

NSTA Pathways to the Science Standards

Guidelines for Moving the Vision into
Practice

Second High School Edition

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Life Science

For decades, many of the nation's life science classrooms have been anything but lively. Biology has been criticized for being content-heavy, overloaded with vocabulary, and tested by rote. Six to seven hundred pages of text, presented to teenagers with limited abilities to reason, constituted what in most cases was the only required science in high schools. By contrast, the classroom of a life science teacher who is moving toward the Standards provides an exciting environment for inquiry and a core of content that is smaller but in greater depth than in the past. Topics are covered in more detail, coursework is integrated, and both teachers and students feel challenged.

New content is the primary force driving a Standards-based life science curriculum. Life science itself is changing rapidly. The Standards define six key areas that should be part of every secondary life science program:

- *The Cell.* Cells are the unit of structure and function of living things.
- *Molecular Basis of Heredity.* Organisms ensure continuity through the genetic code.
- *Biological Evolution.* Change through time has ensured adaptation to changing environments.
- *Interdependence of Organisms.* Energy and nutrients cycle through

the ecosystem.

- *Matter, Energy, and Organization in Living Systems.* Producers store the Sun's energy in organic molecules, and consumers use that energy for life processes.
- *Behavior of Organisms.* Living things respond to stimuli in ways that are both genetic and learned.

For secondary students, the first content area, the study of the cell, is traditionally the first topic presented. Our challenge is to make connections between what students can see with the naked eye (and what concrete thinkers can understand) and what students can see under a microscope. One example is the relationship between structure and function. Just using the microscope can become a source of misconceptions for students who cannot perceive the reality of the view within the ocular.

In a Standards-based classroom, microscope labs will never stand alone. Macroscopic investigations will be paired with microscopic observations to help students bridge the gap from concrete to formal logic. At the same time we will not allow students to rely on rote learning (such as memorizing the names of organelles) to achieve success; vocabulary will be limited, but concepts will be expanded and extended. The cell will be stud-



ied as both a unit of life and a model for the structure/function theme, which is echoed in all life science content areas.

A key understanding in life science is the molecular basis of heredity. The relationships between genetic material, health, disease, and behavior are major issues not only in scientific but also societal contexts. Study of the DNA molecule provides a context for students to understand the nature of modern life science.

But this area of science is moving so quickly that the majority of us lack appropriate content training. In addition, the isolation of our classrooms, the limited nature of school lab facilities, and the difficulty of devoting time to postgraduate training present us with significant challenges in achieving the content standards in molecular biology.

To meet the Standards relating to evolution and the interdependence of organisms, students will need a solid background in mathematics. But this will be difficult to

achieve given that biology, which has traditionally been the first secondary science, has not been perceived as a quantitative science. Even students who do well in math will have difficulty integrating those skills into modern understandings of evolution and ecology.

Similarly, studies of matter, energy, and organization of living things will require students to build on prior understandings of matter and energy. Consequently, today's biology can rarely be accomplished by 9th graders who do not have a strong physical science background. Therefore, to move toward the Standards, many schools are examining the sequence of courses in their secondary programs. Many innovative integrated science curricula, for example, pair exercises in inorganic chemistry and photosynthesis in the same year.

Including behavior as a key content area in life science will be new to many of us. In many classrooms, only one "scientific method" has been taught in the past. Now behavior studies expand our understanding of the nature of science and also often include studies of human behavior. Personal perspectives and the relationship between behavior and individual and community health will be new content areas in many programs.

The shift in life science content may be difficult for many of us for at least four reasons:

- Many of us have not been trained in the new content areas and will need the support of professional development.
- Students may have difficulty mastering the new content because of their level of development or their limited experience in mathematics and physical science.
- Many classrooms have been built and equipped for exercises (like dissection) that will be less common. They lack the facilities (such as gas, water, safe storage) to support the new inquiry experiences.
- We will have to forgo content areas in which our students have been "successful" through memorization and replace them with content areas that require higher levels of logic, mathematics, or other skills.

For traditional life science teachers, what may be most disturbing is what has been left out. The Standards include almost no taxonomy. Systematics is only covered to illustrate the interrelationship between molecular biology and evolution. Similarly, anatomy is only an illustrative tool for the structure/function connection. In the most common textbooks of the 1960s and 1970s, the majority of the content focused on biological nomenclature and descriptive taxonomy, and much of the rest covered anatomy. The reason was pragmatic: Fifteen-year-olds,

who are largely concrete thinkers, could pass a vocabulary test. Only a relatively few students would move on to the more highly logical content of chemistry.

The Standards prescribe inquiry not only as a subject of study (the "way science is done") but also as a method through which content should be learned. This is especially important in high school biology because of the age and experience of most learners. The conceptual journey from concrete to abstract will be repeated for each of the six core content areas for the majority of 9th- and 10th-grade students. Many will experience formal reasoning, methods and patterns of logic, decision-making, and applications for the first time in high school biology. To empower them, we will have to give them the gifts of confidence, excitement, and most important, sufficient time.

Come through the door of tomorrow's life science classroom as it moves toward the Standards. Things look very different:

- Many of the students are 11th and 12th graders and more skilled, because programs will place biology after physical science or integrated with it. Classes are smaller to allow laboratory experiences for all.
- Classrooms are equipped with science tools, materials, and technological resources, including computers and

- access to networks.
- Biology students are using electronic measuring devices and statistical tools. Integration with high school mathematics is the norm. The emphasis on statistics in the National Council of Teachers of Mathematics (NCTM) standards has proven a positive one for life science programs.
- Facilities are available for safely maintaining living cultures. Observation of normal taxes (responses) and behaviors is an essential part of the curriculum.
- The physical arrangement of the classroom is more

flexible. Old-style desks bolted to the floor and facing front are gone. The classroom emphasizes cooperative learning and discovery. The action is not directed toward a podium or focal point, just as the curriculum is no longer directed toward an unalterable set of facts.

- Flexibility extends to time. Block scheduling and cross-curricular connections are the norm. Isolated 45-minute periods aren't flexible enough for tomorrow's life science classrooms.
- Life science programs are clearly integrated with physical science and

mathematics; in many curricula, the courses do not even have separate titles. Unifying Concepts (such as Systems, Order, and Organization; Evolution and Equilibrium; or Form and Function) are the organizers of multidisciplinary studies.

In the pages that follow, we will explore each of the six core life science content standards in detail, with a corresponding example of best practice. The vignettes were selected from thousands of exemplars in American schools.

The Cell

Nature of the Learner

Adolescents who have had the opportunity to explore in the context of the life sciences should be competent at making careful observations through the microscope and making observations and measurements of macroscopic organisms.

As 9th and 10th graders explore life science, they will continue to improve their ability to relate microscopic observations to hypotheses and inferences and to design experiments and analyze data. They will begin to understand models and simulations, make predictions based on the results of experiments,

and relate chemical and molecular structures to observations about structure and behavior.

At least half of the students in beginning biology classes will have occasional difficulty with formal reasoning in this area. For example, they may not be able to relate a text explanation of plasmolysis to a prediction about the effect salinity will have on a cell they can see.

History and Nature of Science

Historically, the study of cell biology has progressed from observation and classification to modern biochemical theory.

Ninth and 10th graders will feel most comfortable with historical science and will need carefully guided experiences to understand modern science. Once students master an idea by rote ("All organisms are made up of cells"), they often resist developing a broader understanding of the concept later in the year. This problem can be minimized by emphasizing the relationship between the limits of technology in each period of scientific discovery. "What was the power of Leeuwenhoek's microscope?" "What could he see?" "What would he have done differently if he had a modern compound microscope?"

Nature of Instruction

Biology classrooms moving toward the Standards place less emphasis on terminology and memorization and more on observation, inference, and synthesis. Fewer topics and more in-depth coverage are essential. This means we will put

- less emphasis on the anatomy of cells and organisms and more emphasis on the relationship between structure and function
- less emphasis on a model cell with every possible organelle and more emphasis on the differentiation of cell structures to accommodate function
- less emphasis on observational labs and more emphasis on investigatory labs

Assessment

Recognizing that students' capacity to reason on paper may be limited, we need to expand assessment to include more practical laboratory challenges and open-ended

responses. Multiple-choice tests do not easily measure the outcomes of a Standards-based life science classroom. However, many hybrid testing situations, which involve simulations, labs, or video presentations followed by written response, have proven to be valid.

Because modern students have so much experience with simulated video images, they often have difficulty believing that what they see through the microscope is "real"—or simply tell teachers that they see what they believe they are supposed to see (from text images). This can be avoided by encouraging students to manipulate the cells they see under the microscope, and then discuss and draw the results of their stimuli (for example, stomata opening and closing in response to humidity; contractile vacuoles reacting to salinity).

Personal and Social Perspectives

Cell biology offers many opportunities for exploring the

personal and societal implications of content. Some of these include

- variations in cell structure within populations
- predictions about the likelihood of disease from observations of cells and tissues
- implications of human actions on cell structure (for example, the effects of smoking on cheek cells)

Science and Technology

Our understanding of life science has increased in direct proportion to the growth of technology. Students should be able to understand the gains in understanding that accompanied the development of microscopes, ultracentrifuge techniques, radioisotope studies, and culture technologies. Unfortunately, the cost of most technologies is still beyond the reach of many classrooms. To circumvent this barrier, we might consider trying to establish partnerships with an industry or university.

A Classroom in Action

Every year for a decade, John Alvarez has begun his biology class with a lab on microscope work. The textbook has examples of such activities with cheek cells, micromerement, and *Anacharis* lysis. John's students complete the labs accurately most of the time.

But each November, when he brings out the microscopes again, he realizes that his students have difficulty relating the structures they see to functions. Because he believes that all students should be able to master cell biology objectives, John spends some time talking with his students and finds that their difficulties fall into three categories:

- *Students with physical limitations.* Some 15-year-olds can't make the fine adjustments necessary to focus a compound microscope on high power; others with strong corrective lenses can't focus through a monocular microscope. Still others can't coordinate sight and fine motor skills.
- *Students who are still concrete reasoners.* Many of John's students have very little difficulty filling out worksheets and identifying the parts of a cell from models. But many others have trouble relating what they see in the microscope to paper-and-pencil diagrams.
- *Students who are only comfortable at the knowledge level.* When

John shows students cells that have undergone structural changes (lysed plant cells, endoplasmic reticulum increases caused by low-level toxins), these students have difficulty relating the change in structure to the stimuli.

Using the Science as Inquiry standards as a guide, John redesigns his biology laboratories to provide experiences that will help students form models by using logic and evidence. Reversing the normal sequence of instruction, he asks students each week during the fall to use evidence to build a model in some context. A diagram on the bulletin board reinforces the model-building process.

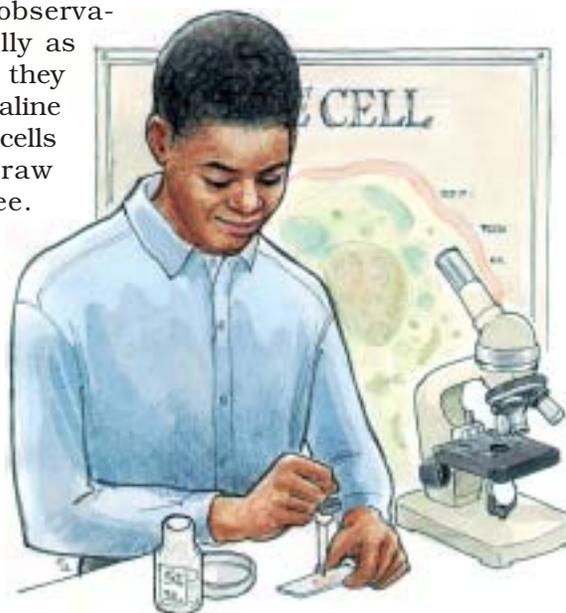
For example, in the unit about cell organelles, students begin by examining *Anacharis* cells under the microscope, drawing their observations as carefully as they can. Then they add 5 percent saline solution to the cells and again draw what they see. They work in groups to respond to these questions: "How many layers are on the outside edge of each cell?" "Which of the layers is stiff?" "Which is affected by salinity?"

The students then draw or build models of what they see. They research their models by making more observations, viewing slides of other types of cells, and reading.

For students who have trouble seeing through the microscope, John uses a variety of technologies, including a small video camera hook-up (a simple security camera mounted vertically) that students can engage or remove to compare their own observations to those of others and a videodisc of slides they can refer to when discussing their observations.

For each cell biology concept in the fall, John's students follow the same path of inquiry. They are always reminded to explore first. Biological terms are introduced much later in each unit. John uses drawings and interviews

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throughout to search for misconceptions.

John's principal has supported his efforts to move toward the Standards even though John told him that he would only cover about two-thirds of the content he had previously covered in the fall semester. Together they examined the textbook to determine which chapters should be omitted to allow this slower pace. Then they informed parents and the school board about the change and included a summary of the Content Standards.

When John gave his students their midterm exam in January, he discovered that in relation to students in previous years,

- This year's students retained more knowledge and had a better understanding of concepts from the fall.
- They were better able to relate structure to function.
- They were less confused by terms that were semantically similar (for example, cell wall versus cell membrane).

Molecular Basis of Heredity

Nature of the Learner

Beginning biologists in grades 9 or 10 can usually follow directions in carrying out chemical or genetics experiments and can build models and make observations about their structure.

With practice, students of this age will improve their ability to draw inferences based on chemical reactions, isolate variables in experiments, and use combinatorial reasoning in genetics.

High school students will only be beginning to make predictions based upon probability, identify the information needed to solve genetics problems without prior models, and understand genetic control systems. Even when they can reliably solve problems in permutation and combination, probability, and statistics in mathematics class, they will have difficulty transferring that information to situations in life science. (We may have to help them make this transfer or, if they are 9th graders, teach them simple statistics and probability.)

History and Nature of Science

Today, genetics is based on chemistry, and students need to be able to relate the geometry of models to the behavior of unseen molecules. Too great an emphasis on 19th-century genetics can prevent

students from appreciating the implications of modern genetics.

For example, once students are able to predict the ratios of Mendelian traits, they often overgeneralize and believe that many or most traits in humans can be predicted this way. This overconfidence can become a barrier to further understanding. The work of historical figures should be used to illustrate processes (such as statistics or geometric modeling) rather than as sources for facts.

Nature of Instruction

A Standards-based biology course needs to follow student experiences in physical science and must have mathematics integrated throughout of the course. Geometry and statistics can be reviewed and illustrated by genetics experiments. The methods of mathematical and geometric modeling will be new to most students.

While genetic engineering laboratories are commonplace in many biology classrooms, traditional work with *Drosophila* is still useful when teaching the value of mathematics, models, predictions, and inferences. Making a prediction about three generations of organisms and seeing it verified (within predetermined confidence intervals) successfully integrates mathematics and life science.

Assessment

One of the best uses for historic data in genetics is in assessment. Examples might include Mendel's data, Chargoff's experiments, or plots of fossil statistics. Students should be able to find patterns in data and to understand the range of variation due to chance. We can either provide pre-selected samples of offspring (for example, bags of peas in approximately 9:3:3:1 ratios) for students to analyze and explain, or we can provide data tables.

A less appropriate method of assessment is a human pedigree; very few human

ing model "genes" and asking students to decode them.

Personal and Social Perspectives

The study of genetics provides a basis for understanding the human condition, including developmental differences and disease. This can be vital to adolescents as they explore their relationship to others and their personal best.

Many textbooks oversimplify the nature of gene action to provide situations in which students can solve mathematical problems. While the development of math skills may be important, it is more important that students un-

Science and Technology

DNA science is an empirical base for forensic science, genetic engineering, and discoveries in evolutionary science. Today's genetic technology has such widespread application that understanding the processes should be part of every secondary biology course.

The equipment required for students to perform genetic transformations or DNA fingerprinting is expensive. However, many teachers and schools have found great success by creating county consortia and purchasing laboratory equipment for advanced labs in common. One California county circulates all the equipment for genetic transformation laboratories among its schools all year, reducing the cost per classroom to a manageable figure. County school service agencies can be invaluable in arranging such shared-time equipment.



TAPESTRY

phenotype characteristics are truly Mendelian. Asking for definite interpretations of human characteristics can lead to overgeneralizations.

For students who have difficulty with formal reasoning, physical models can be important tools for assessment. Most of us are comfortable with laboratories where students use models, paper clips, or paper units to simulate DNA. That same material can be converted to an authentic assessment by creat-

ing model "genes" and asking students to decode them. understand variability and probability in relationship to genetics. The tendency of young biologists to look for absolutes will hinder understanding. A role-play of genetic counseling could be an application or an assessment. By asking students to assume the role of health care professional for an imaginary client, we can help them understand the difference between probability and inevitability and the importance of behaviors in determining health.



Topic: heredity
Go to: www.scilinks.org
Code: PAH04

A Classroom in Action

Tarzza Jones's fellow teachers use videos and movies frequently. But the passive nature of watching movies and the time it takes disturb him. He wants to move his class toward inquiry, but doesn't want to abandon the information in the school video collection entirely.

Tarzza knows that at times his sophomores are concrete reasoners and they understand only vaguely the process of geometric modeling in biochemistry. Using materials from a variety of sources, he develops a unit in which students "rediscover" DNA, and he interweaves it with the classic BBC movie *The Race for the Double Helix*. His goal is to help students follow the logic and methods of Watson and Crick.

Day 1: Students extract DNA from fresh materials. They are encouraged to explore the viscosity and appearance of the spooled DNA. They describe their physical observations in a journal and use their imaginations to create "if-then" statements that relate observable physical properties to possible molecular shapes.

Day 2: Students take a look at Watson and Crick and explore what was known about DNA in their time. They also examine the tables from Chargoff's classic experiments. They develop a series of arguments to "prove" that genetic material is a protein and outline the physical char-

acteristics of DNA known by chemists in 1950. The class views the first 15 minutes of the film, in which Watson is presented as a student looking for a research idea.

Day 3: An enlargement of Rosalyn Franklin's image of DNA is on the board. Class begins with speculation: "What can you see?" They watch the next 20 minutes of the film. Rosalyn Franklin's work is featured as well as arguments of biologists about the structure of DNA. Tarzza encourages students to identify with the scientists in the film, including Franklin. "Was it fair to use her work?" he asks. "Was she given appro-

priate credit?" For homework, students take home copies of Chargoff's data with ox and human thymus, spleen, and liver as well as Franklin's photos. Students are challenged to draw up a series of conclusions about what the data says about the molecule.

Day 4: It's time for model building. Tarzza asks, "Can you create a model that is geometrically compatible with the photo and statistically compatible with Chargoff's data?" "Can you design experiments that would test the accuracy of that model?" Students are given tag-board

continued on next page



models of bases (from BSCS, 1989) and asked to construct a DNA molecule. (Procedures and limitations are presented in the BSCS text.) Students are challenged to develop additional “if-then” statements and to discuss how scientists would test this model.

Day 5: Students watch the end of the movie, and assessment begins. They take home one of two pages with sample research data from scientists who followed Watson and Crick:

- autoradiography and a one-sentence summary of results from Maurice Wilkins’s 1956 paper (with photos similar to those of Franklin but with varying environmental conditions)
- photos of root tips treated with tritiated thymidine taken by Herbert Taylor (DNA picks up thymidine in the first generation; radioactivity is reduced by one-half in the second generation.)

Students are to answer two questions for discussion during the next class: “What do the results imply?” “Do the results support the geometric model or refute it?” Because members of each group have different assignments, they return Monday with much to discuss.

How is Tarzza’s historical simulation different from watching a video about a fa-

mous scientist? Tarzza has identified which processes of the historical scientists are meaningful in today’s science. For example, Watson and Crick’s research illustrates the use of geometric modeling. Moving from photos to geometric models to testable inferences, and then inviting the scientific community to participate in the testing is a sequence that still works today. Moreover, many 10th-grade biology students will have concurrent experience with geometry; so, learning about the methods of Watson and Crick can reinforce the significance of many abstract geometric principles.

Tarzza has not ignored the maturity level of his students, who enjoy seeing scientists as interesting, valuable people, not just brains.

Jeff Goldblum’s performance, the uniqueness of Watson, and the dynamics between Franklin and the men in her shop are all part of the human side of science. Tarzza realizes that the leap from concrete models to formal inferences will be difficult for his students. So he reinforces their attempts by supporting different learning styles and using the affective value of the lesson.

What *shouldn’t* we do with a movie in a Standards-based classroom?

- Emphasize the answer, rather than the process.
- Allow students to take in information passively.
- Show a video from start to finish without active analysis.
- Present the DNA model as a “finished product.”

Resources for the Road

Biological Sciences Curriculum Study (BSCS). (1989). *Advances in Genetic Technology*. Lexington, MA: D. C. Heath.

Chargoff, E. (1950). Chemical Specificity of Nucleic Acids and Mechanisms of Their Enzymatic Degradation. *Experientia*, 6, 201–209.

Taylor, H. (1958). Organization and Duplication of Genetic Material. *Proceedings of the X International Congress on Genetics*, Vol. 1.

Watson, J. D., and Crick, F.H.C. (1953). Genetic Implications of the Structure of Deoxyribonucleic Acid. *Nature*, 171, 964–967.

Wilkins, M. (1956). Physical Studies of the Molecular Structure of DNA and Nucleoprotein. *Cold Spring Harbor*, 21.