Using Technology to Study Cellular and Molecular Biology

under a contract from the
National Institutes of Health

National Center for Research Resources

5415 Mark Dabling Boulevard
Colorado Springs, Colorado 80918

BSCS Development Team
Rodger Bybee, Principal Investigator
Jerry Phillips, Project Director
April Gardner, Curriculum Developer
Sharmila Basu, Curriculum Developer
Carrie Hamm, Project Assistant
Ted Lamb, Evaluator
Barbara Perrin, Production Director
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Philip Bourne, University of California San Diego, La Jolla, California
David Gorenstein, University of Texas Galveston, Galveston, Texas
Amy Lee, King Kekaulike High School, Pukalani, Hawaii
Maryann Martone, University of California San Diego, San Diego, California
Joe Matteson, Pojoaque High School, Santa Fe, New Mexico
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Kim Noethen, Pine Crest Preparatory School, Fort Lauderdale, Florida
Howard Robinson, Brookhaven National Laboratory, Upton, New York
Michael Schmid, Baylor College of Medicine, Houston, Texas
Rich Wasserman, Sand Creek High School, Colorado Springs, Colorado
Leigh Yarbrough, Cimarron High School, Cimarron, New Mexico

Primary Field-Test Teachers
Patrick Beohmer, Carrington Public Schools, Carrington, North Dakota
Patricia Carothers, Monte Vista High School, Danville, California
Carlos Charriez, Northwest High School, Germantown, Maryland
Brenda Chenier, Eastern Senior High School, Washington, District of Columbia
Carol Johnson, John Jay Science Academy, San Antonio, Texas
Amy Lee, King Kekaulike High School, Pukalani, Hawaii
Catherine Ratliff, Lafayette County High School, Oxford, Mississippi
Ann Sisson, Southern High School, Racine, Ohio
Carol Wheeler, Pine Creek High School, Colorado Springs, Colorado

Secondary Field-Test Teachers
Dawn Emanuel, Sallisaw High School, Sallisaw, Oklahoma
Keith Gibbons, Catholic Central High School, London, Ontario, Canada
Terry Houchens, Joliet Central High School, Joliet, Illinois
Patrick Kosher, Cornell High School, Cornell, Wisconsin
Alan Wasmoen, Mt. Michael Benedictine School, Elkhorn, Nebraska

Cover Illustration
The structure of the oncogene H-Ras p21 protein complexed with GTP on the cover photograph was taken from the Protein Data Bank (PDB) (*http://www.pdb.org*), protein number PDB ID: 121P. (Source: Wittinghofer, F., U. Krengel, J. John, W. Kabsch, E.F. Pai. 1991. Three-dimensional structure of p21 in the active conformation and analysis of an oncogenic mutant. *Environmental Health Perspectives*, 93: 11.)

This material is based on work supported by the National Institutes of Health under Contract No. 263-00-C-0039. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the funding agency.

NIH Publication No. 05-5170
ISBN: 1-929614-14-4

Contents

Foreword

This curriculum supplement, from *The NIH Curriculum Supplement Series*, brings cutting-edge medical science and basic research discoveries from the laboratories of the National Institutes of Health (NIH) into classrooms. As the largest medical research institution in the United States, NIH plays a vital role in the health of all Americans and seeks to foster interest in research, science, and medicine-related careers for future generations. NIH's Office of Science Education (OSE) is dedicated to promoting science education and scientific literacy.

We designed this curriculum supplement to complement existing life science curricula at both the state and local levels and to be consistent with *National Science Education Standards*.[1] It was developed and tested by a team composed of teachers, scientists, medical experts, and other professionals with relevant subject-area expertise from schools and institutes from across the country; and by NIH scientists and curriculum-design experts from Biological Sciences Curriculum Study (BSCS), Edge Interactive, and SAIC. The authors incorporated real scientific data and actual case studies into classroom activities. A three-year development process included geographically dispersed field tests by teachers and students.

The structure of this module enables teachers to effectively facilitate learning and stimulate student interest by applying scientific concepts to real-life scenarios. Design elements include a conceptual flow of lessons based on BSCS's 5E Instructional Model of Learning, multisubject integration emphasizing cutting-edge science content, and built-in assessment tools. Activities promote active and collaborative learning and are inquiry-based to help students develop problem-solving strategies and critical thinking.

Each curriculum supplement comes with a complete set of materials for both teachers and students, including printed materials, extensive background and resource information, and a Web site with interactive activities. The supplements are distributed at no cost to teachers across the United States. All materials may be copied for classroom use but may not be sold. We welcome feedback from our users. For a complete list of curriculum supplements, updates, availability and ordering information, or to submit feedback, please visit our Web site at *http://science.education.nih.gov* or write to

Curriculum Supplements Series
Office of Science Education
National Institutes of Health
6705 Rockledge Dr., Suite 700 MSC 7984
Bethesda, MD 20892-7984

We appreciate the valuable contributions of the talented staff at BSCS, Edge Interactive, and SAIC. We are also grateful to the NIH scientists, advisors, and all other participating professionals for their work and dedication. Finally, we thank the teachers and students who participated in focus groups and field tests to ensure that these supplements are both engaging and effective. I hope you find our series a valuable addition to your classroom and wish you a productive school year.

Bruce A. Fuchs, Ph.D.
Director
Office of Science Education
National Institutes of Health
supplements@science.education.nih.gov

1 In 1996, the National Academy of Sciences released the *National Science Education Standards*, which outlines what all citizens should understand about science by the time they graduate from high school. The *Standards* encourages teachers to select major science concepts that empower students to use information to solve problems rather than stressing memorization of unrelated information.

About the National Institutes of Health

Begun as the one-room Laboratory of Hygiene in 1887, the National Institutes of Health (NIH) today is one of the world's foremost medical research centers and the federal focal point for health research in the United States.

Mission and Goals

The NIH mission is science in pursuit of fundamental knowledge about the nature and behavior of living systems and the application of that knowledge to extend healthy life and reduce the burdens of illness and disability. The goals of the agency are to

- foster fundamental creative discoveries, innovative research strategies, and their applications as a basis for advancing significantly the nation's capacity to protect and improve health;
- develop, maintain, and renew scientific resources—both human and physical—that will ensure the nation's ability to prevent disease;
- expand the knowledge base in medical and associated sciences in order to enhance the nation's economic well-being and ensure a continued high return on the public investment in research; and
- exemplify and promote the highest level of scientific integrity, public accountability, and social responsibility in the conduct of science.

NIH works toward meeting those goals by providing leadership, direction, and grant support to programs designed to improve the health of the nation through research in the

- causes, diagnosis, prevention, and cure of human diseases;
- processes of human growth and development;
- biological effects of environmental contaminants;
- understanding of mental, addictive, and physical disorders; and
- collection, dissemination, and exchange of information in medicine and health, including the development and support of medical libraries and the training of medical librarians and other health information specialists.

Organization

Composed of 27 separate institutes and centers, NIH is one of eight health agencies of the Public Health Service within the U.S. Department of Health and Human Services. NIH encompasses 75 buildings on more than 300 acres in Bethesda, Md., as well as facilities at several other sites in the United States. The NIH budget has grown from about $300 in 1887 to more than $27.8 billion in 2004.

Research Programs

One of NIH's principal concerns is to invest wisely the tax dollars entrusted to it for the support and conduct of this research. Approximately 82 percent of the investment is made through grants and contracts supporting research and training in more than 2,000 research institutions throughout the United States and abroad. In fact, NIH grantees are located in every state in the country. These grants and contracts make up the NIH Extramural Research Program.

Approximately 10 percent of the budget goes to NIH's Intramural Research Programs, the more than 2,000 projects conducted mainly in its own laboratories. These projects are central to the NIH scientific effort. First-rate intramural

scientists collaborate with one another regardless of institute affiliation or scientific discipline and have the intellectual freedom to pursue their research leads in NIH's own laboratories. These explorations range from basic biology to behavioral research, to studies on treatment of major diseases.

Grant-Making Process

The grant-making process begins with an idea that an individual scientist describes in a written application for a research grant. The project might be small, or it might involve millions of dollars. The project might become useful immediately as a diagnostic test or new treatment, or it might involve studies of basic biological processes whose clinical value may not be apparent for many years.

Each research grant application undergoes peer review. A panel of scientific experts, primarily from outside the government, who are active and productive researchers in the biomedical sciences, first evaluates the scientific merit of the application. Then, a national advisory council or board, composed of eminent scientists as well as members of the public who are interested in health issues or the biomedical sciences, determines the project's overall merit and priority in advancing the research agenda of the particular NIH funding institutes.

About 38,500 research and training applications are reviewed annually through the NIH peer-review system. At any given time, NIH supports 35,000 grants in universities, medical schools, and other research and research training institutions, both nationally and internationally.

NIH Nobelists

The roster of people who have conducted NIH research or who have received NIH support over the years includes some of the world's most illustrious scientists and physicians. Among them are 115 winners of Nobel Prizes for achievements as diverse as deciphering the genetic code and identifying the causes of hepatitis.

Five Nobelists made their prize-winning discoveries in NIH laboratories. You can learn more about Nobelists who have received NIH support at *http://www.nih.gov/about/almanac/nobel/index.htm.*

Impact on the Nation's Health

Through its research, NIH has played a major role in making possible many achievements over the past few decades, including

- Mortality from heart disease, the number one killer in the United States, dropped by 36 percent between 1977 and 1999.
- Improved treatments and detection methods increased the relative five-year survival rate for people with cancer to 60 percent.
- With effective medications and psychotherapy, the 19 million Americans who suffer from depression can now look forward to a better, more productive future.
- Vaccines are now available that protect against infectious diseases that once killed and disabled millions of children and adults.
- In 1990, NIH researchers performed the first trial of gene therapy in humans. Scientists are increasingly able to locate, identify, and describe the functions of many of the genes in the human genome. The ultimate goal is to develop screening tools and gene therapies for the general population for cancer and many other diseases.

For more information about NIH, visit http://www.nih.gov.

About the National Center for Research Resources

The National Center for Research Resources (NCRR) is a component of the National Institutes of Health (NIH), one of the world's foremost biomedical research organizations. The institutes and centers that compose NIH fund biomedical research to uncover new knowledge that will lead to better health for everyone in the nation. Among the NIH institutes and centers, NCRR has a unique role. Rather than supporting studies of specific diseases or disorders, NCRR supports programs that ensure that essential tools, materials, specialized facilities, and resources for infrastructure and manpower development are accessible to biomedical researchers throughout the nation. In this way, NCRR enables research in many areas of health and complements the missions of the NIH categorical institutes. NCRR's diverse array of resources is concentrated in four divisions:

Biomedical Technology Research and Research Resources: A large network of Biomedical Technology Resource Centers provides the research community nationwide with the newest and most advanced technologies and techniques. Core scientists at these centers collaborate in multidisciplinary investigations and train visiting researchers to apply these technologies and techniques to basic and clinical studies. In addition, NCRR provides institutional grants to purchase expensive state-of-the-art and high-end instrumentation to be used by a number of investigators on a shared basis.

Clinical Research Resources: A national network of General Clinical Research Centers offers NIH-supported investigators and others specialized research environments that are professionally staffed, have state-of-the-art technologies and Web-based networks, and provide collaborative research opportunities. NCRR also supports networks of National Gene Vector Laboratories and Human Islet Cell Resource Centers, a resource for normal and diseased human tissue for research, and science education for K–12 students and the public.

Comparative Medicine: Animal models and colonies (mammalian and nonmammalian), genetic stocks, and biological materials—such as cell lines, tissues, and organs—help meet NIH-supported investigators' resource needs. In particular, the NCRR network of eight National Primate Research Centers is a valuable resource for investigations of human health and disease.

Research Infrastructure: Diverse grant programs help build, expand, and strengthen the nation's biomedical research environment by developing research infrastructure and faculty capacity at minority institutions that award doctorates in the health or health-related sciences; improving biomedical and behavioral research through an NIH-wide program of matching grants for construction and renovation of research facilities; and increasing competitiveness of institutions from states with limited NIH support.

For more information about research resources and resource-related funding opportunities, visit the National Center for Research Resources Web site at *http://www.ncrr.nih.gov.*

Introduction to *Using Technology to Study Cellular and Molecular Biology*

The abilities to develop and use technology are inherent human characteristics. We recognize problems and look for solutions. Technology makes our lives easier and more comfortable. At the same time, critical research technologies have advanced scientific discovery. Where scientists once gazed in awe at individual cells and microorganisms, we now can view the electron clouds of individual atoms and reconstruct detailed three-dimensional structures of biological molecules, such as proteins, and biological structures, such as ribosomes. As the depth and breadth of scientific knowledge have increased, human health and our quality of life have improved.

What Are the Objectives of the Module?

Using Technology to Study Cellular and Molecular Biology has several objectives. The first is to help students understand that technology is a means of solving a problem. As a consequence, students realize that technologies affect all facets of our lives and that technology relates to more than computers.

The second objective is to allow students to investigate how technology is used to deepen and broaden our knowledge of cellular and molecular biology. Lessons in this module help students sharpen their skills in observation, critical thinking, experimental design, and data analysis. They also make connections to other disciplines such as English, history, mathematics, and social science.

The third objective is to convey to students the purpose of scientific research. Ongoing research affects how we understand the world around us and provides the foundation for improving our choices about our personal health and the health of our community. With this module, students experience how science provides evidence that can be used to understand and treat human disease. The National Center for Research Resources believes that education is an important way to accomplish its mission, which includes helping the public understand the importance of technology use and development to health.

The lessons in this module encourage students to think about the relationships among knowledge, choice, behavior, and human health in this way:

Knowledge (what is known and not known) + Choice = Power

Power + Behavior = Enhanced Human Health

The final objective of this module is to encourage students to think in terms of these relationships now and as they grow older.

Why Teach the Module?

High school biology classes offer an ideal setting for integrating many areas of student interest. In this module, students participate in activities that integrate inquiry science, human health, mathematics, and the interweaving of science, technology, and society. The real-life context of the module's classroom lessons is engaging for students, and the knowledge gained can be applied immediately to students' lives.

"Lesson 3 was a great inquiry experience. Students

enjoyed the activity and at the same time, learned how to apply what they know about technology. The scale activity really got students thinking about the size of the cell and what is in the cell. This was a wow activity."—Field-Test Teacher

"The activities made us think. We figured out things ourselves, and we actually did stuff instead of just reading."—Field-Test Student

What's in It for the Teacher?

Using Technology to Study Cellular and Molecular Biology meets many of the criteria by which teachers and their programs are assessed.

- The module is **standards based** and meets science content, teaching, and assessment standards as expressed in the *National Science Education Standards*. It pays particular attention to the standards that describe what students should know and be able to do with respect to **scientific inquiry**.
- It is an **integrated** module, drawing most heavily from the subjects of science, social science, mathematics, and health.
- The module has a Web-based **technology component** on which there is an interactive database and simulations.
- The module includes built-in **assessment tools**, which are noted in each of the lessons with an assessment icon.

In addition, the module provides a means for **professional development**. Teachers can engage in new and different teaching practices like those described in this module without completely overhauling their entire program. In *Designing Professional Development for Teachers of Science and Mathematics*, the authors write that replacement modules such as this one "offer a window through which teachers get a glimpse of what new teaching strategies look like in action."[16] By experiencing a short-term unit, teachers can "change how they think about teaching and embrace new approaches that stimulate students to problem solve, reason, investigate, and construct their own meaning for the content." The use of a supplemental unit such as this module can encourage reflection and discussion and stimulate teachers to improve their practices by focusing on student learning through inquiry.

The following table correlates topics often included in the high school biology curriculum with the major concepts presented in this module. This information is presented to help teachers make decisions about incorporating this material into the curriculum.

If you have any questions about the supplement, please contact the NIH Office of Science Education at *supplements@science.education.nih.gov.*

Correlation of *Using Technology to Study Cellular and Molecular Biology* to High School Biology Topics

Topics	Lesson 1	Lesson 2	Lesson 3	Lesson 4
The development of new technologies is continuous, and the ability to develop new technologies is characteristic of humans.	✔			✔
Technology provides a means of solving a problem.	✔	✔	✔	✔
Biological structures differ in size.	✔			
Different technologies are used to study biological structures of different sizes.		✔	✔	
Biologists use microscopes to study cells.			✔	✔
Proteins are important biological molecules. Their structure is related to their function.			✔	✔
Science and technology influence, and are influenced by, society.	✔			✔

Implementing the Module

The four lessons in this module are designed to be taught in sequence for approximately one week as a replacement for a part of the standard curriculum in high school biology. The following pages offer general suggestions about using these materials in the classroom; you will find specific suggestions in the procedures provided for each lesson.

What Are the Goals of the Module?

Using Technology to Study Cellular and Molecular Biology is designed to help students reach these major goals associated with scientific literacy:

- to understand a set of basic scientific principles related to the nature and role of technology in biological science and to the effects of technology on human health;
- to experience the process of scientific inquiry and develop an enhanced understanding of the nature and methods of science;
- to recognize the role of science in society and the relationship between basic science and human health; and
- to help prepare high school biology students for the technological world they will inherit.

What Are the Science Concepts and How Are They Connected?

The lessons are organized into a conceptual framework that allows students to move from what they already know about technology, some of which may be incorrect, to gaining a scientific perspective on the nature of technology and its importance to science and to their lives. Students begin learning about technology by developing their own definition of it and learning about scale (*What Is Technology?*). Students continue to explore the concept of scale and investigate resolution (*Resolving Issues*). An investigation of how technologies can be used to solve scientific problems related to human health (*Putting Technology to Work*) allows students to gain a deeper understanding of technology's importance to our lives. The final lesson, *Technology: How Much Is Enough?*, allows students to consider the current state of technology and design new technologies to answer questions of relevance to cellular and molecular biology. The following two tables illustrate the science content and conceptual flow of the classroom lessons.

Science Content of the Lessons

Lesson	Science Content
Lesson 1	Technology; scale
Lesson 2	Resolution
Lesson 3	Microscopy; X-ray crystallography; using technology to understand and solve health-related problems
Lesson 4	History of technology development; development of new technologies

Conceptual Flow of the Lessons

Lesson	Learning Focus*	Major Concept
Lesson 1 *What Is Technology?*	Engage Explore Explain	Technology is a body of knowledge used to create tools, develop skills, and extract or collect materials. It is also the application of science (the combination of the scientific method and material) to meet an objective or solve a problem. Scale is a way to represent the relationship between the actual size of an object and how that size is characterized, either numerically or visually.
Lesson 2 *Resolving Issues*	Explore Explain	It is important to identify the right tool (technology) for the job. An important consideration is technology's ability to resolve structural details of biological objects. Two objects can be resolved if they are illuminated with radiation (that is, a probe) of wavelength (that is, size) that is not larger than the distance separating the objects. Generally, the smaller the probe used, the greater the structural detail, or resolution, that results. Detailed structural knowledge about biological objects requires information obtained in three dimensions, not just two.
Lesson 3 *Putting Technology to Work*	Explore Explain Elaborate	Technologies differ in their resolving capabilities, thus providing different information about an object. Solving a problem requires an appropriate technology or series of technologies. Technology provides valuable tools for solving scientific problems of relevance to human health.
Lesson 4 *Technology: How Much Is Enough?*	Evaluate	New technologies are developed, and old technologies are improved and refined, continuously. This must be done to meet the demands created by new and existing problems.

*See *How Does the 5E Instructional Model Promote Active, Collaborative, Inquiry-Based Learning?* on page 9.

How Does the Module Correlate to the *National Science Education Standards*?

Using Technology to Study Cellular and Molecular Biology supports you in your efforts to reform science education in the spirit of the National Research Council's 1996 *National Science Education Standards* (*NSES*). The content of the module is explicitly standards based. Each time a standard is addressed in a lesson, an icon appears in the margin along with the applicable standard. The following chart lists the specific content standards that this module addresses.

Content Standards: High School

Standard A: **As a result of activities in grades 9–12, all students should develop**	**Correlation to *Using Technology to Study Cellular and Molecular Biology***
Abilities necessary to do scientific inquiry	
• Identify questions and concepts that guide scientific investigations.	Lessons 1, 2, 3, 4
• Design and conduct a scientific investigation.	Lesson 3
• Use technology and mathematics to improve investigations and communications.	Lessons 2, 3, 4
• Formulate and revise scientific explanations and models using logic and evidence.	Lesson 3
• Recognize and analyze alternative explanations and models.	Lessons 1, 3
• Communicate and defend a scientific argument.	Lessons 3, 4
Understandings about scientific inquiry	
• Scientists usually inquire about how physical, living, or designed systems function.	Lessons 3, 4
• Scientists conduct investigations for a wide variety of reasons, such as to discover new aspects of the natural world, to explain observed phenomenon, or to test conclusions of prior investigations or predictions of current theories.	Lesson 3
• Scientists rely on technology to enhance gathering and manipulating data.	Lessons 2, 3, 4
• Mathematics is essential in all aspects of scientific inquiry.	Lessons 1, 4
• Scientific explanations must adhere to criteria.	Lesson 3
• New knowledge and methods emerge from different types of investigations and public communication among scientists.	Lessons 3, 4
Standard B: **As a result of their activities in grades 9–12, all students should develop understanding of**	
Structure and properties of matter	
• The physical properties of molecules are determined by the structure of the molecule.	Lesson 3
Standard C: **As a result of their activities in grades 9–12, all students should develop understanding of**	
The cell	
• Cells have particular structures that underlie their functions.	Lesson 3