and other disciplines. He concluded that "evolution instruction is challenging because it is both conceptually difficult and because it may not fit with students' worldviews, histories, and perceptions. Successful instructional planning must take all of these facets into consideration" (Smith 1994: 596).

Clough (1994) agrees with Cobern (1994) and Smith (1994) that potential student concerns about conflicts between science and religion should also be addressed prior to the introduction of evolution in the classroom. He also recommends that teachers (1) distinguish theories of evolution from theories of the origin of life from its inorganic precursors — separate and distinct theories that are frequently conflated by students and the general public; (2) help students to understand the distinction between the use of the word "theory" in science and its use in the vernacular; (3) adopt an instrumentalist perspective with regard to belief in evolution, using the historical example of the use of this approach by Copernicus for heliocentrism and for Kekule in his study of atoms. Finally, and perhaps most important, Clough stressed (4) the need for teachers to respect students' beliefs. If students perceive a lack of such respect from their teachers, it will serve to engender hostility toward science and evolution.

Jensen and Finley (1997) used a historically-rich curriculum and paired-problem-solving to achieve some success in eliminating misconceptions about evolution and the nature of science. They identified three pre-Darwinian theories that were used to make sense of the biological world early in the 19th century. They labeled these teleology, Lamarckian evolution, and natural theology. Because many student misconceptions of evolution are consistent with one of these pre-Darwinian theories, Jensen and Finley reasoned that if they brought these pre-Darwinian theories to the students' attention and then pointed out their flaws, they would be more successful in promoting the development of a Darwinian point of view among students. They reported improved student understanding of evolution using their approach. In addition, they observed an increased use of Darwinian ideas by students and a decreased use of non-Darwinian ideas.

An authoritarian approach will only ... polarize religion and science in the minds of students

The approaches recommended in these articles enable biology teachers to expose students' prior beliefs and set up conditions that may allow students to examine and contrast those beliefs with currently accepted scientific views. These papers represent only a small sample of the recommendations and activities for teaching about evolution that are available in the literature.

Conclusion

Alters's intent that all students both understand evolution and believe it to be the best explanation for life's unity and diversity is a noble one. After all, he argued that we teach other theories, such as the Copernican theory of the solar system, with the intent that students will both understand and believe them. However, the strategies we adopt must employ recommendations based on an understanding of the complex issues resulting from students' pre-instructional beliefs and diverse worldviews. An authoritarian approach will only serve to polarize religion and science in the minds of students, and foster close-mindedness and resistance from many who will then be ignorant of the historical background and the empirical evidence that have led biologists to the evolutionary point of view.

While we may adopt universal belief as our goal, we must also recognize that, given the diversity of worldviews we find in the typical classroom, the goal may be an unrealizable one. In particular, fundamentalist Christians who insist on a literal reading of Genesis may never find sufficient grounds for a reconciliation of their religious beliefs and evolution

(Ruse 2001). The most important issue at stake here, however, is not whether students ultimately accept or reject evolution, but that students develop an accurate understanding of the nature of science and the scientific process, resulting in the improvement in scientific literacy. An education that promotes intellectual maturity and reflective judgment (King and Kitchener 1994) must enable *all* students to understand and appreciate all perspectives, including the scientific one. Instruction designed to achieve this goal must be informed by the metaphor of teaching science as "foreign affairs" (Hills 1989; Cobern 1995). Even if students ultimately choose to reject an evolutionary view of the world, the ability to "see" from that perspective may promote greater tolerance and understanding as well as greater intellectual maturity. Whether students choose to accept (believe) evolution or not, they must come to understand what science is and understand that evolution is a powerful scientific theory that provides a unifying framework for biology.

Since science — and evolution in particular — is judged not to conflict with the basic tenets of many religions organizations and denominations (Matsumura 1995), most students will find that they can retain their religious beliefs while developing a sound understanding of evolution. Many students may even come to accept (believe) that the evolutionary point of view is the best account of the evidence that we have.

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Teaching Evolution: Do State Standards Matter?

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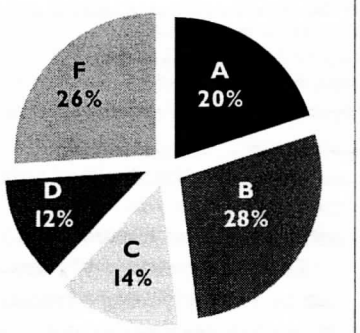
Lerner's (2000) much-publicized evaluation of states' standards for teaching evolution and their impact on science teaching produced a variety of responses among educators. Many scientists were encouraged by the fact that 31 states have satisfactory or better standards, whereas other educators were dismayed that 19 states have standards that are less than satisfactory. Indeed, although the average grade for all 50 states was a passable C, more states received failing grades (F and F-) than were rated excellent (see Figure 1). Ten of the states receiving grades of D or worse do not use the word *evolution* in their educational guidelines, and one (Maine) uses the word *evolution* once.

State standards for teaching evolution are important, for they are presumably the basis for what teachers teach and students learn, and thereby establish the foundation for states' desired educational outcomes. However, a more important factor that influences the quality of evolution education is not discussed in Lerner's report — namely, the evolution-related attitudes and actions of biology teachers. How do states' standards for teaching evolution relate to the acceptance or rejection of evolution by biology teachers?

Table 1 summarizes how the quality of states' standards for teaching evolution relate to the evolution-related attitudes of biology teachers. In states having low standards for teaching evolution (for example, grades of D, F, or F-, such as in Illinois, Kentucky, Ohio, Georgia, and Kansas), relatively large percentages of biology teachers believe that creationism should be taught in science classes in public schools. In some of these states, significant percentages of biology teachers actually teach creationism in their classes, despite the fact that the US Supreme Court's decision in *Edwards v Aguillard* established that it is unconstitutional (Moore 2000). The presence of low standards for teaching evolution also correlates with biology teachers' lack of emphasis on evolution (for example, Tennessee and Oklahoma) and anti-science policies such as the presence of anti-evolution disclaimers in biology textbooks (as in Alabama). As Lerner (2000) noted, although low standards for teaching evolution are concentrated in the Bible Belt, they also occur elsewhere (for example, Ohio and Illinois).

FIGURE 1
STATE EVOLUTION EDUCATION STANDARDS RATED BY LERNER (2000)



States having satisfactory standards for teaching evolution are not much different. For example, in Louisiana (see Aguillard 1999, Moore 1999c, and references therein) where standards are "satisfactory", over 40% of biology teachers believe that creationism is or may be scientifically valid, and they either do or want to teach creationism in their classes (see Table 1). Nearly another quarter of biology teachers avoid or play down the topic, and many of the state's biology teachers do not recall hearing the word *evolution* in their college biology courses. Furthermore, the Louisiana Committee for Science Standards treats evolution as it does witchcraft, the occult, and other fringe ideas that are banned from the state's exit exams.

In Texas, another state having "satisfactory" standards for teaching evolution, evolution receives inadequate coverage in at least half of all biology courses (Shankar 1990; Shankar and Skoog 1993). Thus, the presence of "satisfactory" guidelines for teaching evolution does not mean that large percentages of biology teachers do not endorse (and sometimes teach) creationism in their courses.

What about states that have "good" (for example, Minnesota and South Dakota) or "excellent" or "very good" (for example, Indiana and Pennsylvania) standards for teaching evolution? Although these states have the nation's highest standards for teaching evolution, relatively large percentages of their biology teachers believe that creationism should be included in science classes, spend little time teaching evolution, and question the scientific validity of evolution (Weld and McNew 1999; Rutledge and Warden 2000).

DO STANDARDS MATTER?

Although standards for teaching science have been touted as being important for the reform of science education, the studies summarized in Table 1 show that standards often mean little in biology classrooms. Indeed, prior research shows that relatively large percentages of biology teachers throughout the United States continue to endorse creationism, question evolution, and even teach creationism in their courses, regardless of their state's standards for evolution education (see Table 1 and references

TABLE 1 BIOLOGY INSTRUCTION AND STATE STANDARDS' TREATMENT OF EVOLUTION

State	Rating	Policy or Characterization of Biology Teachers	Reference(s)
AL	D	All biology textbooks used in public schools include a disclaimer stating that evolution is a "theory, not fact".	Moore 2000
GA	F	29% of biology teachers feel pressured to decrease their coverage of evolution and/or increase their coverage of creationism; 30–32% of biology teachers want creationism to be taught in science classes; 27% of biology teachers teach creationism.	Eglin 1983; Buckner 1983
IL	D	30% of biology teachers want creationism to be taught in science classes.	Nickels and Drummond 1988
IN	A	33% of biology teachers spend less than 3 days on evolution; 43% of biology teachers characterize their teaching of evolution as "avoidance" or "briefly mention". At least 20% of biology teachers do not accept or are undecided about the scientific validity of evolution.	Rutledge and Warden 2000; Rutledge and Mitchell 2002
KS	F-	In some schools, up to 50% of biology teachers want creationism to be taught in science classes.	Aldrich 1991
KY	D	Education officials group evolution with gun control and other controversial topics as subjects that "may or may not be suitable for assessment items" on state exams.	Scanlon and Uy 1999
		21% of biology teachers feel pressured to decrease their coverage of evolution and/or increase their coverage of creationism; 69% of biology teachers want creationism to be taught in science classes; 30% of biology teachers teach creationism.	Ellis 1986
LA	C	29% of biology teachers want to teach creationism in their classes; 14% of biology teachers teach creationism; 24% of biology teachers believe that creationism is a scientifically valid concept, and another 17% believe that creationism may be scientifically valid; 23% of biology teachers put little or no emphasis on evolution in their courses.The Louisiana Committee for Science Standards groups evolution with topics such as witchcraft, incest, drug use, and the occult as topics that should be banned from the state exit exam for high school students. Many of Louisiana's biology teachers do not recall hearing the word *evolution* in their biology courses.	Aguillard 1990; Moore 1999c
MN	B	40% of biology teachers spend little or no time teaching evolution.	Hessler 2000
OH	F	15% of biology teachers teach creationism. Most school board presidents believe that creationism should be taught in science classes; 38% of biology teachers want creationism to be taught in science classes.	Zimmerman 1988a; Zimmerman 1987, 1988b
OK	F	33% of biology teachers place little or no emphasis on evolution.	Weld and McNew 1999
OR	B	26% of biology teachers teach creationism in their classes.	Affannato 1986
PA	A	33% of biology teachers do not believe that evolution is central to biology. A recent draft of science education standards requires that teachers present "evidence that ... does not support" evolution.	Weld and McNew 1999; Petto 2000
SD	B	39% of biology teachers believe that creationism should be taught in science classes. 16% of biology teachers teach creationism in their classes.	Weld and McNew 1999; Tatina 1989
TN	F	23% of biology teachers place little or no emphasis on evolution. Ironically, creationism is still taught at John Scopes's school.	Weld and McNew 1999; Moore 1999b
TX	C	Evolution receives inadequate coverage in at least half of all biology courses.	Shankar 1990; Shankar and Skoog 1993

Rating for states' educational standards for teaching evolution taken from Lerner (2000).

therein). As Don Aguillard has noted, creationism is alive and well in biology classrooms (Moore 1999c).

Evolution-related instruction is influenced by educational standards and a variety of other factors such as textbooks, the curriculum, and tests. However, the most important factor in student learning is the teacher. Throughout the United States, many biology teachers avoid (or do a poor job of) teaching evolution, endorse creationism, or, in some cases, *teach* creationism. One important consequence of such behavior by teachers is that the biology education of "over a quarter — and perhaps as many as half — of the nation's high school students is shaped by creationist influence — in spite of the overwhelming opposition of the nation's scientific, educational, intellectual, and media establishments" (Eve and Harrold 1991).

The endorsement of creationism by relatively large percentages of biology teachers is not a new phenomenon. For example, more than 60 years ago biologist Oscar Riddle (1941) reported the popularity of creationism among biology teachers and noted that fewer than half of high school biology teachers taught evolution. Almost two decades later Herman Muller (1959) again observed the popularity of creationism among biology teachers and noted that biology teaching was dominated by "antiquated religious traditions".

When the National Association of Biology Teachers (NABT) established its "Fund for Freedom in Science Teaching" in the 1970s to combat the anti-science campaigns of creationists, many members of NABT were outraged. According to Nelkin (1982: 158), "letters poured into" NABT's national office decrying "vicious scientific attacks on the creationists" and attempts to "promote atheism and agnosticism in the schools". To accommodate its many creationist members, NABT sponsored a well-attended session about creationism at its annual meeting and published several articles promoting creationism in its journal, *The American Biology Teacher* (for example, Gish 1970, 1973; Moore 1973; also see Nelkin 1982). Today, many biology teachers continue to proclaim their endorsement of creationism and rejection of evolution (Harp 1999; Scanlon and Uy 1999; Wolfson 1999; Moore 1999a, 2000).

Standards are not altogether useless in the fight for evolution education. Standards for teaching evolution can provide important support for biology teachers facing protests from creationist students, parents, and administrators

who want creationism to be taught (or evolution *not* to be taught) in biology classes. In addition to state standards, numerous science education organizations (for example, the American Association for the Advancement of Science [1989], the National Association of Biology Teachers [1997], the National Academy of Sciences [1998], the National Research Council [1985], and the National Science Teachers Association [1997]) have issued standards and policy statements urging biology teachers to make evolution a central theme in their classes.

However, states' and science education organizations' standards for teaching evolution have not changed the fact that evolution is often taught poorly — or not at all — in biology classes. As a result, the public (including our former students) overwhelmingly endorses creationism over evolution (for example, Gallup and Newport 1991; Moore 2000; Greenwood and North 1999; Sonderstrom 2000; Finn and Kanstoroom 2000). Throughout the country, large percentages of biology teachers have ignored these standards. If we are to do a better job of teaching evolution — and if our students (future citizens, taxpayers, and political leaders) are going to learn it better — we must do more than establish standards that are ignored.

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The American Scientific Affiliation and the Evangelical Response to Evolution

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The American Scientific Affiliation (ASA) is an association of Christians interested in the interaction and integration of their faith with the scientific disciplines. The ASA was founded in 1941 by scientists of evangelical Christian faith who were concerned about the growing influence of scientific materialism and who desired to present science in a theistic context. *(Read a discussion of the early history of the ASA in* The Creationists *by Ronald Numbers [Berkeley: University of California Press, 1992].)* Today, it is an organization that, with another affiliated society, the Canadian Scientific & Christian Affiliation, has about 2000 members. Together they publish the journal *Perspectives on Science and Christian Faith.*

Members have at least a bachelor's degree in a scientific or engineering field or in the history or philosophy of science. As an organization, the ASA takes no official position on specific scientific questions. All members assent to the following doctrinal statement:

> We accept the divine inspiration, trustworthiness and authority of the Bible in matters of faith and conduct. We confess the Triune God affirmed in the Nicene and Apostles' creeds, which we accept as brief, faithful statements of Christian doctrine based upon Scripture. We believe that in creating and preserving the universe, God has endowed it with contingent order and intelligibility, the basis of scientific investigation. We recognize our responsibility, as stewards of God's creation, to use science and technology for the good of humanity and the whole world.

Members of the ASA represent a wide range of disciplines and bring their expertise to bear on a wide range of issues — including such critically important ones as biomedical and environmental ethics. However, issues surrounding evolution, both scientific and theological, have featured prominently in discussions among ASA members since the organization's inception. Articles on these topics are also commonly presented in the pages of the ASA's journal.

In 1997, a subcommittee of the ASA appointed a "Commission on Creation" to draft a general statement on creation that would reflect points of agreement among those representing a wide spectrum of views. ASA members holding the various perspectives on creation were appointed to the commission, and the resulting "General Statement on Creation" was unanimously approved by them. In addition, several more specific statements were drafted to represent the diversity of views in the ASA. These are labeled Young-Earth View, Old-Earth View, Theistic-Evolution View, and Intelligent-Design View *(see the text of the General Statement on Creation and the views of specific working groups at <http://www.asa3.org/ASA/topics/Evolution/commission_on_creation.html#Commission on Creation>.* Additional statements representing these specific views were written by proponents of the respective positions and appear with the general statement. It is important to emphasize that the general statement is simply a product of the work of the commission, and it *does not* exhaustively represent all the views present within the ASA or within the larger Christian community.

As a member of the commission that drafted the statement, I offer here a few reflections on its value, and on its context within the larger popular controversy over evolution.

To begin, my own position is that there is no inherent conflict between evolutionary theory and a Christian faith with a high view of Scripture. By evolution, I mean the theory that all living things on earth are descended from a common ancestor through a continuous chain of cause-and-effect processes. I believe that there are no necessary breaks or gaps in causal explanations. That is, all transitions in the history of life are potentially explicable in terms of "natural" cause-and-effect processes. This theory is no mere guess or hunch, but an extremely well-supported explanation of the observed record of organic change. It has great explanatory power in drawing together an incredibly wide range of data from many disciplines in an explanatory framework. It has been very effective in generating fruitful and testable hypotheses that have driven new discoveries and advanced our scientific understanding of the universe.

I also fully and unhesitatingly accept the doctrine of creation: God is the creator of all things, and nothing would exist without God's continually willing it to be. God is intimately and actively involved in all natural processes. Every natural process is as much an act of a personal creator as any miracle. The best term I know for this view of

continued on page 27

Why Teach Evolution?

Andrew J Petto

Confronting Dr Zaius, Minister of Science and Defender of the Faith on the "Planet of the Apes", human astronaut Taylor points out the paradox of preserving the dogma of ape primacy while overseeing excavations that demonstrate the prior existence of technologically advanced humans. Taylor's comments reflect our common misunderstanding that science — particularly evolutionary science — is necessarily at odds with religious faith. It is hard to say exactly how long this idea has been with us, but it is clear that the perceived conflict was promoted in popular accounts of the Scopes Trial and is still promoted today by at least some in scientific and religious organizations alike.

Most of the public discussion on evolution — by both opponents and proponents — is based on a caricature of evolutionary theory. One misconception supposes an antipathy between evolution and religious faith and, in particular, between the lack of a predetermined pathway of evolutionary change and the development of moral or ethical behavior. Opponents also portray evolution as "controversial" — including the infamous textbook disclaimers recently struck down by the courts and the "teach the controversy" slogan of the Discovery Institute. Both of these positions overlook the fact that the "controversy" exists only in social, political, and, in some cases, religious discourse; there simply is no controversy within the sciences over accepting evolution.

What Evolution Is

Evolution is a scientific theory about the patterns of similarities and differences we observe among living things on earth through time and space, and it performs three important functions. First, evolution explains these patterns on the basis of descent with modification from common ancestors — the more recent the descent and the more similar the environments, the greater the similarity between descendant and ancestor and among all the descendants over many generations. Second, evolution predicts that as-yet unknown and unexplored biological phenomena ought to display this same pattern. It is the success of this aspect of evolutionary theory to which Pope John Paul II referred in his address to the Pontifical Academy of Sciences in October 1996. Third, evolution provides cogent answers to scientific research questions and generates new questions and research based on its past performance. This aspect of evolutionary theory reaches into many areas of daily life, including medicine, agriculture, pharmaceuticals, industrial design, and even Olympic sports — so much so that Wesley Elsberry of Texas A&M University has suggested that everyday products ought to include an "Evolution Inside" stamp to alert consumers to the role played by evolutionary theory in their conception, production, and successful use.

It is also important to be clear about what evolution is not — a theory about the origin of life, or of the solar system, or of the universe. Evolution is indifferent to the origin of life — whether by some natural conglomeration and animation of organic and replicating compounds or by "seeding" from an extraterrestrial source or by some other process. Evolution begins once life exists, more-or-less as we know it, following the "rules" for living things on earth.

Evolution is also not just "Darwinism". Darwin's idea of descent with modification and predictions about what scientists would discover based on the theory have been confirmed time and again. However, there was much about which Darwin was either ignorant or just plain wrong. The most significant of these, perhaps, is the reliance on the slow accumulation of gradual, step-wise change as the sole mechanism for evolutionary divergence and speciation. In the 120 years since Darwin's death, evolutionary theory has spurred discoveries of numerous processes that can produce speciation. Pointing out deficiencies in Darwin's formulations ignores more than a century of scientific progress.

Evolution and Humans

The real sticking point, though, is *human* evolution — that we share a common ancestor with African apes (most recently) and with all other living things (more remotely). Some anti-evolutionists argue that this ancestry means that we are *only* animals — unconstrained by the moral and ethical constructs that are essential to our humanity. However, a quick perusal of recent books on moral behavior in social animals shows that evolution predicts just the opposite — that such behavior *should* evolve because we depend on social cooperation as the basis for our evolutionary success. Evolutionary theory really says only one thing about our moral tendencies (and failures) — that these are behaviors rooted in our shared biological heritage.

Evolution does not argue that we are *just* animals, but that we are *special* animals. If that specialness involves a sense of awe or awareness or questioning about an existence beyond our experience in nature, then the *capacity* to experience that sense has to be rooted in our evolutionary heritage. The near universality of such extranatural awareness suggests that this is so.

Keeping it Real

So, why teach evolution? To be sure that students know what evolution is — and is not — when they become citizens. What we need to do is to be sure that evolution is taught completely and accurately, so that our public discourse on evolution-related issues can be informed by current scientific practice and understanding. This is the charge that Michael Ruse often takes to philosophers of science — to base discussions of the implications and expectations of scientific ideas and theories on what is current in the sciences as scientists understand and practice it. It is wrong to use science to prove — or disprove — specific theological constructs and precepts; it is just as wrong to base a scientific premise solely on religious scripture or tradition. It is like trying to prove the existence of the human soul by means of dissection. We teach evolution because it is the theoretical basis of modern biology — and there is no way to understand biology completely or correctly without understanding evolution. As the prominent geneticist Theodosius Dobzhansky wrote nearly 40 years ago, "Nothing in biology makes sense except in the light of evolution."

Andrew Petto is Associate Professor of Liberal Arts at the University of the Arts in Philadelphia, where he teaches life science, evolution, and general scientific literacy. He serves on the Board of Directors of the Philadelphia Center for Religion and Science and of NCSE, where he is also editor of RNCSE.

[*This note first appeared in March 2001 in* Spiral, *the newsletter of the PCRS. It is reprinted here by permission.*]

Paleo Picks

They say that all kids love dinosaurs. Well, some of us never grow up. But as we mature, our interests broaden from just dinosaurs to an interest in the entire history of life on earth. The last two years have seen a number of new books devoted to paleontology and the evolution of life, as well as the reissue and revision of some older titles geared towards an interested lay audience. Here are some of the best books on paleontology that are currently available. Some are coffeetable-style picture books; others are detailed and information-rich encyclopedias. (Many are also useful references for teachers of earth science and biology.) All are informative, up-to-date, and altogether enjoyable. And all of them are now available on the NCSE web site: <www.ncseweb.org/bookstore.asp>. And remember, every purchase benefits NCSE!

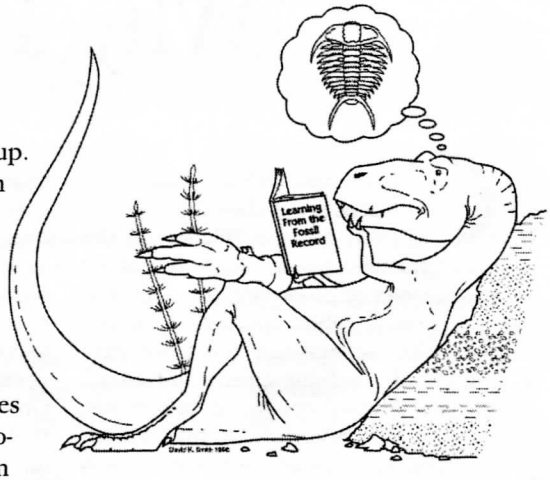


Illustration by Dave Smith, used with permission of the University of California Museum of Paleontology

Paleontology and the History of Life

The Simon & Schuster Encyclopedia of Dinosaurs & Prehistoric Creatures: A Visual Who's Who of Prehistoric Life
edited by Barry Cox, RJG Savage, Brian Gardiner, and Colin Harrison
revised and updated by Douglas Palmer
The last 500 million years of evolution are vividly portrayed in *The Simon & Schuster Encyclopedia of Dinosaurs & Prehistoric Creatures*, which contains detailed descriptions of "a panorama of enormous diversity, from predatory dinosaurs to primitive amphibians, from giant armored fish to woolly mammoths, saber-tooth tigers and dire wolves", in the words of the publisher, complete with over 600 original paintings "prepared according to the best research of today in close collaboration with world-renowned paleontologists."

The Book of Life: An Illustrated History of the Evolution of Life on Earth
edited by Stephen Jay Gould
This classic book, now in its second edition, provides nothing less than it promises in its title: a detailed account of the history of life on earth over the last four billion years. J John Seposki Jr, Michael Benton, Christine Janis, Christopher Stringer, and Peter Andrews, under the general editorship of NCSE Supporter Stephen Jay Gould, are responsible for the thoroughly understandable text; the vivid and compelling illustrations are the work of John Barber, Marianne Collins, Ely Kish, Akio Marishima, and Jean-Paul Tibbles.

Planet Ocean: A Story of Life, the Sea, and Dancing to the Fossil Record
by Brad Matsen
illustrated by Ray Troll
Dozens of Ray Troll's imaginative full-color paintings and block prints are accompanied by Brad Matsen's text explaining the history of life on our ocean-covered planet. It is difficult to say which is more entertaining, the illustrations (such as "Trilobite Safari", which depicts two plaid-wearing human hunters bearing a huge trilobite on a stick between them) or the text, which, referring to the Burgess Shale, says, "The clearest notes of complex life's first songs echo in the dark shale of the Canadian Rockies. We heard them just after the turn of the century, though we didn't hear the tune clearly until the mid-1970s. But what's a few decades among eukaryotes?"

Atlas of the Prehistoric World
by Douglas Palmer
As its title suggests, *Atlas of the Prehistoric World* contains a collection of dazzlingly detailed paleogeographic maps, tracking shifts in land masses and climates from the Vendian Period to the present. In addition, Douglas Palmer, who teaches Earth and Natural Sciences at Cambridge University, narrates the story of life's evolution over the course of the last four billion years and provides a sparkling history of and guide to earth science. Accompanied by over 250 full-color photographs and illustrations, *Atlas of the Prehistoric World* is a wonderful reference for the student, the teacher, and the enthusiast alike.

The Variety of Life: A Survey and a Celebration of All the Creatures that Have Ever Lived
by Colin Tudge
Truly an epic work, Colin Tudge's *The Variety of Life* attempts to chronicle the history of life in all its

<http://www.ncseweb.org/bookstore.asp>

diversity from a modern phylogenetic perspective. As the reviewer for *Booklist* comments, "Safari hunters look docile compared to Tudge, who in a single volume captures not only lions and tigers but also every other living creature (and millions of extinct ones). And he accomplishes his massive capture with no snare other than the one he spins out of scientific classification." A must for any aficionado of evolutionary biology.

Wildlife of Gondwana: Dinosaurs and Other Vertebrates from the Ancient Supercontinent
by Patricia Vickers-Rich and Thomas Hewitt Rich
Lavishly illustrated, *Wildlife of Gondwana* describes the past diversity of life on Gondwana, the supercontinent that later dispersed into Antarctica, India, Australia, Africa, and South America. The authors spent eight years writing this book, then another two years revising it. As Patricia Vickers-Rich writes on its Amazon.com page, "Tom and I very much enjoyed writing this book.... We were able to see and record information about so many new Gondwana fossils, and it led us into many new research projects and introduced us to many new people we never knew before. It was a fantastic journey for us — across Gondwana today and in the past."

Dinosaurs

In the Presence of Dinosaurs
John Colagrande
illustrated by Larry Felder
Ranging from the Triassic to the Cretaceous, Colagrande presents a veritable menagerie of Dinosauria. With one hundred full-color plates by the acclaimed illustrator Larry Felder, *In the Presence of Dinosaurs* is a lively and well-researched exploration of the habitat and behavior of these magnificent creatures, drawing both on the fossil record and on the living descendants of the dinosaurs. Jack Horner, author of numerous dinosaur books and Curator of Paleontology at the Museum of the Rockies, contributes the foreword.

Encyclopedia of Dinosaurs
edited by Philip J Currie and Kevin Padian
A comprehensive and authoritative reference to the dinosaurs. Writes Douglas Preston, author of *Dinosaurs in the Attic*, "I can't imagine anyone with an interest in dinosaurs — layman, student, or scientist — not wanting to own this magnificent book." The science editor of the San Francisco *Chronicle* says that "[e]very public library and every school in America should own it, for it is the most valuable and up-to-date reference work on the intriguing subject ever published." Coeditor Kevin Padian is the President of NCSE.

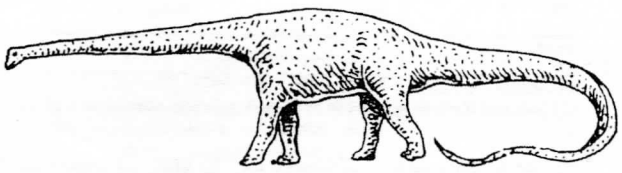
The Mistaken Extinction: Dinosaur Evolution and the Origin of Birds
by Lowell Dingus and Timothy Rowe
Perhaps the most up-to-date and comprehensive treatment of dinosaur evolution currently available, *The Mistaken Extinction* discusses both the origin of birds and the supposed extinction of the dinosaurs in detail, offering a very accessible discussion of modern taxonomy and cladistics en route. Writing in *The New York Times Book Review*, John Noble Wilford comments, "If their richly illustrated book is perhaps too comprehensive for cover-to-cover reading, it is well organized to be used for years as a reference work on all kinds of dinosaur and bird lore."

For the Kids

Dinosaur Ghosts: The Mystery of Coelophysis
by J Lynett Gillette
illustrated by Douglas Henderson
Science comes alive in Lynett Gillette's story of the remarkable discovery of fossils at Ghost Ranch, where, 225 million years ago, hundreds of *Coelophysis* dinosaurs perished "in a tangle of necks, tails, arms, and legs." What catastrophe caused their death and burial? In considering the various scenarios — volcano? flood? poisoned water? asteroid? — Gillette painlessly introduces young readers to the scientific method. Profusely illustrated, with haunting paintings by Douglas Henderson.

The Little Giant Book of Dinosaurs
by Thomas R Holtz Jr
illustrated by Terry Riley
As *The Little Giant Book of Dinosaurs* reminds us in its opening words, "There was a time when nobody knew about dinosaurs." With the aid of Terry Riley's numerous black-and-white illustrations, Thomas R Holtz carefully and concisely explains how the dinosaurs were discovered, what we know about them, where they came from, and where they went. The book includes a useful glossary as well as lists of dinosaurs by epoch and by location. The author, who teaches at the University of Maryland, College Park, is a member of NCSE.

Raptors, Fossils, Fins & Fangs: A Prehistoric Creature Feature
by Ray Troll and Brad Matsen
With vividly colored illustrations by Ray Troll (whose delightful illustrations grace every issue of *RNCSE)* and text by Brad Matsen, *Raptors, Fossils, Fins & Fangs* describes the history of animal life from the Cambrian to the present, using representative species from trilobites to you and me. Perfect for children aged 5–9 and the people who love them (with timelines on every page for curious grownups). "Troll and Matsen are the best", writes Peter Ward of the University of Washington: "This book is for all the kids, grown and otherwise, who still love fossils."



NCSE on the Road

A Calendar of Special Events, Presentations, and Lectures

Date	January 11, 2002
City	Cleveland OH
Presenter	Eugenie C Scott
Title	Creationism, Evolution, and Public Education
Event	Center for Inquiry Conference: Science and Religion
Time	7:30 PM
Location	Cleveland Museum of Natural History
Contact	Robert Segedi, rsegedi@cmnh.org

Date	January 31, 2002
City	New York NY
Presenter	Eugenie C Scott
Title	Competition and Evolution
Event	Lifeline Series at All Souls Unitarian Church
Time	6:30 PM
Location	All Souls Unitarian Church
Contact	Julie Brannan, info@lifelinescenter.org

Date	February 16, 2002
City	Boston MA
Presenter	Eugenie C Scott
Title	Genomics and the Creationism Controversy
Event	"Genomes Around Us" Symposium
Time	3:00 PM
Location	Sheraton Boston
Contact	Eugenie C Scott, scott@ncseweb.org

Date	March 1, 2002
City	Detroit MI
Presenter	Eugenie C Scott
Title	Teaching Evolution (and Surviving)
Event	MABT/MSTA annual meeting
Time	TBA
Location	TBA
Contact	Lynda Smith, lsmith@remc11.k12.mi.us

Date	March 24, 2002
City	Arlington VA
Presenter	Eugenie C Scott
Title	What's New in the Anti-evolution Movement?
Event	AIBS annual meeting
Time	8:30 PM
Location	Keybridge Marriott
Contact	Richard O'Grady, rogrady@aibs.org

Date	March 26, 2002
City	New York NY
Presenter	Eugenie C Scott
Title	Evolution and Education
Event	Presentation in "Intelligent Design" Series
Time	8:30 PM
Location	American Museum of Natural History
Contact	Nathaniel Johnson Jr, natj@amnh.org

[Check the NCSE web site for updates and details — <http://www.ncseweb.org>.]

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The Children's Crusade for Creation

Steve Randak

The nightmare of every biology teacher happened at our school. Creationists petitioned the school board to have creation science added to the biology curriculum. The outcome was mixed.

WHY US?

Why did it happen at Jefferson High School, Lafayette, Indiana, in the shadow of Purdue University? It seems reasonable to assume that if you are not teaching evolution, you greatly reduce your chances of a confrontation. As you increase both the time spent on evolution and the effectiveness of your instruction, the risk of creationist intervention should logically increase.

After an introductory unit on the nature of science, we teach one semester of ecology and one semester of evolution, with genetics and the cell included in evolution. John Moore's deductions of evolution are the skeleton upon which we build the second semester's study (Moore 1993). In addition to teaching the big ideas in biology, we spend considerable time teaching life skills with goal setting, group learning, student choice, and oral testing. We use several tools that increase the chance that the 80% of the time spent in labs will result in critical thinking skills development.

Because the class is team-taught, student-centered, and constructivist, students tend to enjoy it and they learn (Randak 2000). These factors work together to create an environment that stress students with creationist beliefs. To relieve that stress, we teach a comprehensive 5-week introductory unit on the nature of science. It includes not only the scientific method but a condensed history of science and a consideration of how science is distinguished from nonscience. The commitment to developing a deeper understanding of the nature of science comes, in part, from our involvement with a NSF-sponsored ENSI program (ENSI 2000). The ENSI philosophy assumes that if students develop an understanding of what science is and how to distinguish science from nonscience, they will have fewer problems when confronted with evolution (Nickels 1996). In the past it worked. This time it did not, and we wondered why.

STUDENT-DRIVEN CREATIONISM

Contrary to our expectations, the entire initiative to add creationism to the curriculum was student-driven; no adult took an obvious role. We know from talking with students that one of our chemistry teachers offered a great deal of support for the creationist view. In the past, he had spent the first several weeks of school preaching the creationist dogma; he appeared to have stopped because of administrative pressure, but he recently started preaching in his classroom again. The inspiration from this one adult may have been the reason this creationist action happened or it may truly have been a student-initiated response to our effective teaching of evolution. Our superintendent holds this latter opinion. He feels that creationist parents and students are upset because we teach evolution effectively.

THE CRUSADE

The school's Christian Club served as the springboard for the initia-

Steve Randak teaches biology at Jefferson High in Lafayette, Indiana. In his 33-year career, he has received Indiana's Outstanding Biology Teaching Award and the Presidential Award for Excellence in Science Teaching.

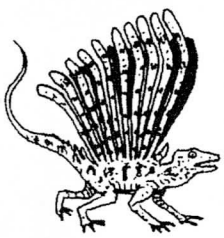
The America Scientific Affiliation and the Evangelical Response to Evolution *continued from page 22*

God's creative activity is "continuous creation". Furthermore, I believe that knowing God through creation is an act of faith and cannot be a conclusion obtained through scientific investigation. However, scientific observation provides no proof of the existence of a creator God; indeed it cannot. Nor does scientific description, however complete, provide any argument against a creator. Since God acts through process, evolution and the theology of creation are perfectly compatible. In fact, I see them as mutually reinforcing. An evolutionary understanding of creation illuminates our theological understanding, and theology places our scientific discoveries in a more comprehensive context and provides necessary moral guidance in the scientific endeavor.

Much of the controversy over evolution and creation seems to rest firmly on the widely held view that evolution and Christianity are in necessary and irreconcilable conflict. However, this conflict view has been thoroughly discredited by both theological and historical scholarship. Christian theologians representing many theological traditions (including evangelicals) have long recognized that a faithful reading of Scripture does not demand a young earth, nor does it prohibit God's use of evolutionary mechanisms to accomplish His creative will. Many evangelical Christians in Darwin's time found no inherent conflict between evolutionary theory and Scripture. In fact, several of the authors of the *Fundamentals* (the

tive. These students organized and obtained hundreds of student signatures and dozens of faculty signatures on a petition requesting that "creation science" be added to the biology curriculum. We found that even among faculty the claim "It is only fair that both sides be presented" was very compelling (even 2 of our 16 science staff signed the petition). The chemistry teacher's signature was missing.

Most of the students and adults that signed the petition do not understand that science has little to do with the playground idea of fairness — that science is a competition of ideas where ideas are accepted on the strength of the supporting evidence. We spent considerable time refuting the scientific claims for creationist arguments both with individual students and in small groups.



However, we quickly discovered that our rejection of the science in "creation science" caused students supporting that position to take our criticism as an attack on their religious beliefs. To quote one student, "It is bad enough that you teach the earth is old; you should not be able to attack my evidence that the earth is young." When these students felt their faith was under siege, they often reverted to nonscientific accusations, such as "evolution is a religion" or "it is only a theory". To a teacher, it is humbling to see students in the midst of gaining critical thinking skills revert to such tactics.

One positive outcome was that the engagement energized all our students. We had more interest in the study of evolution and higher grades in that part of the course than ever before — even though this class had not performed as well as previous classes on the other parts of the course.

The outcome

What is most encouraging about this story is the way our school corporation responded. The superintendent immediately expressed his support for our curriculum and kept us informed of his actions, while the biology staff mutually decided to maintain a low profile in the media. The superintendent educated the school board about the nature of science and the law and, with the help of the science department head, convinced the one wavering board member. The students were respectfully treated by the administration and the school board. At its public meeting, under the glare of local and national television lights, the school board was told politely that the curriculum would not be altered. It all seemed to work in the way a science educator would hope. But there are lingering issues that we see as a mixed outcome.

The warning

When things calmed down and I had some free time, I called Eugenie Scott at NCSE. I was curious to know how our experience fit into the larger picture. What she told me was a shock. I assumed that student-led crusades for "creation science" were common. They are not. I assumed that school boards and superintendents often do the right thing. They do not. I was told that our resolution was the ideal, not the norm, and at that moment I experienced more concern than any time during the many months of controversy.

Children crusading for creation science or "intelligent design" in the name of fair play is a compelling idea to an unaware public. If the tactic is used successfully in school districts less ideal than ours, it will surely meet with success — and science education will suffer.

[Ed: In the spring of 2001, Joe Baker, a high-school student at Pennridge High School in Perkasie, Pennsylvania, also petitioned the school board in his district to include creationism in the science curriculum. The request was not granted, and Baker graduated in May, after nearly a year of student-centered activism to oppose evolution in the curriculum.]

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set of volumes that gave us the term "fundamentalist") accepted some form of evolutionary theory. Even BB Warfield, a theologian who argued forcefully for Biblical inerrancy, accepted the validity of evolution as a scientific description of origins. The principal advocates of evolutionary theory in America included Asa Gray, George Frederick Wright, and James Dana — all committed Christians.

This is of course not to deny that a number of Christian theologians and scientists both past and present have had significant objections to certain aspects of evolutionary theory. Charles Hodge, a respected and influential theologian at Princeton in the early 1800s, is an example of a highly competent scholar who saw Darwinian evolution as incompatible with the Christian faith. Scholarly theological critiques of evolution such as his, however, provide no basis whatsoever for propounding a "warfare" metaphor for the relationship of evolution and the Christian faith. The history of the evangelical Christian response to evolution is detailed in a number of excellent scholarly books. These include *The Post-Darwinian Controversies* by James R Moore (Cambridge [UK]: Cambridge University Press, 1979), *Darwin's Forgotten Defenders* by David N Livingstone (Grand Rapids [MI]: Wm B Eerdmans Publishers, 1987), and *Evangelicals and Science in Historical Perspective*, edited by David N Livingstone, DG Hart, and Mark A Noll (Oxford: Oxford University Press, 1999).

Defining Evolution

John Wilkins

The term "evolution" as we now use it commonly refers to change of species over time and is usually associated with Darwin's theory of the descent of species by natural selection. (Richards 1992a: 95)

Introduction

When we try to explain evolution to those who do not know much about it, one of the problems we have is the definition of what counts as evolution. In part, this is because some of the definitions found in the scientific literature, including textbooks and popularizations of evolutionary theory, use technical terms that do not seem to convey to the public that evolution explains the diversity of living forms. In part, it is also because the popular idea of evolution as it is found in dictionaries, science fiction, and philosophical potboilers is a holdover of concepts that have long been abandoned in the biological sciences, if not in theology or in the "science" of popular media.

It is important to understand these various definitions relative to each other and to show that accepting evolution as defined in the sciences does not commit one to accepting another form, as proposed by theology or philosophy. In particular it is important to realize that, contrary to many nonscientific uses of the term, evolution is neither a progressive process — modern theory does not make it inevitable that the latest is the best — nor can we expect to be able to predict the "next step" in evolution.

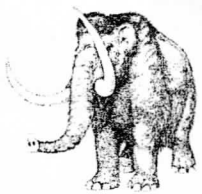
To understand the current meaning of the word "evolution", it is useful to take a journey through history and trace the various meanings of the word "evolution" as the modern view takes form.

The history of "evolution"

Evolution before Darwin

Initially, the Latin word *evolutio* meant the unrolling of a scroll. This gives the flavor of the inevitable recitation of a story or message. The story is already written, and all that is required is to "read off" the message in an orderly fashion from beginning to end. "Evolution" was therefore a natural term for the early developmental biologists, such as the Dutch entomologist Jan Schwammerdam in 1669 and Charles Bonnet in the 1740s, to apply to the development of an embryo (Richards 1992a, 1992b; Mayr 1982). This appears to be the first recorded use of the term in a biological context.

Early evolutionists, like Jean Baptiste de Lamarck and Erasmus Darwin (Charles's grandfather), believed that species also changed in such a predetermined fashion (by ascending the Ladder of Nature, called the *scala naturae*). The term "evolution" was applied to the transmutation of one species to another in the early years of the 19th century, by Lamarck's disciple Etienne Geoffroy Saint-Hilaire and Geoffroy's student, embryologist Etienne Serres, to describe such views. Charles Lyell, in the influential second volume of his *Principles of Geology* (1833),



I believe that one of the most important contributions of the "Statement on Creation" is to combat the tired portrait of evangelical Christians as being driven by their acceptance of the truth of the Bible to oppose the theory of evolution — if not the whole of the modern scientific enterprise. The reality is that there is a very wide spectrum of views, which the ASA statement reflects. Furthermore, people often assume that acceptance of evolutionary theory is a function of the "liberalness" of one's theology. On the contrary, as James R Moore observed, in the late 1800s Darwinism was "accepted in substance only by those whose theology was distinctly orthodox" and rejected by those with more liberal theologies (see the preface of *The Post-Darwinian Controversies*).

There is an extensive scholarly record on the philosophical and theological implications of evolutionary theory by Christian scholars. The fruits of these efforts need to be more widely known and discussed. There is a desperate need for the heated conflict that has surrounded the issue of evolution to cool down. The evolution/creation "warfare" view has effectively inhibited productive popular dialogue on important theological and scientific issues — it is now time to finally lay it to rest!

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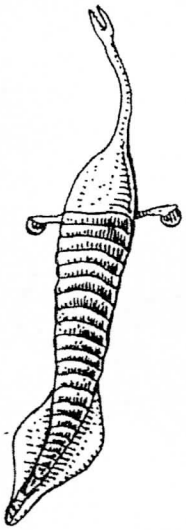
which Darwin received during the voyage of the Beagle and which prepared him to formulate an evolutionary view, attacked Lamarck and Geoffroy on transmutation, and borrowed the term "evolution" from Serres to describe their views. By 1833, then, when Lyell's work was published, it had become common usage to equate "evolution" with the transmutation of species.



So evolution originally referred to the supposed series of changes that a species was predetermined to undergo, in the same way that an embryo is preprogrammed to develop. Such views persisted into the first half of the 20th century, despite Darwin's theory, which asserts no such predetermined series or stages. These views are called *orthogenetic* ("straight line") theories of evolution (Mayr 1982) and are in great disfavor today. All that persists of that original meaning is that species change over time. However, the use of "evolution" in its original sense is still common in astronomy to describe the sequence of stellar development (Gould 2000).

Darwin's view of evolution

Before Darwin, transmutation of species generally meant that a species as a whole changed into a more complex species through some (unspecified) process. Darwin intended no such meaning when he introduced evolutionary theory in *On the Origin of Species* (1859). First, he realized that change was not necessarily a process of increasing complexity or perfection. Second, he proposed a specific mechanism that explained why new species were different in appearance and behavior — natural selection. Third, and most important, Darwin saw that the origin of a new species did not involve an entire species' undergoing change. He saw that the origination of a new species might occur in only a part of the parental species — in a subpopulation. The remaining populations of the original species could remain unchanged.

Species to Darwin were just permanent varieties. The species he had studied in the wild, and those he read about in the work of others, and most of all his alternately loved and hated barnacles (he spent 9 years cataloguing modern and fossil barnacles before publishing the *Origin*), all exhibited variation, including what were then called "races", or subspecies. This is the meaning of "races" in the subtitle of the *Origin* ("The preservation of favoured races in the struggle for life") — varieties within a species.

The fact that speciation occurred in subpopulations implied that species shared common ancestry with others that had split off from the same or related parental stock. So Darwin concluded that there was an "insensible series" of varieties — or what we would speak of today as genetic variants — from geographic differences to fully distinct but interfertile varieties or races, to distinct and mutually infertile species. This conclusion is not generally accepted today. The contemporary view is that species arise not from genetically distinct races, but from local and isolated populations that may initially be much the same genetically as the main populations of a species.

However, Darwin did not use the word "evolution" in the first edition of the *Origin* (although he used "evolving" in the sense of "unfolding" in the final paragraph). Only later, in the *Descent of Man* (1871; see Gould 2000), was Darwin forced to adopt the term "evolution", partly because it was in common use, and also because his associate Herbert Spencer had used the term two years before Darwin went public on evolution. The fact that the ideas he outlined are often included in the general understanding of "evolution" causes some confusion, which can be alleviated by carefully distinguishing among the components of Darwin's theory.

The main components of Darwin's theory are

1. that species change (*transmutation*): Darwin's preferred term was "descent with modification");

e´ vo·lu´·tion

Etymology: Latin *evolution-*, *evolutio* unrolling, from *evolvere* Date: 1622

1 : one of a set of prescribed movements
2 a : a process of change in a certain direction : UNFOLDING
b : the action or an instance of forming and giving something off : EMISSION
c (1) : a process of continuous change from a lower, simpler, or worse to a higher, more complex, or better state : GROWTH
(2) : a process of gradual and relatively peaceful social, political, and economic advanced : something evolved
3 : the process of working out or developing
4 a : the historical development of a biological group (as a race or species) : PHYLOGENY
b : a theory that the various types of animals and plants have their origin in other preexisting types and that the distinguishable differences are due to modifications in successive generations
5 : the extraction of a mathematical root
6 : a process in which the whole universe is a progression of interrelated phenomena

From *Merriam-Webster OnLine* **<http://www.m-w.com/>** June 19, 1999

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2. that related species are descended from a common ancestor (*common descent*);
3. that the main mechanism by which species become distinct from one another is *natural selection*; and
4. that species arise geographically near to their ancestor (*biogeography*).

His theory had several other components, some of which are now rejected (his model of inheritance is the main one), but they are minor components of his evolutionary theory and can be ignored here (Wilkins 1998).

In the book that effectively crystallized the Modern Synthesis of genetics and Darwinism, Ronald Fisher began by saying

> Natural Selection is not Evolution. Yet, ever since the two words have been in common use, the theory of Natural Selection has been employed as a convenient abbreviation for the theory of Evolution by means of Natural Selection, put forward by Darwin and Wallace (Fisher 1930: xi).

Fisher may be historically inexact, but there is a solid point here: natural selection is what many people mean by "evolution". This impression is reinforced by the writings of such luminaries as Richard Dawkins, who makes selection the core of his view of evolution.

But natural selection is also the mechanism by which species do *not* change. Selection only forces change if a population is not well-suited to competing for resources or overcoming risks in its local environment. If a species is well-adapted, then selection will inhibit change; this is called *balancing selection*. Thus, we have to distinguish between the mechanism that is sometimes an agent for change from the process of change itself (*see Figure 1*).

Before Darwin, the prevailing view was that species are *types*. A type was both a means of identifying and classifying an organism and also a force that caused it to exhibit certain physical characteristics. The type made that organism what it was. Organisms that varied too far from the type were "monsters", degradations of the type (for example, a French biologist contemporary of Linnaeus, Georges Buffon, thought that evolution was a degradation of a number of created types; Lovejoy 1959). Entire species were called monsters, because they were too far removed from the central type of a family or genus of organisms. Such central types were called the *archetype* by Richard Owen.

Darwin imagined the archetype as an actual historical ancestor — that the variation present in an ancestral population could be the basis for descendant populations both to share important identifying characteristics and to differ significantly in some ways from the ancestor. Furthermore, he saw that neither the archetype nor the type of a single species exerted any influence on the subsequent history of a lineage. For Darwin, types were just the most common form of a species or genus. The type might remain stable, or it might change. In modern terms, we would say that the type is just the *mode* of the distribution of species' characters. What causes the type to remain stable or to change is another matter. Whether the type changes or remains stable, the cause might be selection or some other process, such as random drift.

Evolution after the discovery of the gene

Modern definitions of evolution are based on the fact that all organisms living in breeding populations are generally quite similar, but no two individuals are exactly alike. They have differences due to their heredity, their upbringing, and their life histories. Some of these differences are of evolutionary significance: all of them involve their genes in some way; their dispositions to grow in particular ways, their ability to react to and make use of their environments, and even their abilities to deal with disease and injuries are genetically influenced, but not necessarily determined. Selection acts at base on genetic differences among organisms, not on an individual gene. Moreover, these *differences* have to occur in populations by virtue of the normal processes of genetic recombination in reproduction.

Darwin's theory was extended by the so-called "biometrics" movement (which is the foundation of

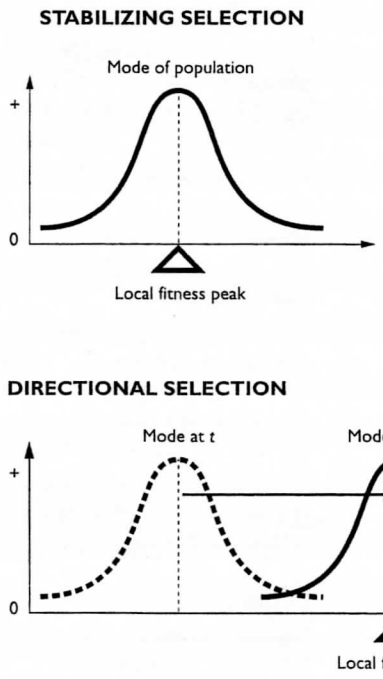


FIGURE 1

Selection can cause evolution or it can stop it, depending on whether the population that is evolving has the best possible combination of traits for the local environmental conditions — the local fitness peak. If it does, then selection is called "stabilizing selection" and favors those at or close to this peak. If the population is not at this peak, then selection will shift the population profile so that it approaches the fitness peak; this is called "directional selection". However, not all fitness peaks can be reached through selection. For selection to act in this way, the genes that could provide a better combination of traits must arise through mutation or recombination.

both statistics and population genetics) and melded together with Mendelian genetics beginning about 1920. This culminated in the Modern Synthesis (henceforth, the Synthesis) forged in the works of Fisher, Theodosius Dobzhansky, Ernst Mayr, JBS Haldane, Sewall Wright, and Julian Huxley between 1930 and 1942. For the architects of the Synthesis, it was natural to use the powerful set of theoretical and analytic techniques of genetics to define evolution (see references and discussion in Bowler 1984). Thus, Huxley, summarizing the views developed by Dobzhansky and others in the development of the Synthesis, wrote:

> Mendelism is now seen as an essential part of the theory of evolution. Mendelian analysis does not merely explain the distributive hereditary mechanism: it also, together with selection, explains the progressive mechanism of evolution (1942: 26)

and

> [W]hat evolves is the gene-complex; and it can do so in a series of small if irregular steps, so finely graded as to constitute a continuous ramp (1942: 68).

The "allele-frequency" definition of evolution has survived to become the "standard" definition in textbooks and discussions about the nature of evolution. Here is a more-or-less random collection of quotations from various sources to illustrate how different views have developed based on this initial insight.

> Biological evolution ... is change in the properties of populations of organisms that transcend the lifetime of a single individual. The ontogeny of an individual is not considered evolution; individual organisms do not evolve. The changes in populations that are considered evolutionary are those that are inheritable via the genetic material from one generation to the next. Biological evolution may be slight or substantial; it embraces everything from slight changes in the proportion of different alleles within a population (such as those determining blood types) to the successive alterations that led from the earliest proto-organism to snails, bees, giraffes, and dandelions (Futuyma 1986: 7).

> [E]volution can be precisely defined as any change in the frequency of alleles within a gene pool from one generation to the next (Curtis and Barnes 1989: 974).

> The fundamental evolutionary event is a change in the frequency of genes and chromosome configurations in a population (Wilson 1992:75).

> On the simplest perspective of all, biological evolution is analyzed initially as changes in allelic frequencies at a single locus. More complicated phenomena must be explained by means of combinations of these minimal units (Hull 1992: 185).

> Natural selection deals with frequency changes brought about by differences in ecology among heritable phenotypes; evolution includes this as well as random effects and the origin of these variants (Endler 1992: 221).

> Since evolution may be defined as cumulative change in the genetic make-up of a population resulting in increased adaptation to the environment, the fundamental process in evolution is change in allele frequency (Hartl 1988: 69).

> Organic ... evolution, or biological evolution, is a change over time of the proportions of individual organisms differing genetically in one or more traits; such changes transpire by the origin and subsequent alteration of the frequencies of alleles or genotypes from generation to generation within populations, by the alterations of the proportions of genetically differentiated populations of a species, or by changes in the numbers of species with different characteristics, thereby altering the frequency of one or more traits within a higher taxon (Futuyma 1986: 551).

Notice that some say that observable change in the frequencies of alleles is sufficient to define evolution, while others, such as Futuyma, think it necessary to go into more detail. For the purpose at hand, the dispute is unimportant.

A more important controversy, however, is between the proponents of the allele-frequency definition and those who reject it altogether as too narrow:

> I pointed out more than a decade ago (1977) that the reductionist explanation, so widely adopted in recent decades — evolution is a change in gene frequencies in populations — is not only not explanatory, but is in fact misleading. Far more revealing is the definition: "Evolution is change in the adaptation *and* in the diversity of populations of organisms" (Mayr 1988: 162).

> Evolution may be defined as any net directional change or any cumulative change in the characteristics of organisms or populations over many generations — in other words, descent with modification.... It explicitly includes the *origin* as well as the *spread* of alleles, variants, trait values, or character states. Evolution may occur as a result of natural selection, genetic drift, or both; the minimum requirements are those for either process.

Natural selection does not necessarily give rise to evolution, and the same is true for genetic drift (Endler 1986: 5).

> Population geneticists use a different definition of evolution: a change in allele frequencies among generations. This meaning is quite different from the original; it now includes random as well as directional changes ..., but it does not require the origin of new forms. It is roughly equivalent to microevolution (subspecific evolution; macroevolution involves major trends, or trans-specific evolution...). Unfortunately, the use of the population genetics definition often results in an overemphasis on changes in allele frequencies and an underemphasis on (or no consideration of) the *origin* of the different alleles and their properties. Both are important in evolution....An additional problem is that, for quantitative genetic traits, the frequencies of alleles at many contributing loci can change while the overall mean and variance of the trait remain roughly constant (Endler 1986: 7–8).

And even those who stress the genetic character of evolution sometimes take a broader view:

> Evolution is a directional and essentially irreversible process occurring in time, which in its course gives rise to an increase of variety and an increasingly high level of organization in its products (Julian Huxley cited in Newman 1956: 278).

These examples illustrate that there is a wide range of approaches to defining evolution and that "experts" disagree over what to emphasize in their definitions. Some think that genes are a very good place to start, while others insist that important concepts about evolution are not captured in allele-frequency definitions.

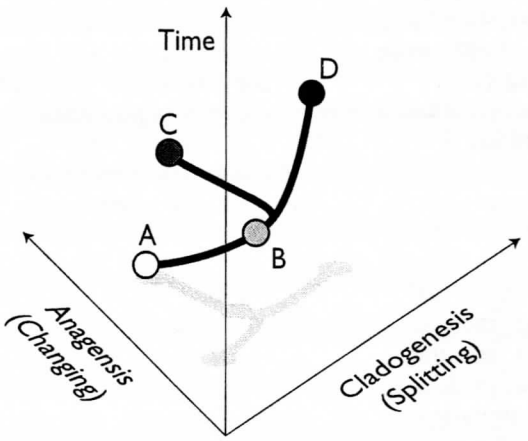


FIGURE 2
The difference between anagenesis and cladogenesis. Species A becomes species B through a series of changes to its gene frequencies in anagenesis, but no phylogenetic tree is formed. If two separate lineages change, or one of them does, so that each branch is isolated from the other, then the splitting of the lineage causes cladogenesis, resulting in species C and D and forming a phylogenetic tree.

However, when it comes down to the nature of the evolutionary process, much of this is a matter of semantics — what to spell out and what to leave implicit. Despite the superficial differences in these descriptions, the apparent disagreements do not usually entail differences of opinion about what happened in the course of evolution, at least not in broad outline.

Issues in evolution

Macroevolution

Creationists, and anti-evolutionists in general, frequently claim that macroevolution is not deducible from the allele-frequency definition of evolution. They very often claim that there are barriers to changing beyond the "kind" (an ill-defined term with no fixed meaning, which seems roughly equivalent to "species") — although such change has been observed many times as new species have been observed to evolve from old ones. This is the lowest level of macroevolution, as we will see in a moment.

Some anti-evolutionists even allow for evolution of one species into another, but deny that the emergence of "major" groups, such as families or orders in the Linnaean hierarchy, can be the result of microevolutionary change. Often, this concession to microevolution is made only to accommodate the species diversity we see today from the necessarily restricted variation among the original "kinds" that are supposed to serve as the founding populations at the Creation or that were carried on the Ark.

Even among scientists, the term "macroevolution" is a vague concept. Many authors think that there is a qualitative difference between adaptive evolution and the origins of higher taxa or forms. In the original formulation, Y'uri'i Filipchenko (in 1927) used the term to mean origination of a novel species by splitting from an ancestral species — what we now call *speciation or cladogenesis*. Today it is more widely used to mean "large-scale" change, such as the evolution of novel "body-plans", "grades" of ecological niche specialization, or "key innovations".

Those who prefer the allele-frequency definition of evolution argue that every such novelty began as minor variations on a theme in the origination of a slightly different species and that large-scale changes are the result of continued evolution of this kind over large periods of time. Often they think that evolution is always gradual (*anagenetic*) and that evolutionary trees (*phylogenies*) are just the additive sum of these gradual changes. Nobody denies either cladogenesis or anagenesis these days, but there is a fair bit of debate over the right mix (*see Figure 2*).

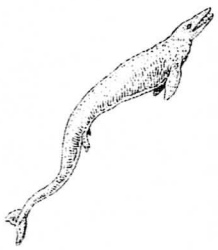
Varieties of evolution

Let us now look at the surviving meanings of evolution in order of

increasing exactness, along with the names of some of the scientists with whom the ideas are associated (Bowler 1983, 1984; Mayr 1982; Mayr and Provine 1980; Ruse 1979/1999; *see Figure 3*).

I take the broadest definition of biological evolution to be:

- *Transmutation (descent with modification)*: This is the notion that new species emerge from existing species and that all existing species are the product of change in older ones. Early transmutationists: Lamarck, Erasmus Darwin (Charles's grandfather), Saint-Hilaire, Robert Chambers (author of the *Vestiges of Creation,* first published in 1844), and Charles Darwin. This view was common by the 1830s, and Darwin did not invent the idea.



A slightly narrower conception of evolution:

- *Common ancestry:* Related species have changed from a common ancestor species; that is, the reason that species are similar and are related in classification is because they have evolved from a shared ancestral species. This is also called *phylogenetic change,* or more simply, *phylogeny.* In a limited way, both Lamarck and Erasmus Darwin proposed common ancestry, but the first complete account was propounded by Charles Darwin.

Narrower still:

- *Biogeographic distribution:* Related species arise as geographic neighbors; this is the view that no new species arises except in close contact with its most related species. This view was proposed by Alfred Wallace and Charles Darwin. Of course, the fact that new species arise as biogeographic neighbors is explained by common ancestry, but Wallace formulated this model before the common ancestry model was published.

Evolutionary theory also has some strictly *Darwinian elements*:

- *The struggle for existence:* More individuals will be born than the environment can support, so not all organisms survive to reproduce. Darwin derived this idea from Lyell, Thomas Malthus, and Alphonse de Candolle.
- *Variation among individuals:* All organisms generate offspring that are slightly different from each other, so there is variety within all populations. This is one of Darwin's original contributions to biology, although he was influenced by de Candolle.
- *Natural selection:* The local environment is more favorable to organisms with a particular variety or combination of traits within a species. Those so favored survive longer and reproduce more, resulting in that variety's becoming more common in subsequent generations than other varieties in the species. Darwin was not the first to recognize natural selection, but he was the first to use it as a mechanism of evolution.
- *Sexual selection:* In sexually reproducing species, mate choice sustains display traits — the sex that needs to compete for mates will show variations in the characteristics associated with this competition. Darwin is the sole author of this mechanism of evolutionary change.

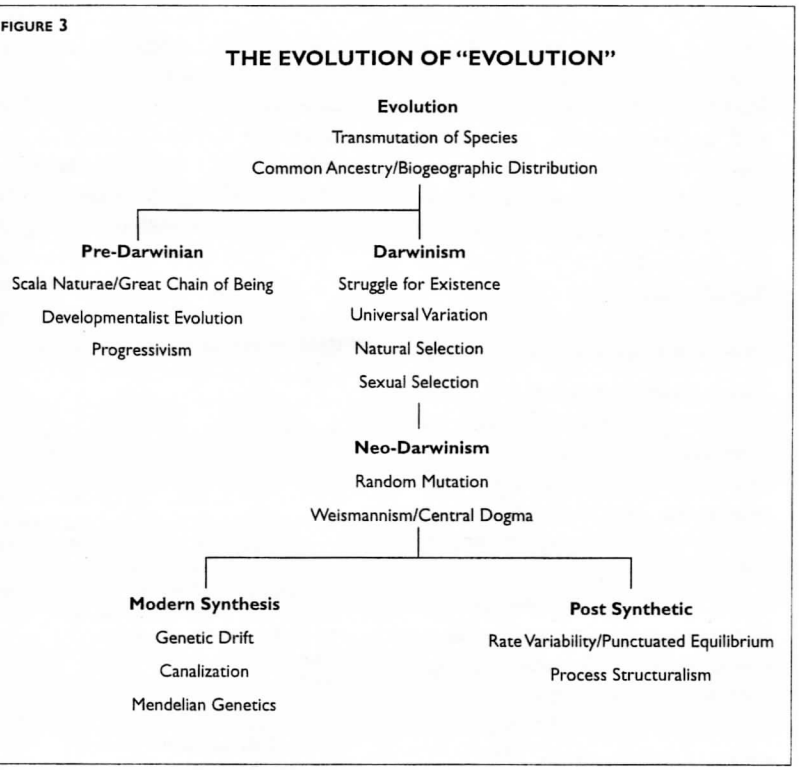
The *Neo-Darwinian elements* are:

- *Random mutation,* or *blind variation:* Changes arise in genes at random, without respect to the survival needs of organisms and species.
- *Weismannism:* Information from the somatic cells of the body is not inherited. This principle was proposed by August Weismann in 1882. The molecular genetic equivalent, due to Crick and Watson, is the *Central Dogma* of genetics: information is not passed from proteins to nucleotides (DNA or RNA).

The *synthetic elements* are:

- *Drift:* Many changes occur that are not selected for, due to sampling accidents in population. Models of drift were sketched in the 19th century by Darwin, George Romanes, and Moritz Wagner, but they came into their own with the advent of the Synthesis. There are different (and not necessarily incompatible) models of drift. One is genetic drift (after Sewall Wright). This includes genetic neutralism, which involves selectively neutral mutations becoming fixed in a population (after Motoo Kimura). This includes "founder effect" models of speciation, formulated by Mayr and Hampton Carson.
- *Canalization:* Developmental processes are robust and resist change. Models of canalization were proposed by Conrad Waddington and Ivan Ivanovich Schmalhausen. This notion is also sometimes called the "developmental constraints" model of evolution (see Schlichting and Pigliucci 1998).
- *Mendelian genetics:* Heredity is the passing on

FIGURE 3



of discrete units of genetic material, which recombine in certain ways and frequencies, and which are either dominant or recessive. As the name implies, Mendelian genetics derive from the work of Gregor Mendel, as "rediscovered" by Correns, De Vries, and Tschermak in 1900 (Stern and Sherwood 1966). Mendelian genetics was incorporated into the synthesis by Fisher and Haldane.

Postsynthetic elements include, but are not restricted to:

- *Rate variability:* Evolution occurs at many different rates, from the instantaneous to the gradual, all of which are gradual and continuous at some scale. For example, GG Simpson (1944), Mayr (1942), and more recently, Niles Eldredge and Stephen Jay Gould (1972) in their famous punctuated equilibria model, examine how the pace of evolutionary change can vary under different circumstances.
- *Process structuralism:* Some changes are biased by their structural relations and form. The foundation of process structuralism was laid by D'Arcy Thompson (1917) and recently revived by Brian Goodwin (1994), and others. Complex structures and systems are not free to vary independent of their relationships with other components of the complex.

The long inferential chain

It is very hard to work out the implications of the effects of processes of local variation on large-scale ones. If gene frequency changes in local populations are the foundation for all evolution, it still may not be evident that a new species will arise, that there will be some trends in evolution, or that the patterns of life at any one time will reflect a process of speciation and retention of novelties in large groups.

In part, this is because the chain of inference from population-level genetics to macroevolution is a very long one. Even if genes determined everything about species, we would not be able to generalize and elaborate these facts with any clarity or detail. We are limited in our ability to take all these things into account and lack the time and skills to work it all out fully. Reconciling the conservative character of genetic transmission with the tremendous potential for evolutionary change that is inherent in the genetic variation among individuals is particularly hard for those who lack a full appreciation of the way genes recombine and affect the development of organisms. This is especially true of secondary and post-secondary students and the general populace.

The allele-frequency definition, if adequate, would leave us unsatisfied that evolution really *had* been explained. Geneticists have observed in small scale a general resistance of the molecular components of the genome to change from the "norm" or "wild type". For this reason, if any biologist were to be anti-evolutionist, it would typically be one who works at the molecular level, such as a molecular geneticist or biochemist.

Allele *frequencies* change due to environmental factors acting on the population, to the relationships of mating within and between populations, and to sheer chance effects. To be able to predict accurately what will happen to a population in the future, one would need to have a full list of all the external influences on the population, along with knowledge of the size and structure of the population itself, including the mating behavior of the organisms within the population. Moreover, as Gould has emphasized (Gould 1989, 1996), contingency plays a large part in evolution, so that even if we had all this information, we could at best provide probabilities that specific outcomes might occur. The important thing to recognize is that we must consider the phenomenon of evolution simultaneously at many levels — the ecological, climatological, geological and developmental, as well as genetic.

Progress, or a lack of it

Since Lamarck, the view that evolution is progressive has been a recurring theme in biological writing. Even before Darwin published the *Origin,* his friend Herbert Spencer wrote that there was a general law of the "homogenous to the heterogeneous" — that is, life and the universe in general inevitably became more complex. Although some think differently (Ruse 1996), I believe that Darwin came to a contrary conclusion: that evolution had no direction or inevitability. Sometimes it seems that directionality does occur, but often this pattern is due to our own predilection for noticing only the emergence of large, obvious taxa, as when we refer to the "Age of the Reptiles" or "Age of the Mammals".

Many people believe that evolution necessarily leads to complexity or specialized forms of life. Most organisms, however, are single-celled, and yet their adaptations to specific environments and predation are anything but "simple". Multicellular life is not the goal of evolution: indeed, it is a statistical blip in the overall diversity of living things. Of course, any increase over nothing is an increase, so it is obvious there has been *some* innovation in the course of evolution on any scale one cares to measure, but whether it progresses is the subject of massive debate (Nitecki 1988).

One form of progress that is generally accepted by most commentators is the "arms race" or "escalation" form of evolution, where two or more species coevolve as they attempt to get the edge over their predators or prey (Vermeij 1987). This is also called the "Red Queen" effect, from the character by that name in *Through the Looking Glass* who has to run as hard as she can just to stay in one place (Van Valen 1976).

However, the common misunderstanding is that there is a "next step" in evolution (usually, human evolution). This is our old friend the developmental sense of evolution, the *scala naturae.* Although popular with science fiction screenwriters, it has no scientific basis. It may be that if there is a next species that evolves from humans, it will be a herbivorous and apelike animal that survives just fine in post-apocalyptic conditions. Brains, for example, take a lot of energy to maintain. Brains bigger than ours may turn out to be a liability, not an asset.

What Evolution Includes

To summarize, we can see that the concepts expressed by the word "evolution" have themselves evolved. There is change, there is phylogeny (the multiplication and extinction of lineages), there is selection and drift (the dynamics of reproducing populations), and there is the genetic and biological basis that underlies all these changes — all these (and more) have fallen under the rubric "evolution". Eli Minkoff (1983: 575) consolidated the contemporary understanding this way:

> Evolution
> - Originally, a synonym for ontogeny....
> - According to Lamarck and his contemporaries, the unfolding of (evolutionary) potentials as each species ascends the *scala naturae*.
> - From 1809 on, the transformation of one species into another; phyletic evolution.
> - According to many geneticists..., changes in the gene frequencies of populations.
> - Anagenesis plus cladogenesis. Phylogeny and the changes in gene frequencies that produce phylogenetic change.

In the nearly two decades since the publication of Minkoff's book, there have been many exciting developments in evolutionary research. Models of evolutionary change based on our emerging understanding of developmental and regulatory genes, transposons, somatic hypermutation, endosymbiosis, and other previously unrecognized mechanisms for producing and maintaining biological variation present exciting new opportunities for evolutionary biology. Although the precise role and contribution of each of these mechanisms to the pattern of evolutionary change is still unfolding, it is certain that they will add to a fuller understanding of evolution as well as a new definition of evolution that incorporates these mechanisms.

Acknowledgments

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My Experiences of Evolution in School

Brandon Seger

After school had started last fall, I knew that there would be the momentous day later in the year when the biology class would consider evolution. In my Southern California community, there are many religious students, and I anticipated some problems when students at my school who opposed evolution for religious reasons came to class in the week the evolution unit would be presented. Early in the year I spoke with my biology teacher. At first I was concerned that we might not be doing the evolution unit, since a couple of the other biology classes were not going to.

"So after the second semester, we will get into more of the animal chapters?"

"Yes, like the chordates and the invertebrates", replied my teacher.

"As well as evolution?"

My teacher smiled and told me, "Yes, we will be getting into that as well."

A few weeks after, I brought up the issue again. Since I knew that some of the students in the class bitterly rejected the theory of evolution, I asked him about some of his experiences in earlier years of teaching. He informed me that the previous year, when he was teaching the evolution chapter, one girl came up to him after class and presented him with the admonition, "You're going to hell!"

A few months passed, and I had no more conversations with my teacher about the issue. However, about a week before the beginning of March, the teacher showed us his schedule. I saw on the calendar that the following week would be spent studying the evolution chapter. After he presented the schedule, I came up to speak with him more about the following week's plans for teaching the evolution chapter and to learn more about his past experiences. In this conversation, my biology teacher informed me that the chronology of events is the same each year: the first day, the students are very quiet, and then the next day, the students come back outraged. He assumes that the students go home to their parents and then return the next day, fortified by their parents' opposition to the chapter, but this year it was to be a little different.

On the first day of the evolution unit, I walked to my biology class early and sat down at my desk. I watched as the students came in and grabbed the evolution chapter packet, piled in a stack near the entrance door. Only one student class growled in displeasure as she picked up the packet and glanced at the bold, black title "Evolution".

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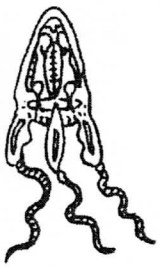

After the bell rang, the teacher walked to the center of the room, and before doing the lecture, he presented a "disclaimer", as he called it. In this disclaimer, he told the class that everyone has a right to his or her personal beliefs, that the purpose of the day's presentation was not to change anyone's beliefs, but that it is state law to teach the chapter. All the students sat quietly and listened to the teacher's speech. The first day ran more smoothly than I had anticipated, but it was what the teacher had experienced in the past.

On the following day, our teacher showed a section of the Carl Sagan video *Cosmos* in class. In this particular video clip, Sagan discussed the origin of life and commented on evolution. At one point in the video, there was an animated scene that traced the path of life on the earth, showing animals evolving from primitive organisms to modern ones. Just as this video was finishing, a burst of laughter came from a couple of students from the opposite side of the room. They were apparently laughing because they found the material to be unbelievable.

For the rest of the unit, we completed the worksheets in the study packet, as well as a myriad of labs (on topics such as divergent evolution and variations in a population). Through it all, rather than passionate outbursts from the students opposed to evolution, as I had originally expected, these students simply made fun of evolution. On the day of the variations lab, a group of students was laughing and ridiculing evolution ("Hey teacher, since we have long fingers, does that mean we evolved from ducks?" and "If evolution is true, why don't I look changed in the morning?"). Later on, as the bell rang and the students left the room, I was headed out when I heard my teacher say with vexation, "Man, they don't pay attention. They're expecting to be wolves in the morning. It doesn't work that way."

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The other notable event of the evolution unit was the test, made up of 66 multiple-choice questions and an essay. For the essay, the students had to write about either the differences between Lamarck's and Darwin's evolutionary theories or the evidence for evolution. I chose to write on the evidence, so I could summarize the evidence and provide some of my own commentary.

I asked the teacher about the results, and he informed me that there were some students who doodled in their study packets (such as drawing the face of the devil), as well as a few students who wrote their entire essay explaining why they thought evolution is false.

These were my unfortunate experiences of learning evolution in school. I hope that supporters of evolution can improve the situation by promoting a better public understanding of evolution, and science in general for that matter. The willful rejection of evolution by students is more tragic because they never learned what evolution really is. They just retreated into their ignorance and ridiculed ideas that they did not understand.

[This article is adapted from the version currently available at the Darwin Day web site <http://darwin.ws/day/features/seger1.btml> and is reprinted with permission.]

PSYCHIC BOOK REVIEWING?

Readers usually expect that someone who writes a book review has actually *read* the book he or she is discussing. However, Pat Goltz, who submitted to Amazon.com® a review of *Evolution: The Triumph of an Idea* by Carl Zimmer, told the readers that he or she had not read — and had no intention to read — the book under "review", writing:

> This will not be a traditional review because I have not actually read the book. I have no intentions of doing so. I merely want to comment on some rather obvious facts. The book is subtitled "The Triumph of an Idea". This can be highly misleading simply because the REASON for the triumph is that the people promoting the idea have managed to flummox a sizeable portion of the population. Indeed, it is an idea that has had profound impact on the human race. HOWEVER, the theory of evolution has no basis in fact, and I am well aware that Stephen Jay Gould has been less than totally honest with the public about this. It is actually unconstitutional for this group to have been given access to our public television system for their ideas, because these are RELIGIOUS ideas. We can neither prove nor replicate any experimental results on evolution, and attempts to do so have been a dismal failure. There is nothing scientific about it; it is all pure speculation. So if you want to read a "feel good" exposition of a bunch of flawed ideas, then this may well be a good place to start. But I will save my money. Perhaps, in my "copious spare time", someday I'll check it out from the library and take it out of circulation for a few weeks. But I won't spend a dime on purchasing one! Just ask yourself: of which other theory is the question commonly asked, "Do you BELIEVE in the theory of evolution?" Folks, this is a clear demonstration of the fact that evolution is a religious belief, not a scientific theory. So, caveat emptor on this one.

When an alert reader complained to Amazon.com® about this review, an employee responded:

> Thank you for writing to Amazon.com® to bring this review to our attention. Please rest assured that these comments have been removed from our database and will shortly disappear from the web site.
>
> We do exert some editorial control over our customer reviews and strive to block these kinds of reviews. Our intention is to make the customer review forum a place for constructive commentary and feedback, so reviews that fall outside these guidelines are removed from the web site.

Amazon.com® did indeed remove the "review" within hours of sending out that response.

The Big Tent and the Camel's Nose

Eugenie C Scott
NCSE Executive Director

[*In January 2001, "intelligent design" creationist William Dembski, author of* The Design Inference, Intelligent Design: The Bridge Between Science and Theology, *and the forthcoming* No Free Lunch, *posted an essay entitled "Is intelligent design testable?" on the* Meta *discussion board, an on-line forum devoted to discussion of science and religion <http://www.metanexus.net> (Dembski 2001a). In his essay, Dembski attributed to me the view that intelligent design is untestable, and then proceeded to argue — unconvincingly, to my mind — to the contrary. My response follows.*]

William Dembski has responded to my January 18 Tom Jukes Memorial Lecture at UC Berkeley. Others are responding on *Meta* and elsewhere to the focus of his essay, whether natural selection is testable, and I shall not do so here. I should, however, comment on views attributed to me.

I was not really dealing with the testability of "intelligent design" (ID), though that is the impression one might get from Dembski's essay. In this public lecture, I discussed both traditional "creation science" and neocreationism, and compared them. I talked about Behe's irreducible complexity idea, and Dembski's Design Inference, and illustrated the religious motivation for fighting evolution. I am not especially concerned with whether ID is testable. I look at the testability of ID the same way I look at the testability of traditional young-earth creationism (YEC): YEC can make empirically or logically or statistically testable statements (the earth was covered by a body of water, all living things are descended from creatures that came off a boat) but its foundational claim that everything came into being suddenly in its present form through the efforts of a supernatural creator is not a scientifically testable claim. I shall let theologians argue over whether special creationism is good theology, but invoking omnipotent supernatural causes puts one smack out of the realm of science, protestations of the validity of "theistic science" notwithstanding. One cannot use natural processes to hold constant the actions of supernatural forces; hence it is impossible to test (by naturalistic methodology) supernatural explanations (Scott 1998). Whether a supernatural force does or does not act is thus outside of what science can tell us.

Similarly, ID can make empirically or logically or statistically testable claims (certain structures are irreducibly complex; by using probability arguments like the "design filter" one can detect design) but the foundational claim that a supernatural "intelligence" is behind it all is not a scientifically testable statement. (And please, let us be grownups here: we are not talking about a disembodied, vague "intelligence" that *might* be material, we are talking about God, an intelligent agent who can do things that, according to ID, mortals and natural processes like natural selection cannot. Not for nothing does Dembski say that ID is the bridge between science and theology.)

In my talk, I was not deploring the untestability of ID *per se* but the fact that its proponents do not present testable models. I was referring to the fact that ID proponents do not present a model *at all* in the sense of saying what happened when. At least YEC presents a view of "what happens": the universe appeared a few thousands of years ago, at one time, in its present form; living things are descended from specially created "kinds" from which they have not varied except in trivial ways; there was a universal flood that produced the modern geological features; and humans are specially created apart from all other forms. So what happened in the ID model?

I said (and have said repeatedly) that the message of ID is "evolution is bad science", without providing

an alternative view of the history of the universe. This is not trivial: in books by Philip Johnson, as well as in Jonathan Wells's new *Icons of Evolution* (2000), teachers are told that they should be teaching students about how evolution is a weak, unsubstantiated "theory in crisis", to quote former anti-evolutionist Michael Denton.

The theories of astronomical, geological, and biological evolution attempt to explain evidence demonstrating that the universe has been around for a long time and has gradually unfolded from a different form to its present form. There are lots of details in there, about when and how things happened: when our galaxy formed, when other galaxies formed, when earth formed and out of what matter, when warthogs or whortleberries or liverworts came to resemble their present forms, and so on. Something happened, and we are trying to figure out what and trying to figure out the mechanisms that brought it about. ID tells us that evolution did not happen (what else is one supposed to take away from *Icons of Evolution*?) but it does not tell us what *did*.

Unless ID proponents can come up with an actual model of "what happened", all they have is a sterile anti-evolutionism that adds little to YEC beyond the specific ideas of irreducible complexity and the design filter.

The reason ID proponents are so vague about an actual picture of what happened is that they strive to include YECs, progressive creationists (PCs), and theistic evolutionists (TEs) among their theorists and supporters (though the TE gang must feel rather uncomfortable, Dembski himself having proclaimed that "ID is no friend of theistic evolution" [Dembski 1995]). This is not just a big tent; it is one bulging with people who must be eyeing one another warily. Phil Johnson may want everyone just to be nice for the time being until evolution is vanquished, and then they can work out their disagreements, but if you think evolutionists squabble, wait until you see what happens when the ID folks have to sort out their differences.

As Ronald Numbers and Kelly Smith independently urged at last summer's "Design and Its Critics" conference, if ID is going to attain any level of scholarly respectability, its proponents are going to have to distinguish their model from the discredited, unscientific YEC model, even if that means losing the support of biblical-literalist Christians (*see* RNCSE *2000 Jul/Aug; 20 [4]: 40-43 for Kelly Smith's comments.*) For aspiring scholarly movements, the enemy of my enemy is not my friend.

Given my odd line of work, I am concerned with practical issues such as what teachers are being told to do and what effect this will have on American education. As near as I can tell, teachers are being encouraged to teach students that evolution did not happen and, if it did, that natural selection is not the cause of it, and that in any event we have to leave room for the direct actions of a Creator, and all this is still called science. But to keep all the ID factions quiet, an actual picture of what happened, which is what evolution is trying to explain and what ID *has* to explain, is never mentioned.

What should teachers teach? Apparently, judging from *Icons of Evolution*, they should teach the familiar old YEC saws about the weaknesses of evolution. Evolution is bad science, they say. So to my way of thinking, ID does not rise above familiar anti-evolutionism, though it may be served up in probability theory and information theory with a side order of biochemistry. There is no coherent ID model of what happened for teachers actually to teach.

This invites the question of what, according to the proponents of ID, should teachers teach about the following issues?

1) Is the universe a few thousand years old or billions? Most ID proponents will, if forced, uncomfortably confess that they accept an ancient age of the earth, but they are quick to dismiss the question as unimportant, presumably to keep the YECs in their anti-evolution tent. But should a teacher teach that the earth is millions or thousands of years old? You cannot have it both ways if you are proposing a K-12 curriculum. What is the ID model? What happened?

2) Is the geological column, which shows a succession of species through time, "real" or an artifact? At least the YECs present a model of what happened: the arrangement of species in the geological column is a result of sorting by Noah's flood, rather than their appearance at different times. Does ID accept the geological column as "real"? This is a simple thing to agree to: it is still possible to argue (as Jonathan Wells does) that the arrangement of species through time does not represent descent with modification, but Dembski and his colleagues are going to have to come clean as to what this means. Minimally, it means the special creationists are wrong, but it also requires the progressive creationists and the theistic evolutionists to fight it out as to whether the succession of species through time represents separate creations or a genealogical pattern of related species.

3) Did living things descend with modification from common ancestors? This is what biological evolution is all about — and where the ID big tent starts showing the strain of trying to stretch over incompatible views. How is ID going to accommodate both theistic-evolutionist Michael Behe and special-creationist Paul

Nelson? More important, what do proponents of ID expect teachers to teach? What happened?

I think that I know the answer. Teachers are supposed to teach that evolution did not happen. Of course, if they did, they would be teaching a view that is well outside the scientific mainstream, and be doing their students no favors. I like to remind people that evolution is taught matter-of-factly at every solid university in the nation, including Brigham Young, Notre Dame, and Baylor. But more importantly for our purposes here, ID does not present a coherent model of "what happened", making it impossible for teachers to present ID as an alternative to evolution, as its proponents seek.

Now, maybe Dembski or other ID proponents will tell me that they are not trying to influence the K-12 curriculum, that they are merely trying to build a scholarly movement at the university or intellectual level, trusting that eventually ID will be validated and, like other intellectual movements, will trickle down to the K-12 level. If Dembski had attended my talk, he would have heard me advocate exactly this strategy. I do not think that ID will enter the academic mainstream, but if it does, then obviously it will eventually be taught in high school.

But I do not think that ID proponents are willing to wait until they get this validation: Jonathan Wells, whose book provides disclaimers to be copied and placed in K-12 textbooks, is obviously concerned primarily with the K-12 curriculum; Phillip Johnson's *Defeating Darwinism* (1997) is explicitly aimed at high school students; and the CRSC's Steven Meyer is an author of a substantial "Afterword" to teachers in the ID high-school textbook, *Of Pandas and People* (Davis and Kenyon 1989). Bruce Gordon, currently interim director of The Baylor Science and Religion Project, has correctly noted that ID "has been prematurely drawn into discussions of public science education, where it has no business making an appearance without broad recognition from the scientific community that it is making a worthwhile contribution to our understanding of the natural world" (Gordon 2001).

So, what happened, Bill? Will you go beyond "evolution is bad science" to give us an actual model of what happened?

[*Dembski responded to my article on* Meta *(Dembski 2001b). Despite lavishing 2500-odd words on his response, he carefully avoided committing ID to any position on the age of the earth, the geological column, and common descent. The big tent continues to strain at the seams.*]

Acknowledgments

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Science Defender ET Hall Dies at 77

The Associated Press reported the death of archeologist ET Hall on August 11, 2001. Hall is best known among students of human evolution as the scientist who exposed the Piltdown hoax. In 1953, Hall pioneered the use of radiographic techniques to confirm his suspicions based on archeological evidence that the Piltdown skull was not that of an ancient human.

In 1988 Hall was part of an international team that examined the Shroud of Turin. This team determined that the shroud most likely was made between 1260 and 1390 CE. This examination should have put to rest claims that the shroud was the cloth used to entomb the body of Jesus of Nazareth after his crucifixion and that the image on the cloth was his likeness.

Hall was the director of Oxford University's Research Laboratory for Archaeology and the History of Art from 1955 to 1989.

RESOURCES

Origin of Life

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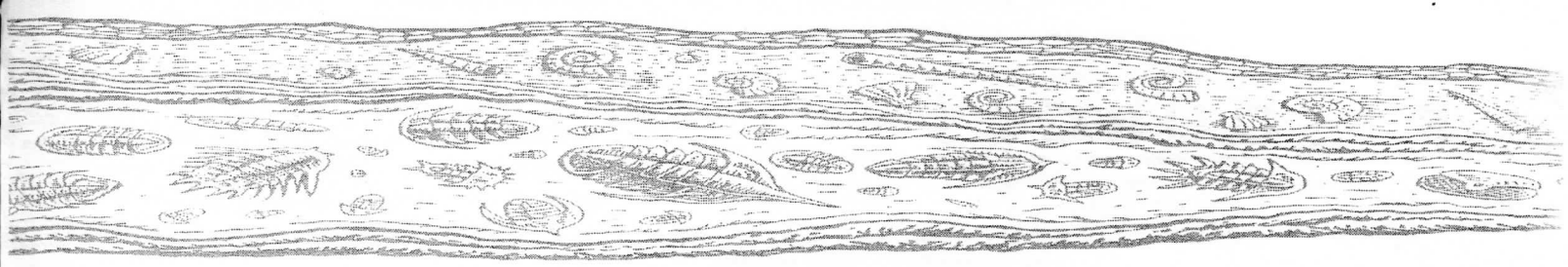

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New Findings on Whale Evolution

Ray Sutera reported in *RNCSE* (2000; 20 [5]: 33-41) on recent findings in whale evolution. Since then, new fossil specimens have resolved some of the unanswered questions in the field.

Writing in *Nature*, Thewissen and others (2001) reported their analysis of two early Eocene cetaceans from Pakistan. Both these specimens have well-defined legs and clearly show the transition from land to water environments. According to the authors, these findings help to bring molecular and morphological studies of whale evolution into closer agreement by providing intermediate fossils that better illustrate the evolutionary pathway taken by ancestral whales. In the accompanying News and Views article, Christian de Muizon of the Musée National d'Histoire Naturelle in Paris assessed these new fossils this way: "[They] should take their place among other famous intermediates such as the most primitive bird, *Archaeopteryx*."

By coincidence, in an issue published the very next day, the journal *Science* also featured a research article on whale evolution. This article by Gingerich and others (2001) reports two important findings. First, more complete limb skeletons and a few key ankle and wrist bones show clearly how early whales swam. Second, these fossils add to our understanding of the diversity of swimming adaptations in early whales and link them clearly to the even-toed hoofed mammals (Artiodactyla) — a conclusion reached independently in the *Nature* article. In a Perspective article in the same issue of *Science*, Rose (2001) remarks that although these new finds resolve some of the outstanding questions in the study of whale origins, other questions remain unanswered.

For non-scientists, the National Museum of Natural History in Washington DC opened a new special exhibit in early October on the evolution, ecology, and natural history of whales. "Masters of the Ocean Realm: Whales, Dolphins and Porpoises" runs through January 2, 2001. And the November 2001 issue of *National Geographic* contained a well-illustrated popular account of whale evolution by Douglas H Chadwick (2001).

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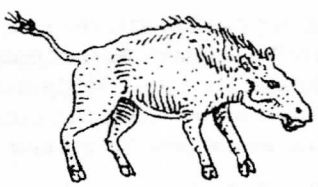

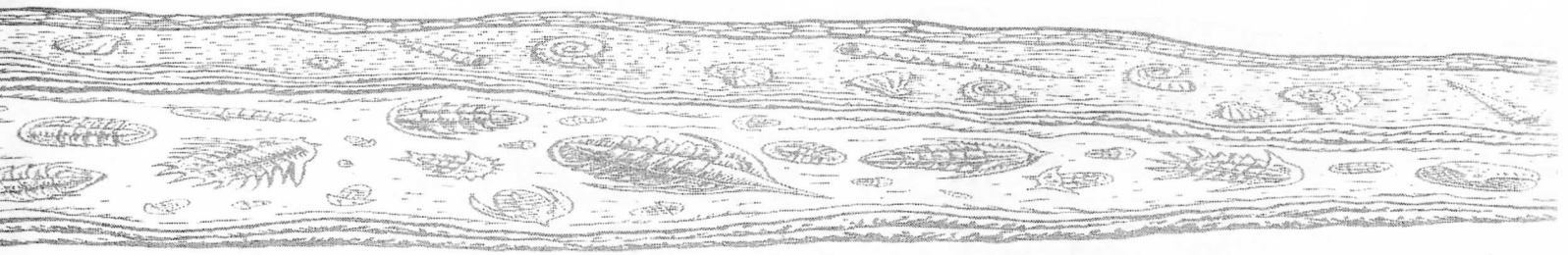

Earth and Space Sciences

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NCSE Member Gets A Leg Up on Seacow Evolution

In an article published in *Nature* just as the issue of *RNCSE* was going to layout, NCSE member Daryl Domning reported a nearly complete skeleton of a fossil seacow. The specimens from Jamaica are an intermediate form between a fully terrestrial ancestral species and the fully aquatic modern seacow species. The crucial evidence linking these to ancestral species are the weight-bearing pelvis, well-developed legs, and strong sacrum (for securing the pelvis to the vertebral column). The aquatic adaptations were similar to those for the early whales that were recently described in *Nature* and *Science* (*see p 45*).

For more information, see Domning DP. The earliest known fully quadrupedal sirenian. *Nature* 2001 Oct 11; 413: 625–7.

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RESOURCES

Special Issues

Culotta E, Sugden Á, Hanson B. Humans on the move. *Science* 2001 Mar 2; 291: 1721. Introduction to a special section on human migrations — including papers on the first Europeans, mating between modern *Homo sapiens* and Neanderthals, stone-age technology, and genetic evidence for migrations.

Dennis C, Gallagher R, Campbell P. Everyone's genome. *Nature* 2001 Feb 15; 409: 813. The editorial of the issue of *Nature* devoted almost entirely to the human genome as sequenced by the Human Genome Project. A wall chart and an educational CD-ROM are included. *Related reading: New Scientist* 2001; 169 (2278): 3-8. A series of short articles on the human genome sequence.

Gee H. Nature insight: Astrobiology. *Nature* 2001 Feb 22; 409: 1079. Introduction to a special section containing 7 articles on the origin of life, life in extreme environments, evolution of morphological complexity, searching for extraterrestrial life, humans in space, and more.

Jasny BR, Kennedy D. The human genome. *Science* 2001 Feb 16; 291: 1153. The editorial of the issue of *Science* devoted almost entirely to the human genome as sequenced by Celera. It includes a giant poster fold-out and a CD-ROM.

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Genes and Biological Complexity

A recent discussion in *Science* by Szathmáry and others (2001) explored the concept of biological complexity, focusing particularly on assessing the claim that evolution has increased biological complexity throughout life's history. In their treatment, the authors write:

> Although we have an intuitive appreciation of biological complexity — often thinking in terms of morphological or behavioral complexity, or the variety of cell types in an organism — the term itself is notoriously hard to define. ...
>
> Is the number of genes in an organism's genome an appropriate measure of biological complexity? It has been assumed that eukaryotes have more genes than bacteria, animals have more genes than plants, and vertebrates have more genes than invertebrates — which nicely fits with the traditional notion of a *scala naturae*. The recent flurry of completed genome sequences, including our own, suggests that this is not necessarily the case. Rather surprisingly, it turns out that the worm *Caenorhabditis elegans* has 18 424 genes in its genome, the fruitfly *Drosophila melanogaster* 13 601, the plant *Arabidopsis* about 25 498, and humans about 35 000. This suggests that there must be other, more sensible genomic measures of complexity than the mere number of genes. ...
>
> We propose that biological complexity might be better explained by considering networks of transcription factors and the genes they regulate, rather than by simply counting the number of genes or the number of interactions among genes ... but for now we lack a way to measure the magnitude of this difference.
>
> So, we need to distinguish between two forms of genomic complexity: one measured by the number of genes and the other by the connectivity of gene-regulation networks. The complexity of organisms (in terms of morphology and behavior) correlates better with the second definition.

See the complete article at <http://www.sciencemag.org/cgi/content/full/292/5520/1315> .

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[*Thanks to David Wayne Ussery for alerting NCSE to this article.*]

Online Profile of Creationist Positions

Mark Wilson of the Department of Geology at the College of Wooster in Ohio has prepared a web page that profiles the claims and positions of present-day anti-evolution organizations. His article entitled "The New Creationists" is based on a presentation he gave in February 2000 and updated in August 2001. The page is available at <http://www.wooster.edu/geology/NewCreationists.html>.

Reactions to PBS's *Evolution*

The recent PBS series *Evolution* has generated a great deal of interest and discussion. In particular, those opposed to evolutionary theory and evolution education have been prolific in their criticisms and condemnation of the series, the producers, the network, and various scientists and educators who are featured in the series. Wesley Elsberry has collected links to many of these reactions (as well as those of a few favorable responses) at <http://www.antievolution.org/events/pbsevo.html>. Those with suggestions for other links should contact Wesley by email, <welsberr@inia.cls.org>.

BOOKREVIEWS

The Emperor's New Clothes: Biological Theories of Race at the Millennium

By Joseph L Graves Jr
New Brunswick NJ: Rutgers University Press, 2000. 252 pages.

Reviewed by C Loring Brace, Museum of Anthropology, University of Michigan, Ann Arbor

A book that concludes with the declaration that biological races do not exist and that the concept of "[r]ace ... was socially constructed arising from the colonization of the New World and the importation of slaves, mainly from western Africa" (p 193) merits a salute right off the bat. The author's intentions are declared in the first page with the words, "Specifically, my goal is to show the reader that there is no biological basis for separation of human beings into races and that the idea of race is a relatively recent social and political construction" (p 1). It is race itself and the grip it has on the public mind that he is presenting as the emperor without clothes. If races are social constructs and not manifestations of biological reality, how did the universal acceptance of their existence ever come about?

The book is an exploration of the development and application of the view that race is a social construction from the ancient Greeks to the present day. It gets off to a somewhat rocky start. Aristotle is credited with authorship of the *Systema Naturae* and the idea that living creatures are hierarchically organized in a *scala naturae*. In fact, that title was used by Linnaeus in the 18th century. Aristotle's *Historia Animalium* may have qualified him as the "Father of the Biological Sciences", but in it he did not arrange the creatures described in a logical hierarchy of differential worth. It was the Enlightenment application of Aristotelian logic that actually accomplished the construction of that "Great Chain of Being", and Linnaeus did embody that approach.

After that somewhat bumpy beginning, the book gets better and better as it goes on. It really comes into its own with the discussion of the establishment of eugenics in the 19th century. In chapter 6, "Pseudoscience and the Founding of Eugenics", he characterizes its founder, Sir Francis Galton, as "an intellectual mediocrity, a sham, and a villain" (p 100), and he backs this up with a demonstration of why that was the case. This is worth the price of the book in the first place. In chapter 7, Graves makes the case that the leader of the American eugenics movement, Charles B Davenport, director of the Eugenics Records Office at the Cold Spring Harbor Laboratory on Long Island, had engaged in "one of the largest medical frauds of the twentieth century: the pellagra cover-up" (p 121). The next chapter, "Eugenics, Race, and Fascism", is ominously subtitled "The Road to Auschwitz Went Through Cold Spring Harbor".

After the realization of its applications in Nazi Germany led to a decrease in the enthusiasm for eugenics, Graves traces its resurgence in a more modern and subtle form. In chapter 10, "The Race and IQ Fallacy", he declares that "No one better typifies the return to scientific racist ideology in the period after World War II than eugenicist Arthur Jensen" (p 159), Professor Emeritus of Educational Psychology at the University of California, Berkeley. Jensen, most recently in *The g Factor: The Science of Mental Ability* (1998), takes race to be a self-evident entity and assumes the existence of racial differences in mental ability as his "default position". This constitutes his null hypothesis, although there is nothing null about it. It is a racialist assumption by definition. Graves goes on to discuss the misunderstanding and misuse of the concept of heritability by Richard J Herrnstein and Charles Murray in *The Bell Curve: Intelligence and Class Structure in America* (New York: The Free Press, 1994).

Graves is a laboratory scientist — both a strength and a weakness as far as his book is concerned. His scientific grasp and his mastery of up-to-date sources puts his presentation on a rock-solid basis. On the other side of the coin, many of his most important points are cloaked in the kind of crabbed and minimalist writing that is *de rigeur* in scientific journals, ultimately being rendered in symbolic form as equations. This is no problem for the scientifically literate, but it will be less satisfying for the general public, which could well stand to learn from the case that Graves makes. The text is only 200 pages long, and could easily have been fleshed out for the general reader. As Graves shows when the occasion demands, he is quite capable of rendering things in perfectly fluent prose. One could only wish that he had kept that up throughout. Even with this caveat, however, *The Emperor's New Clothes* is a fine start for thinking about race at the dawn of a new millennium.

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EVOLUTION

WGBH Educational Foundation, Boston, and Clear Blue Sky Productions, Seattle.

Reviewed by Timothy H Goldsmith, Yale University

If I were to give a prize for the single best idea anybody ever had, I'd give it to Darwin for the idea of natural selection. Ahead of Newton, ahead of Einstein, because his idea unites the two most disparate features of our universe: the world of purposeless, meaningless matter in motion on the one side, and the world of meaning and purpose and design on the other. He understood that what he was proposing was a truly revolutionary idea.

These words are spoken early in the television production *Evolution*, which aired on the Public Broadcasting System in the United States in September 2001. With them, the philosopher Daniel Dennett captures eloquently the power and the beauty of evolutionary theory and at the same time identifies the intellectual dilemma faced by those who lodge their understanding of nature in a literal reading of scriptures. In view of the guerrilla warfare over the teaching of evolution that is taking place in school boards and state legislatures around the United States, the appearance of this series is both timely and useful.

Many of the arguments presented by the anti-evolutionists as "evidence" — those that go beyond the desire to see science accommodate the unobservable and the unmeasurable — are hollow echoes from the 19th century. For example, the incompleteness of the fossil record and the alleged perfection of the human eye are regularly trundled out as if understanding of evolution has remained frozen since the publication of *One the Origin of Species* in 1859. For viewers interested in the history of ideas and the scope of contemporary evolutionary theory, the seven episodes of PBS's *Evolution* provide diverse and fascinating examples of how rapidly our understanding of this important natural process is growing. For example, recent discoveries of transitional forms in the evolution of whales illustrate how paleontology continues to provide confirmation of the Darwinian concept of descent with modification.

Since Darwin's day the catalog of simple eyes of invertebrates has expanded greatly. These are not transitional forms to the vertebrate eye, but they show that eyes of varying degrees of complexity have arisen scores of times. Recent computer models validate how easy this is. Starting with a small sheet of light-sensitive cells and conservative assumptions about incremental changes, optically respectable eyes with spherical lenses can evolve in a few hundred thousand generations, ample time for evolution. At the molecular level, the recent research on a family of genes that control the expression of still other genes during the embryological development of animals as different as mammals and insects reveals an underlying order to diverse body plans that was unanticipated a generation ago. Although much remains to be discovered, neither macroevolution nor the Cambrian explosion are as mysterious as the anti-evolutionists would have us believe.

The series begins with a segment on Darwin himself. In this episode, the writers have used Darwin's older brother Erasmus as a kind of foil: a contrast to Charles's caution and a vehicle for revealing the development of his ideas about natural selection. This approach works well, and the resulting picture of the naturalist is accurate in its important details. Those familiar with the Richmond portrait of Darwin as a young man may feel that on the screen he appears a bit hefty, and they may be disconcerted by his failure to age during the following 30 years. But I quibble.

Subsequent episodes share the interrelations of organisms as an overarching theme. One explores the significance of extinction. Perhaps 99% of all species that have ever existed have gone extinct, which is hardly evidence for intelligent design. The mean lifetime of a species is estimated to

DO YOU BELIEVE IN ... PHYSICS?

Without being highly educated in physics, we can only read summaries of the theory [of relativity], accept the points on *faith*, and then successfully repeat to others what we have learned. But the theory of relativity is not unique in this regard. All of us are capable of understanding far more than we do; we just don't have the time to educate ourselves in every field.

[*This reply appeared in the "Ask Marilyn" column by Marilyn vos Savant in the September 9, 2001 issue of* Parade *magazine, page 7.*]

The Story of Life on Earth

By Margaret Munro
illustrated by Karen Reczuch
Toronto: Groundwood Books,
2000. 64 pages.

Reviewed by William Thwaites, Professor Emeritus, Biology Department, San Diego State University

Margaret Munro and Karen Reczuch's *The Story of Life on Earth* is a picture book for children. It gives a summary of the earth's history as we know it today with special emphasis on biological evolution. I was pleased to see that the Azoic and Proterozoic Eons occupy 15 of the book's 64 pages. I think that these vast periods of time are often overlooked in children's books in favor of the more picturesque Phanerozoic Eon with its many plants and animals. There is a nice timeline inside both covers that shows the relative length of each era of the earth's history. The line of course shows that the Proterozoic wins hands down for length.

Munro's narrative is a straightforward but suitably simplified account covering the major way points in biological evolution. I wish that public school texts in the US could treat the topic as matter-of-factly. However, there could have been fewer facts and more explanations of how we know about prehistoric times. True, Munro does offer the occasional explanation. For example, on page 41 we read: "We know dinosaurs roamed the planet because people have been digging up their fossilized bones all over the world." I especially like the use of the first person pronoun and the word "people" in place of "scientists". I would give an A+ for page 41.

I would only give a grade of C for page 11's statement that "Many scientists believe lightning or cosmic rays zapped chemicals in the warm seas, creating the molecules needed to build the first living cells." Our friends the creationists use such statements to suggest that well-supported scientific conclusions are merely a matter of "belief". It would have been better had the author said something like the following: "In the laboratory, we can make the complex chemicals of life from simple molecules using an electrical spark. So lightning could have formed these molecules on the primitive earth."

On the other hand, I suppose that it really does not matter exactly what the text says. The book is mostly about Karen Reczuch's drawings. They are beautiful and, I think, paleontologically correct. If the purpose of the book is to awaken in young readers a sense of awe and curiosity about the sciences, it should serve quite well.

Evolution Media Review *continued*

be 4 million years, and the demise of species during bouts of mass extinction creates opportunities for the adaptive radiation of surviving organisms. The final message on extinctions is a reminder that human behavior — habitat destruction, pollution, climate change, poaching, and the introduction (accidental or deliberate) of species into new environments — is causing extinctions at an alarming rate. In our success, we have become the ultimate "weed species".

The program on evolutionary arms races demonstrates that most prevalent forces driving evolution usually come not from the physical environment but from other organisms. As an adaptation to minimize predation, the rough-skinned newt has gained the ability to secrete enough tetrodotoxin to kill several humans. In turn, one predator, the red-sided garter snake, has evolved a genetic resistance to the newt's poison. But even for these snakes, eating such newts has its price because, although the snakes are not killed, they become sluggish and more vulnerable to their own predators. Such examples show viewers that evolutionary adaptations are frequently compromises. However, the interplay between pairs of species is much easier to understand than the network of interactions that characterize an ecosystem. The same episode explores the consequences of the fact that human inventiveness in discovering antibiotics has been accompanied by the folly of indiscriminate use. Subjected to such intensive natural selection, a variety of infectious organisms are evolving drug resistance faster than the pharmaceutical industry can respond. As the program illustrates vividly, Russian prisons are an incubator for forms of the tuberculosis bacillus that could bring us the next pandemic. But to provide perspective, leaf-cutter ants have been agriculturists and using antibiotics for 50 million years without getting into this kind of trouble.

Other programs explore contemporary understanding of why organisms come in two sexes, ideas about the evolution of the human mind, and the new field of evolutionary psychology. Although even human behavior has been shaped by evolution in important ways, cultural evolution, lubricated by language, outpaces natural selection. Consequently, in the realm of culture — of ideas — "for the future of humankind, evolution may be no more than what we make of it". But as we continue to live in a world of organisms shaped by biological evolution, we need to understand better the con-

sequences of our actions lest "what we make of it" is a complete mess.

Scientists who have ignored the political efforts to undermine the teaching of biology should be sure to view the final episode. "What about God?" addresses the politics of science education with unusual candor. Some of the scenes of conflicted high school students and their teachers are particularly compelling. At one level, the adolescents stir a measure of admiration for spunk as they urge the school board to harmonize biology with the different picture of the world they receive at home. But the deeper message, clearly understood by their anguished teachers, is that for these kids, at this age, it is close to impossible to teach them how science is different from faith. The scenes from Wheaton College, an interdenominational Christian institution, show the struggle unfolding with students who are a few years older. For some, hearing about evolution from a scientist who professes a strong religious faith can have more impact than all the evidence in the textbooks.

My one criticism of this coverage is that it may leave the impression that anti-evolutionists are all young-earth creationists. Such is not the case; anti-evolutionists occupy a broad theological spectrum, and they are not all Christians. Moreover, as the courts have seen through the sham of "creation science", other "alternatives" to evolution have emerged. The latest, masquerading as cutting-edge science, is another echo from the past called "intelligent design theory". It asserts that the molecular machinery of cells is "irreducibly complex" and therefore requires a designer (unidentified). Hardly a theory in any useful meaning of the word, it is another example of what Richard Dawkins has called an argument from personal incredulity.

This PBS series may not change many committed minds, but viewers who approach it with curiosity will be rewarded by some intriguing views of evolution at work. For those who want to dig deeper, there is a richly illustrated and lucidly written companion book by Carl Zimmer (*Evolution: The Triumph of an Idea.* New York: HarperCollins, 2001. 384 pages).

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WEB LOCATIONS VISITED IN THIS ISSUE

NEWS ITEMS

TOPIC Calvin College Hosts Design Conference
OWNER Calvin College
LOCATION <http://www.calvin.edu/fss/dembschd.htm>
LAST VISIT October 4, 2001

TOPIC Joint Letter to Congressional Conference Committee on HR1
OWNER American Geophysical Institute
LOCATION <http://www.agiweb.org/gap/legis107/evolution_letter.html>
LAST VISIT October 4, 2001

TOPIC Position Statement on Evolution in the Classroom
OWNER Tennessee Darwin Coalition
LOCATION <http://fp.bio.utk.edu/darwin/>
LAST VISIT October 4, 2001

ARTICLES

TOPIC The Goal of Evolution Education: Belief or Literacy?
OWNER Gallup News Service
LOCATION <http://www.gallup.com/poll/releases/pr010214c.asp>
LAST VISIT September 28, 2001

FEATURES

TOPIC Teaching Evolution: Do State Standards Matter?
OWNER Thomas B Fordham Foundation
LOCATION <http://www.edexcellence.net/topics/standards.html>
LAST VISIT October 4, 2001

TOPIC The American Scientific Affiliation and the Evangelical Response to Evolution
OWNER American Scientific Affiliation
LOCATION <http://www.asa3.org/ASA/topics/Evolution/commission_on_creation.html# Commission on Creation>
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TOPIC Defining Evolution
OWNER Talk.Origins Archive
LOCATION <http://www.talkorigins.org/faqs/darwin-precursors.html>
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TOPIC The Children's Crusade for Evolution
OWNER Evolution and the Nature of Science Institute
LOCATION <http://www.indiana.edu/~ensiweb/>.
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TOPIC The Big Tent and the Camel's Nose
OWNER Metanexus: The Online Forum on Religion and Science
LOCATION <http://www.metanexus.net>
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TOPIC On-line Profile of Creationist Positions
OWNER Wooster College
LOCATION <http://www.wooster.edu/geology/NewCreationists.html>
LAST VISIT October 4, 2001

TOPIC Reactions to PBS's *Evolution*
OWNER: Wesley Elsberry
LOCATION <http://www.antievolution.org/events/pbsevo.html>
LAST VISIT October 4, 2001

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   Smith FZ. Geocentrism re-examined. *Journal of Nice Things* 1985; 21 (3): 19–35.

   Waters IC, Rivers HI, and others. Swept away in a flood of enthusiasm [editorial]. *Reports of the National Center for Science Education* 2995 Jan-Feb; 1015 (1): 22–9.

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