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ABSTRACT

This bulletin features articles on real world evolutionary biology, revolutionary classroom science, a review of new curricula in evolutionary biology, and the use of case studies to illustrate points in evolutionary biology. The articles are: (1) "'Real World' Evolutionary Biology: A Pragmatic Quest. Interview with BioQUEST's John Jungck" (Harvey Black); (2) "Revolutionary Science in the Classroom: Interview with Science Education Researchers Jim Stewart and John Rudolph" (Harvey Black); and (3) "New Evolutionary Biology Curriculum Enables Students To Think Like Biologists" (Susan Smetzer-Anderson). (DDR)

PRINCIPLED PRACTICE

In Mathematics & Science Education

NATIONAL CENTER FOR IMPROVING STUDENT LEARNING & ACHIEVEMENT IN MATHEMATICS & SCIENCE

ARTICLES

Modeling for Understanding in Science Education (MUSE) ◦ Visit the NEW MUSE web site online! www.wcer.wisc.edu/ncisla/muse

Evolutionary Biology Instruction — What students gain from learning through inquiry

Students using the evolutionary biology curriculum described in this newsletter are excited about learning science: Engaged in actual scientific inquiry, they are collaboratively investigating and piecing together rich data and theory—and gaining a deep understanding of evolutionary biology and Darwin's model of natural selection. Students' enthusiastic learning and gains in understanding make *a compelling case for teaching evolutionary biology through inquiry*.

The longer-term benefits students gain—in terms of *broader educational and professional options*—are discussed here by science education researchers John Jungck, Jim Stewart, and John Rudolph. Jungck proposes that pragmatists can make a strong case for including evolutionary biology in the high school science curriculum — to help prepare students to participate in science-based fields, such as medicine, agriculture, bacteriology, and other fields that require problem-solving skills. Optimism about what this vision for learning suggests—and pragmatism about the investment such instructional change requires—are both candidly addressed.

As they engage in scientific inquiry that unveils the course, nature, and impacts of long- and short-term changes that living organisms experience, high school students can gain a deeper understanding of the nature of science—and the nature of the world they inhabit.

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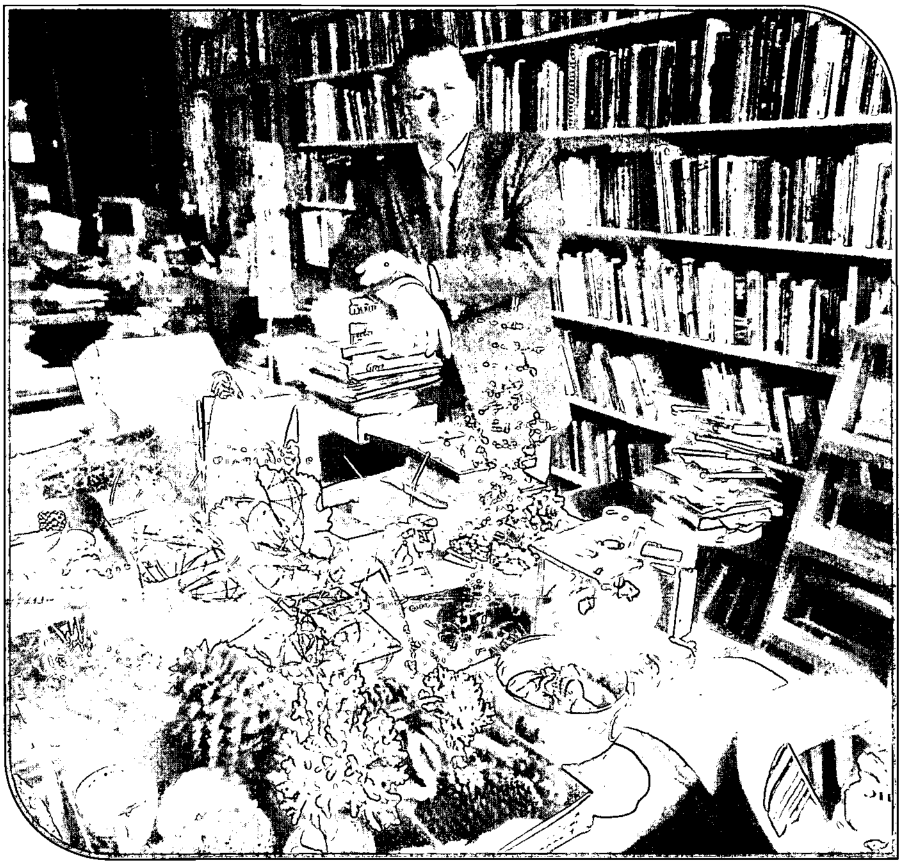
"Real World" Evolutionary Biology: A Pragmatic Quest

INTERVIEW WITH BioQUEST'S JOHN JUNGCK

by Harvey Black

John Jungck, Principal Investigator for the BioQUEST Curriculum Consortium and Professor of Biology and Mead Chair of the Sciences at Beloit College in Beloit, WI, talks about the practical reasons why students should learn evolutionary biology as inquiry.



Why should high school students study evolutionary biology? John Jungck, Principal Investigator of the BioQUEST Curriculum Consortium, contends that evolution's importance can be made clear to students by demonstrating its operation in such "real world" matters as HIV/AIDS infection and spread, the development of resistance to antibiotics by microbes, and resistance to pesticides by insects. Jungck has assisted science teachers in their professional development for 23 years in his work with the BioQUEST Curriculum Consortium at Beloit College in Beloit, WI.

"Unfortunately, most of the public discourse about evolutionary biology has focused on the ideological battle about human origins, and that has adversely deflected attention from the utilitarian aspects of evolutionary problem solving," Jungck asserts. He points to an array of examples to make his case about the necessity of applying evolution to understanding everyday phenomena. Looking at HIV, Jungck notes that "by investigating the genes of the virus and tracing the way it changed—or evolved—" HIV groups and subtypes were differentiated over time. In Thailand, for example, two subtypes of the virus are now known to be prevalent: the first (predominant) subtype appears to be spreading primarily through heterosexual transmission; the second primarily (and more slowly) through drug use and homosexual contact. Jungck also notes that through conducting evolutionary inquiry, scientists could clarify the origin of the virus.

Other contemporary examples where evolutionary biology applies include the growing resistance of bacteria and insects to certain antibiotics and agricultural pesticides, respectively. For example, certain prescription drugs can treat and cure bacterial disease, but overuse and misuse of these drugs is allowing certain bacterial populations to evolve resistance to the drugs over time. Scientists have noted that certain strains of tuberculosis are now resistant to powerful drugs that once fought the disease. Similarly, insects can develop resistance to pesticides. As resistance increases, farmers might need to use more or stronger pesticides to protect crops, yet still experience yield and income losses—either due to crop loss or through the costs of the pesticides they are applying. Food, forage, and fiber prices will reflect these costs as well. To break these negative cycles, Jungck reflects, it is important to understand how such resistance evolves and take appropriate preventive steps.

EVOLUTION CAN BE TAUGHT AS INQUIRY

In the classroom, teachers and students can use some fairly simple techniques to observe evolution at work. Wisconsin Fast Plants,[1] for example, have a life cycle of 35–40 days (seed to seed). By following three or four generations over a semester, students can observe evolutionary changes in plant structures (e.g., how the number of hairs on plant stems can be varied by selection and breeding).

In the classroom, such observation opportunities enable students to develop a range of important mental skills. Says Jungck. "You're honing students' abilities to reason with evidence, to construct an argument that is analytical, quantitative, ... Even if a student concludes that there is some kind of special creationism [through scientific inquiry], they've done it in a very different kind of framework. They've done it with concrete examples, evidentiary kinds of bases." As students learn to engage in evolutionary inquiry, they learn that, in making a scientific argument, what counts is evidence and causal reasoning about that evidence.

Such an inquiry-based approach varies greatly from the way evolution is typically taught. "The mainstream of biology education has been fact-laden and a march through the phyla — a reproduction of 'the great chain of being,'" Jungck argues. In contrast, through the more dynamic approach built into the use of Fast Plants, students engage in problem solving with data that they themselves have collected and examine the mechanisms behind evolution.

As students learn to engage in evolutionary inquiry, they learn that, in making a scientific argument, what counts is evidence and causal reasoning about that evidence.

Jungck believes that teachers need to learn how to teach evolution as inquiry, but he notes that most high school teachers have not had the opportunity themselves to learn evolution as inquiry. For teachers, Jungck argues, there is "a tremendous need for research opportunities, labs, and workshops in these areas." The BioQUEST Curriculum Consortium (www.BioQUEST.org), based at Beloit College in WI, provides one way to meet this need. Throughout the year, BioQUEST, of which Jungck is one of the leaders, holds teacher workshops emphasizing the use and importance of the problem-solving analytical approach.

Problem-solving and analysis skills that involve historical inferences are hardly confined to evolution, Jungck notes. Sciences such as cosmology (the study of the origin of the universe) and historical geology also make use of these skills. "Our sciences are tied together," he remarks. "If you have a good, viable theory of cosmology, it allows an astronomer to interpret observations or to seek out information, to look with a new probe into the universe to test a hypothesis. A paleontologist or a historical geologist can't rewrite history, but the evolutionary ramifications of such things as plate tectonics and the whole distribution of continents on the planet is absolutely critical to understand. We've too much focused on science with an experimental paradigm," he states. Physicists use carbon dating; chemists explore reactions involving conversion of one chemical to another "over eons"—even sciences that superficially seem to be solely lab based have significant historical aspects.

UNDERSTANDING EVOLUTION IS GOOD JOB PREPARATION

Many of the jobs that our children eventually will seek demand the ability to understand and apply evolutionary thinking, Jungck observes. If a student wants to pursue a traditional profession in health, for example, a strong understanding of evolutionary biology is essential. "A physician should be well informed about the power of contemporary genetic and evolutionary techniques related to epidemiology, antibiotics, and other kinds of pharmacology. Any time people make decisions that affect human immune systems—people's abilities to handle a variety of pathogens—a deep understanding of evolution is critical," Jungck asserts.

Even beyond science and health professions, companies are out to attract the "best and the brightest"—well-prepared students familiar with scientific concepts and processes who are able, in other words, to think critically, trace cause and effect, problem-solve.

Consequently, Jungck argues, there is a need for thinking beyond the walls of the academy and enlisting businesses in the effort to increase understanding of evolution and evolutionary impacts. He thinks, for example, that much stronger links need to be forged between education and engineering, energy, and agriculture. For companies in these fields, such links are, Jungck notes, in their own best interests. Jungck emphasizes that these concerns are pragmatic, and his advice for school boards involved in controversy over evolution science is to appeal to pragmatism. Equipping students to participate in a modern, science-based world is far from an esoteric endeavor. Says Jungck, "It's important to start with the immediate and concrete." We need an educated workforce, employees capable of understanding modern scientific concepts and questions, pursuing workable solutions, and presenting logical arguments based on evidence—all qualities that evolutionary reasoning can enhance.

[1] Fast Plants, rapid cycling members of the cabbage and mustard family (genus Brassica) were developed through 25 years of selective breeding by Dr. Paul Williams and colleagues at the University of Wisconsin–Madison. With a life cycle of 35–40 days (seed to seed), the plants can easily be grown in the classroom under continuous fluorescent light. (See www.fastplants.org)

Revolutionary Science in the Classroom

INTERVIEW WITH SCIENCE EDUCATION RESEARCHERS JIM STEWART AND JOHN RUDOLPH

by Harvey Black

Science education and curriculum researchers Jim Stewart and John Rudolph (both of University of Wisconsin–Madison) outline ways high school students can learn—and benefit from learning—evolutionary biology as inquiry.

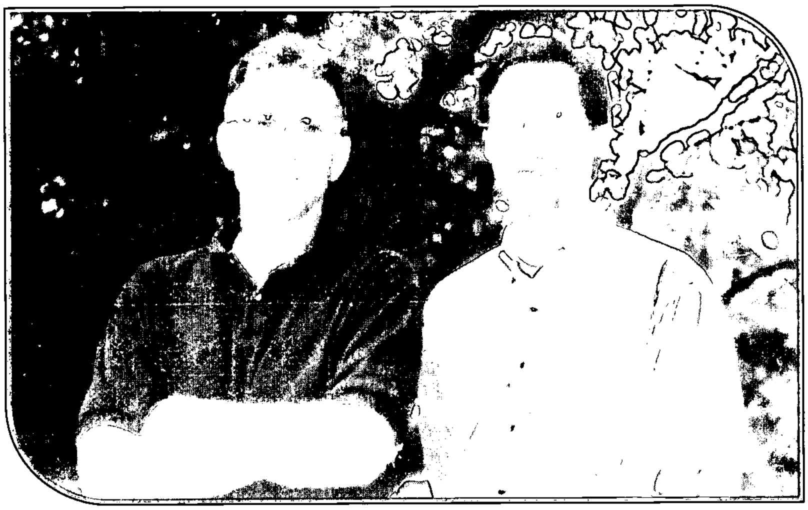


Photo by Paul Baker

"The way science is taught in most schools doesn't help students understand what scientists do and how they think," says Jim Stewart, professor of science education at the University of Wisconsin–Madison and a researcher at the National Center for Improving Student Learning and Achievement in Mathematics and Science. "Students are typically taught science as a rhetoric of conclusions," he says. "They don't come away with any understanding of why scientists come to their conclusions the way they do. Students also don't understand why proposed conclusions are tentative, as are just about all scientific conclusions."

"Moreover," adds John Rudolph, researcher and assistant professor of curriculum and instruction at the University of Wisconsin–Madison, "a recent National Science Foundation document[1] reports that fewer than one in four people in the United States have an understanding of science as a process." Yet science significantly influences almost every aspect of our daily lives. From computers to cancer research, science and engineering affect just about everything we do every day. If U.S. citizens are to be competent decision makers, they need to have a grasp of how scientific research affects their personal, professional, and political lives, even how government policies and funding direct scientific research. "It's important," Rudolph states, "for people to understand how and under what conditions scientific knowledge is gained and used." To be prepared to thrive in a science-permeated society, students need a strong grounding in scientific processes and concepts.

"SCIENCE IS MORE THAN LAB WORK"

Students need to learn to engage in the intellectual work of science, to gain an understanding of both scientific content and processes, states Rudolph. He argues, however, that "hands-on" scientific experiments are not necessarily the best—or only—way to convey scientific understanding. "A more well-rounded scientific experience would involve students in developing scientific arguments based on evidence, confronting alternative explanations, adjudicating between those, and coming to some consensus about what explanations best fit the data," says Rudolph.

The evolutionary biology curriculum Stewart and his research team have developed, studied, and seen applied by teachers at Wisconsin's Monona Grove High School provides an unusual opportunity for students to dig deeper into science. The new curriculum gives students a chance to develop their intellectual skills and to cultivate a more robust understanding of scientific processes and concepts.

The evolutionary biology course challenges students to develop explanations for observed phenomena— students have to examine data, present their ideas as sound scientific arguments, and learn how to defend their propositions with scientific reasoning.

Through the course students also confront the uncomfortable reality that there might be a number of possible explanations for the same observations. "At Monona Grove, students develop data-based explanations. Various groups of students' explanations might not be the same, however, and they might not come to a resolution. Students might find that there is continuing disagreement as to what is really happening with a given phenomenon. This is what happens in science. Science is a slow process by which people come to some reliable knowledge about the world. In their work, scientists examine evidence and propose claims and counterclaims. It is not as straightforward as some textbooks would lead you to believe," states Rudolph.

Stewart adds, "Students also need to come to grips with the fact that scientists must revise theories in the face of data that contradict earlier findings."

People living in Charles Darwin's day (Darwin died in 1892) struggled with the same misperceptions about science that today's high school students face, the researchers state. People tend to expect science to be experimental and laboratory based—to yield clear and certain answers.

"Evolutionary biology provides an excellent example of the diversity of scientific practices. Evolutionary biologists use a combination of methods to come to knowledge about the world," says Rudolph. "The difficulty with trying to understand evolutionary change is that it occurs so very slowly. It's not something that can be observed in real time, and so different methods of research are required." Among the methods plied by evolutionary biologists are historical analysis and probabilistic models. Other fields in which scientists study processes that occur over extended periods of time are plate tectonics, cosmology (the study of the universe), and stellar evolution.

EDUCATORS FACE HURDLES IN REFORMING INSTRUCTION

Getting all these points across in the classroom—the tentative nature of science, arguments based on evidence, the idea that science is far more than what goes on in a lab or what can be measured with certainty—can be a challenge for teachers already grappling with many reform demands. Although the national science education standards address these points, "the difficulty is that the policy documents present a vision of what science education should be, but are vague about how teachers might implement the vision in the classroom," says Rudolph. (The evolutionary biology curriculum designed by the NCISLA research team provides tools that teachers can use as they seek to implement the standards in their classrooms. For more detail, see pages 7 and 10 of this newsletter. See also www.wcer.wisc.edu/ncisla/muse.)

Furthermore, Rudolph adds, the movement toward accountability in instruction might also block implementation of the type of science education reforms he and his colleagues advocate. For example, many people would like to emphasize fact-based learning in the classroom, Rudolph notes. This type of instruction, however, often doesn't allow for arguing and debate over evidence, and students are likely to miss the opportunity to learn very valuable reasoning and argumentation skills.

In addition, the pressure to prepare students for college might, ironically, work against wider implementation of inquiry-based instruction. "The time it takes to engage students with data-based argumentation might be seen by some teachers and administrators as a luxury, given the perceived need to cover a lot of content for college entrance requirements or other high-stakes tests," states Stewart. Granted, argumentation and in-depth investigation require time to focus on one or a few related topics (e.g., earth-moon-sun dynamics, celestial motion) over a school quarter or semester. Stewart and his team, however, reason that if students' abilities to engage in scientific inquiry and argumentation are strengthened, they will be better prepared to pursue post-secondary science courses and careers. (Anecdotal evidence from their research at a Wisconsin high school suggests this is the case. See "New Evolutionary Biology Curriculum Enables Students to Think Like Biologists," page 7.)

"A more well-rounded scientific experience would involve students in developing scientific arguments based on evidence, confronting alternative explanations, adjudicating between those, and coming to some consensus about what explanations best fit the data," says Rudolph.

Added to the above hurdles, are teacher-education deficiencies. Typically, most high school science teachers have not had a chance to learn scientific research skills themselves during their own college careers or through school-supported professional development programs. School administrations, Stewart notes, should encourage teachers to get the experience and professional development that would enable them to confidently engage their students in a more complete science experience. For example, there are workshops, he points out, in which teachers can become more familiar with evolutionary biology and ways to teach it. The BioQUEST Curriculum Consortium (www.BioQUEST.org; see page 2) is a good resource for teachers seeking rich learning opportunities in biology.

Yet Stewart worries that teachers seeking such enrichment might get less than adequate support from school administrations. The time it takes to build a respectable science program goes beyond that typically provided by schools. For example, a school's administrators might expect a two-week (often less) workshop to be sufficient as teacher professional development. But researchers and teachers collaborating at Monona Grove High School spent several months at a time developing curricula[2] for evolutionary biology, astronomy, and genetics that reflect the aims of science education. Although such a developmental time frame might appear a luxury in today's high-pressured educational environment, the researchers have evidence that such long-term investment bears rich fruit — both in terms of teachers gaining content knowledge and pedagogical skills, and in terms of students learning and understanding science. (For related reports and articles, see the NCISLA Publications page at www.wcer.wisc.edu/ncisla.)

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"Significant change requires a significant investment of time and resources," states Stewart. These curricula, he notes, reflect a respectable investment in teacher professional development on the part of school administrators at Monona Grove. Such investment might appear steep, but in the face of teachers' professional development needs and wants—and student learning goals—the researchers contend that it is worthwhile. Clearly, states Stewart, school leaders know that there's more involved in professional development than investing "$12.00 an hour for two weeks a summer."

"Significant change requires a significant investment of time and resources," notes Stewart.

Monona Grove High School stands out, notes Stewart, as a clear exception to typical schools, where such innovation is rare.

RESULTS AND RESOURCES ON-LINE AT NCISLA WEB SITE

Findings of long-term science education studies conducted by Stewart and colleagues are accessible through journal articles and reports listed at the NCISLA web site (www.wcer.wisc.edu/ncisla, "Publications" page). Interested readers might also check out the "Readings for the Road," on page 11 of this newsletter.

In addition, Stewart and his colleagues have recently placed on-line the evolutionary biology curricula mentioned here and described in more detail on page 7 of this newsletter. The new NCISLA Modeling for Understanding in Science Education (MUSE) web site (www.wcer.wisc.edu/ncisla/muse) now features both in-depth astronomy and evolutionary biology curricula and teacher tools, of special interest to educators seeking to strategically reform science instruction and support teacher professional development.

[1] National Science Board. (2000). *Science and engineering indicators—2000* (NSB-00-1). Arlington, VA: National Science Foundation.

[2] These curricula were co-developed with lead teacher-researcher Sue Johnson and researchers Jennifer Cartier, Sam Donovan, and Cindy Passmore. See the NCISLA web site's (www.wcer.wisc.edu/ncisla) Publication and Teacher Resources pages for more information about the Modeling for Understanding in Science Education curricula and results from studies conducted at Monona Grove High School.

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NEWSLETTER INFORMATION

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∘ ∘ ∘ CENTER MISSION ∘ ∘ ∘

Dedicated to improving K–12 mathematics and science education for all children, the Center's mission is to craft, implement in schools, and validate principles for designing classrooms that promote understanding of important ideas in mathematics and science. Based on long-term, in-class research, the Center aims to —

1. *Identify important, unifying ideas of science and mathematics that students should learn.*
2. *Describe how students learn these ideas with understanding.*
3. *Identify elements of classroom instruction that help students achieve learning with understanding, and demonstrate in classrooms that these forms of instruction result in students learning big ideas of mathematics and science with understanding.*
4. *Describe how professional development programs can be designed to foster teaching for understanding, and demonstrate that these research-based programs in turn foster instruction that results in students learning big ideas of mathematics and science with understanding.*
5. *Identify the requirements for effective school organization that support students learning important mathematics and science ideas with understanding.*
6. *Create strategies to provide information and procedures so that Center research findings can be used to create similar classrooms.*

Conducted in large urban areas as well as smaller cities and towns with diverse student populations (including low-income, linguistic-minority, and ethnic-minority students), Center research studies aim to identify ways in which particular design elements enable low-income and minority students to learn and achieve at high levels.

New Evolutionary Biology Curriculum Enables Students to Think Like Biologists

by Susan Smetzer-Anderson

Students participating in a new 9-week evolutionary biology course[1] at Wisconsin's Monona Grove High School have made an important discovery: They've learned that they themselves can conduct collaborative investigations, propose scientific explanations, and apply theories (such as Darwin's theory of natural selection) to the analysis of complex, historical data. Rather than merely memorizing definitions and explanations, these students have learned to construct scientific arguments and debate their strengths and weaknesses.

Through the new, innovative curriculum, high school students learn about the nature of scientific inquiry in evolution. The students are challenged to grapple with three historical explanations of species diversity.[2] As they analyze data-rich case studies about species development, the students learn to work together as a research community and also come to realize that scientists are like detectives, piecing together evidence and theory.

Students' responses to the course have been positive. Importantly, science education researcher Jim Stewart, of the National Center for Improving Student Learning and Achievement in Mathematics and Science (NCISLA) at the University of Wisconsin-Madison, notes that participating students developed *a sophisticated understanding* of evolutionary biology and the natural selection model.

Students learn to analyze data and develop scientific arguments through the evolutionary biology course developed by NCISLA researchers and collaborating teachers.

PROBLEM-SOLVING REPLACES LEARNING BY ROTE

The new natural selection curriculum, accessible at the NCISLA web site (www.wcer.wisc.edu/ncisla/muse) is consistent with the goals set forth in the National Science Education Standards and the Benchmarks for Scientific Literacy documents. Based on a modeling approach to scientific inquiry, the new course departs from the "more typical" evolutionary biology "taught in traditional classrooms, where students usually rely on a textbook that elaborates 20 pages of definitions and concepts," comments science education researcher John Rudolph. "Imagine a 10th-grader coming to grips with any of this content with real understanding in less than two weeks. This information tends to be thrown at students and taught in a very top-down way."

Most U.S. adults learned the textbook version of evolutionary biology, if they learned it at all. Few learned science as a process that allowed them to inquire about their world, as recommended by the 1995 national science standards. The research team contends that learning by rote continues to substitute for scientific inquiry in many of today's classrooms, particularly with regard to evolutionary biology.

"Typically, there are few, if any, opportunities for students to actually solve problems, as evolutionary biologists do," states researcher Sam Donovan. "Students may get a question at the end of a book chapter, such as 'What is natural selection?' But students will get no sense that evolution is a problem-solving endeavor."

Evolutionary biologists study patterns and interactions among organisms. For example, in the desert southwest, the yucca moth and the yucca cactus depend on each other for survival. How did this interdependence develop, and what functions does it serve? Questions like these drive scientific inquiry, data collection, and explanation building. Students, however, rarely have an opportunity to experience this scientific process. As a result, they often leave school with a very foggy picture of the nature of scientific inquiry.

The research team, led by Stewart and collaborating teacher Sue Johnson, has designed and evaluated the impacts of science-as-inquiry courses for more than 12 years. For the past five years, the team has been developing and pilot-testing the evolutionary biology course described here. Although it focuses on Darwin's theory of natural selection (see The Natural Selection Model, page 9), the course also introduces students to other explanations for species diversity.

"Because one of our goals is to build a classroom research community that encourages student reasoning and discussion, we want to address up front the major views that students bring to the study of evolution," states researcher Cindy Passmore.

At the beginning of the course, students read about William Paley's (1743–1805) model of intelligent (divine) design, Jean Baptiste Lamarck's (1744–1829) model of species adaptation, and Charles Darwin's (1809–1882) model of natural selection. After they read abridged versions of each author's

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original work, they discuss the authors' different explanations for species diversity. Students then explore the phenomena that inspired the authors' scientific models. Students examine fossils, as discussed by Lamarck; they dissect an eye to examine the structures that so fascinated Paley; and they view some of the pigeon breeds described by Darwin in *Origin of Species* (1859).

"Given the assumptions informing these theoretical models, any of them can work," states Donovan. "However, not all the assumptions are consistent with a scientific worldview." By examining them the first few weeks of class, the students have a chance to compare the models and the assumptions on which they are based. They also clarify the distinct mechanisms that underlie the natural selection model. From this foundation, the students analyze three cases of species adaptation, employing the natural selection model to define processes that might have led to changes or adaptations in the species over time. (See Scientific Case Studies Propel Students' Learning.)

SCIENTIFIC CASE STUDIES PROPEL STUDENTS' LEARNING

The MUSE evolutionary biology course features three increasingly challenging case studies. These case studies do not lend themselves to quick interpretation. Rather, the case studies provide students entrée to the practice of evolutionary inquiry and understanding of complex biological concepts and processes.

Students work on the case studies in groups, analyzing and discussing data and their possible interpretation within the framework of the natural selection model. The in-class analysis, discussion, and presentations to other investigative teams in the class require up to a week per case study. NCISLA researchers have found that as students engage deeply in data-based inquiry and model-based reasoning, the students cultivate a much deeper understanding of evolutionary biology. (See the reading list on page 11 for articles about students' learning.)

FEATURED CASE STUDIES

1. Seed variations To introduce students to the tools of evolutionary inquiry, this case provides a very detailed data set about seed characteristics of a hypothetical plant species.

2. Monarchs and viceroys Taking an approach very different from that taken in traditional science text books, this case study engages students in considering the origins and selective advantage of bright (warning) coloration of different butterfly species.

3. Sexual dimorphism in pheasant coloration This case requires students to account for evidence and develop a research grant proposal that explains the importance of reproductive success (versus survival advantages) conferred by bright coloration of male pheasants.

Case study materials are available at www.wcer.wisc.edu/ncisla/muse, within the Natural Selection Unit Overview and Materials section.

STUDENTS CONFRONT COMPLEXITIES OF EVOLUTIONARY INQUIRY

Using the natural selection model actually forces students to confront the same scientific dilemmas that evolutionary biologists confront. "Because they are often unable to directly observe events, evolutionary biologists rely on historical data and probabilistic models, such as natural selection, to understand evolutionary change," explains Passmore.

Various types of data, such as fossil records, similarities among organisms, and molecular information, make up the indirect evidence evolutionary biologists use. Students learn how difficult it is to sift indirect evidence as they evaluate data that are both rich and perplexing. Working together, the students begin to learn that science is as much about conducting collaborative inquiry as drawing conclusions. They construct explanatory models about increasingly complex research cases and present these to their classmates for discussion, analysis, and debate. The course builds a scientific community as the students learn to ask questions and critique one another's work.

"The course definitely challenges students to learn and understand evolution at a deeper level than merely memorizing definitions or theories," states Johnson.

Passmore adds, "Students can't 'fudge' their answers in this class. They have to confront their own understanding and take responsibility for their learning. From the beginning, we set up classroom norms about how they can question, discuss, and present their ideas and models, similar to what scientists do in their work."

According to the researchers, the students become very involved and animated as they work together on scientific questions, even if at first they are uncomfortable with the new learning environment. The different course structure, Johnson points out, might also be challenging to teachers, because it is so student centered. She states, "Although the teacher is a contributor, he or she is not center stage."

Johnson's comment raises an important question facing the research team: How can this education strategy be implemented by other teachers in other schools? Although this course is in line with the science standards, it still differs from typical science instruction. The group is aware of the difficulty of transferring the innovative strategy adopted at Monona Grove High School to other schools, where teachers might rely on traditional textbooks for curriculum coverage.

NEW CURRICULA REQUIRES INVESTMENT IN TEACHERS

Donovan notes, "Dropping this type of instruction into a normal, year-long science class would be a challenge. It requires teachers to establish new classroom norms to guide student interactions. It also means that teachers will need to learn how to assess student mastery of those norms."

Rudolph adds, "In some ways, the top-down strategy that most teachers use makes for easier classroom management — especially where teachers feel challenged to cover the textbook." For example, new high-stakes tests in some states exert pressure on teachers to "teach to the test." To assure that their students pass these tests, teachers might try to cover a lot of material, but not in great depth because of time constraints. As a result, students miss the opportunity to engage in in-depth inquiry.

Lead researcher Jim Stewart respects teachers' skills, as well as the predicaments they face. "Many very accomplished teachers have the same intent we do — to challenge students to work hard, inquire, and more deeply understand science. But it's difficult for them to do this on their own in their classrooms, without support."

Many teachers work in schools where curricular changes take a long time to happen. They also might be challenged in the same ways their students are, having themselves been taught at universities and schools that science involves memorizing definitions, rather than inquiring into ideas or theories. "If you really think about it," Stewart adds, "the challenge of teacher education reaches into both university science and education classrooms."

Changing science instruction, including the way evolutionary biology is taught, requires a reassessment by the education community of its goals for science education. Teachers also need support to try new strategies, such as those initiated at Monona Grove High School. The importance of administrators' support, states Stewart, cannot be underestimated.

THE NATURAL SELECTION MODEL

Proposed by Charles Darwin, the model of natural selection posits that

1. organisms produce more offspring than are able to survive.
2. because of limited resources, members of a species struggle among themselves for survival.
3. variation naturally exists among individuals of the same species.
4. some variations increase the likelihood that certain individuals will survive to produce offspring.
5. because variations are inherited, the offspring of survivors will likely possess the advantageous variations as well.

STUDENTS ENJOY INTELLECTUAL SPOTLIGHT

With the pilot study behind them, the MUSE research team has continued to refine the new evolutionary biology curriculum. Now posted to the NCISLA web site (www.wcer.wisc.edu/ncisla), the curriculum is accessible to teachers nationwide. Based on studies conducted of students' learning, the researchers are finding that students developed a sophisticated understanding of the natural selection model through participating in the course. Two former students, Megan Pfeiffer and Matt Kebbekus, displayed their understanding at a poster session of the 1999 National Society for the Study of Evolution conference. According to Johnson and Stewart, the two students were representative of their entire class.

Kebbekus, now a college student at the University of Wisconsin–Madison, describes his experience at the national meeting: "We put together posters based on our class work, and our posters were very articulate and clear." The posters featured the students' explanations about why male ring-necked pheasants are brightly colored in comparison to the duller-colored females. The posters also outlined an experiment the students devised to test their explanations.

Remembering his science-teaching days, Stewart says, "I couldn't imagine selecting any of the students I taught — as bright as they were — and bringing them to a national meeting and having them interact with evolutionary biologists the way these students did. They understood the evolutionary biology. And any of the students in the class could have done just as well."

After the meeting, Kebbekus' father approached Sue Johnson to talk about the class and his son's experience. "He thanked me," Johnson said, "because his son became thoroughly engaged in this class. He was coming home at night and talking about the cases we were working on. He was excited, he said, because what students were thinking was important, and he wasn't expected to just parrot back something the teacher had said."

Matt Kebbekus concurs, "I liked being able to think for myself and apply creativity to science. After finishing the class and participating in the conference, I feel confident discussing evolution with anyone."

[1] For a more detailed course description, see the NCISLA Research Report, No. 00-1: *A course in evolutionary biology: Engaging students in the "practice" of evolution*, by Cynthia Passmore and Jim Stewart (available at www.wcer.wisc.edu/ncisla/publications).

[2] The course materials include abridged readings of Jean Baptiste Lamarck's (1744–1829), William Paley's (174 3–1805) and Charles Darwin's (1809–1882) theories of organism design. These materials are available at www.wcer.wisc.edu/ncisla/muse/.

EVOLUTIONARY SCIENCE CURRICULA DEBUT ON-LINE!

NCISLA's Modeling for Understanding in Science Education (MUSE) project has launched a new, in-depth web site to feature three sets of science curricula consistent with the goals set forth in the National Science Education Standards and Benchmarks for Scientific Literacy. The curricula and teacher's guides support middle and high school science instruction focusing on astronomy (earth-moon-sun dynamics), evolutionary biology (natural selection), and classical genetics (forthcoming in late 2002), with each unit unfolding over nine weeks.

Led by Jim Stewart, NCISLA researcher and professor of Curriculum and Instruction at the University of Wisconsin–Madison, the MUSE team for more than 12 years has worked with ten teachers and approximately 1,250 students at Wisconsin's Monona Grove High School. Through this intensive partnership, the team has developed new curricula, studied students' learning, and supported teachers' professional development.

The MUSE project's central premise is that scientific modeling enables students to learn to engage in scientific inquiry as they learn key concepts and ideas. The MUSE team's teacher-partners claim that their instructional practices have changed in significant ways, and they have marveled at their students' learning and capacities to reason deeply about complex scientific ideas and to present arguments justifying proposed scientific models. Students' understanding of scientific models, assessed through various means, has been found to increase throughout the courses. (See, for an example, *in Brief: High School Students "Do" and Learn Science Through Scientific Modeling,* Winter 2000, on-line at www.wcer.wisc.edu/ncisla/publications.) The middle and high school students who have participated in the MUSE courses and studies are representative of the range of students that attend the school from surrounding rural and suburban areas.

[www.wcer.wisc.edu/ncisla/muse]

Modeling for Understanding in Science Education (MUSE)

Web Site Offers Teachers Rich Science Curricula – for Free!

EARTH-MOON-SUN DYNAMICS (celestial motion)
NATURAL SELECTION
CLASSICAL GENETICS

- **scientific modeling**
- **course materials**
- **scientific benchmarks & standards**
- **assessment strategies**
- **classroom learning environments**

The Modeling for Understanding in Science Education (MUSE) project represents a significant teacher-student-researcher collaboration. Based on long-term research and development, the new MUSE web site features in-depth curricula. These on-line resources provide teachers access to scientific modeling strategies that can enable students to engage in inquiry and learn key concepts and ideas with understanding.

WHAT WILL YOU FIND AT THE MUSE WEB SITE?

- An overview about using scientific modeling as an instructional approach
- Course materials and teacher's guides focusing on natural selection, earth-moon-sun dynamics, and classical genetics
- The scientific benchmarks and standards addressed by the MUSE curricula
- Strategies for assessing student learning
- Research reports about students' learning, including research about students'—

  a. knowledge of Darwin's model of natural selection

  b. abilities to use the natural selection model to reason about diverse data in sophisticated ways

  c. intellectual skills associated with scientific modeling and defense of models
- Examples of student work from the project classrooms
- Extended descriptions of the classroom learning environment

The curricular materials presented on the MUSE web site are rich and well documented. The web site also serves as a professional development tool for teachers. Teachers are invited to investigate and use the free MUSE curricula and also to inform the MUSE team about their experience navigating the web site.

READINGS FOR THE ROAD

Interested in reforming science education practices and curricula?
The research-based articles, papers, and books listed below might be useful.
See also the NCISLA web site (www.wcer.wisc.edu/ncisla/).

BOOKS

Teaching about evolution and the nature of science
National Academy of Sciences Working Group on Teaching Evolution
Washington, DC: National Academy Press. (Available at http://www.nap.edu/catalog/5787.html)

Inquiry and the National Science Education Standards: A guide for teaching and learning
National Research Council, Committee on the Development of an Addendum to the National Science Education Standards on Scientific Inquiry. Steve Olson and Susan Loucks-Horsley (Eds.). Washington, DC: National Academy Press. (Available at http://www.nap.edu/catalog/9596.html)

JOURNAL ARTICLES

Reconsidering the nature of science as a curriculum component
Rudolph, J. L. (2000). Journal of Curriculum Studies, 32, 403–419.

Evolution and the nature of science:
On the historical discord and its implications for education
Rudolph, J. H., & Stewart, J. H. (1998). Journal of Research in Science Teaching, 35 (10), 1069–1089.

Considering the nature of scientific problems when designing science curricula
Stewart, J., & Rudolph, J. L. (2001). Science Education, 85, 207–222.

A modeling approach to teaching evolutionary biology in high schools
Passmore, C., & Stewart, J. (in press). Journal of Research in Science Teaching.

NCISLA RESEARCH REPORT

A course in evolutionary biology: Engaging students in the "practice" of evolution (Res. Rep. 00-1)
Passmore, C., & Stewart, J. H. Madison, WI: National Center for Improving Student Learning and Achievement in Mathematics and Science. (Available at http://www.wcer.wisc.edu/ncisla)

If you would like more information about these publications, contact the . . .

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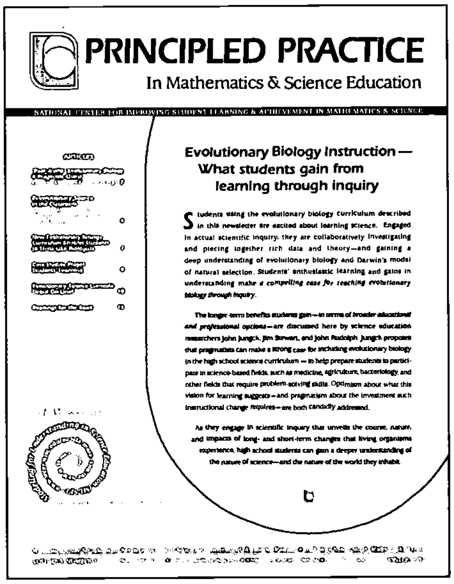
PRINCIPLED PRACTICE
In Mathematics & Science Education
NATIONAL CENTER FOR IMPROVING STUDENT LEARNING & ACHIEVEMENT IN MATHEMATICS & SCIENCE

Evolutionary Biology Instruction — What students gain from learning through inquiry

Students using the evolutionary biology curriculum described in this newsletter are excited about learning science. Engaged in actual scientific inquiry, they are collaboratively investigating and piecing together rich data and theory—and gaining a deep understanding of evolutionary biology and Darwin's model of natural selection. Students' enthusiastic learning and gains in understanding make *a compelling case for teaching evolutionary biology through inquiry*.

The longer-term benefits students gain—in terms of *broader educational and professional options*—are discussed here by science education researchers John Jungck, Jim Stewart, and John Rudolph. Jungck proposes that pragmatists can make a strong case for including evolutionary biology in the high school science curriculum — to help prepare students to participate in science-based fields, such as medicine, agriculture, bacteriology, and other fields that require problem-solving skills. Optimism about what this vision for learning suggests—and pragmatism about the investment such instructional change requires—are both candidly addressed.

As they engage in scientific inquiry that unveils the course, nature, and impacts of long- and short-term changes that living organisms experience, high school students can gain a deeper understanding of the nature of science—and the nature of the world they inhabit.

Evolutionary Biology Instruction

A Special Issue of PRINCIPLED PRACTICE

Practical questions addressed in this newsletter include —

- Why should we teach students evolutionary biology?
- How does *learning through inquiry* support students' learning and understanding of evolutionary biology?
- In what ways does the new Modeling for Understanding in Science Education (MUSE) curriculum support both teachers' professional development — and students' learning evolutionary biology — with understanding?

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