Scientific Inquiry: Learning Science by Doing Science

By Nancy P. Moreno, PhD
Baylor College of Medicine

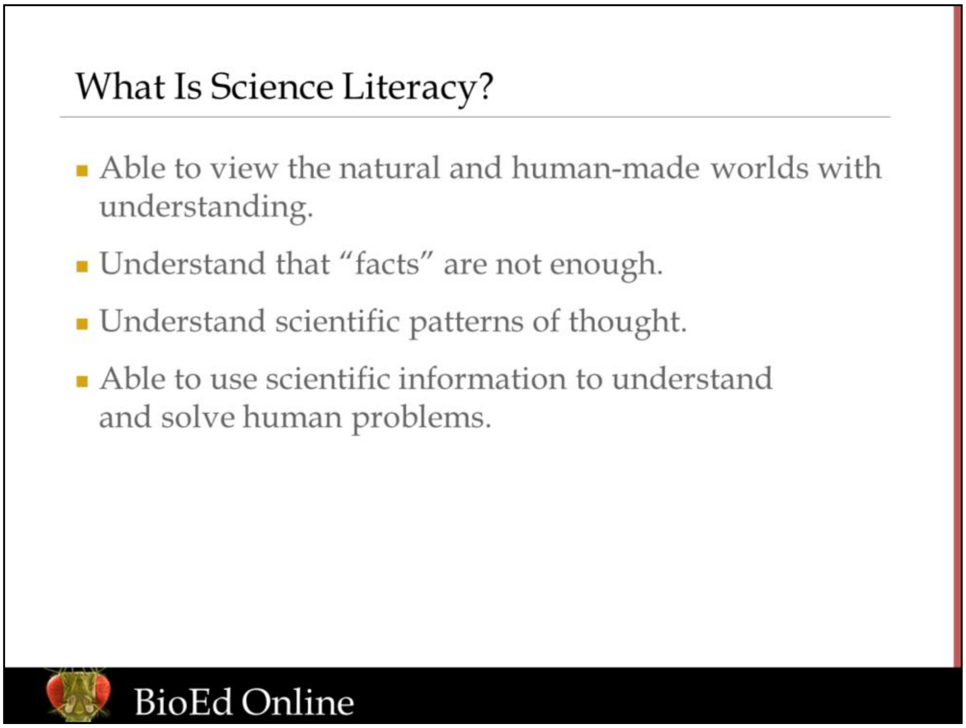
BioEd Online

What is science?

Textbooks and the media often convey inaccurate portraits of scientists and what they do. Science can be viewed as a body of knowledge and as a way of building knowledge. It consists of asking questions about the natural and manmade worlds and looking for answers to those questions in a systematic and repeatable way. In general, scientists believe that questions about how the world works can be answered; scientific knowledge is subject to change; and knowledge gained from the study of one part of the world (or universe) can be applied to other parts.

Reference:

American Association for the Advancement of Science. (1993). *Project 2061: Benchmarks for Science Literacy*. New York: Oxford University Press.



What is science literacy?

Scientifically literate persons are able to use science knowledge in their everyday lives to make decisions. In addition, scientifically literate persons are able to describe and predict natural phenomena, and to evaluate articles and reports in the popular press that are related to science. Science literacy also implies that a person understands how scientists build knowledge by asking questions and conducting investigations, and is able to pose and evaluate arguments based on evidence.

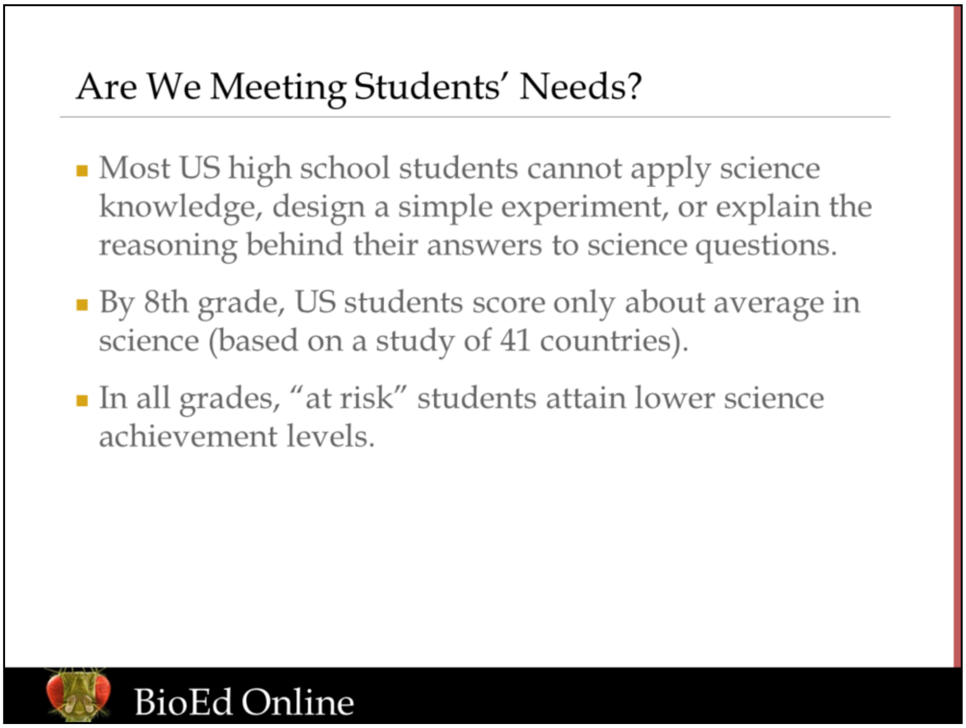
Reference:

National Research Council. (1996). *National Science Education Standards*. Washington, DC: National Academy Press.

Why do we need science?

Students in the 21st century need to develop baseline science knowledge and technology skills. More and more jobs are requiring facility in at least basic computing and telecommunications. We are surrounded by technology on a daily basis. Supermarket scanners employ LASER technologies to read barcode labels, package delivery systems use scanners and computer-based technologies to track each shipment from door to door, and modern pharmaceutical companies apply the latest advances in biology to create new and unique medicines and treatments for diseases.

In addition, workplaces are demanding that employees be able to work as teams and solve problems. Science teaches students to think critically, use evidence appropriately, and work collaboratively to solve problems. At the same time, science knowledge helps students to make better choices about their own health and lifestyles and to be more informed as voters.



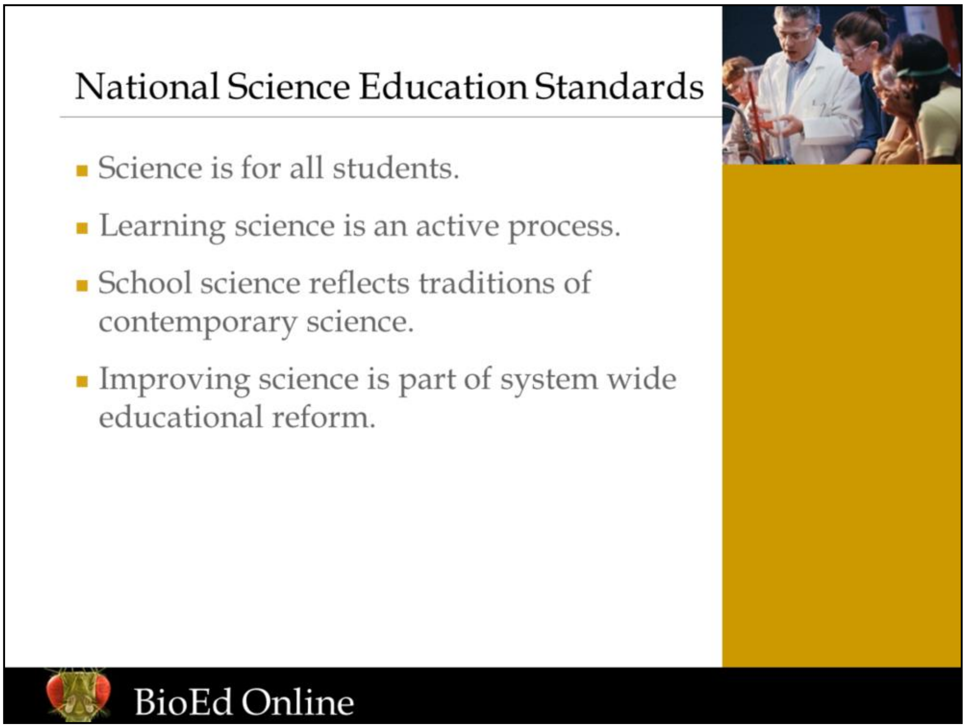
Are we meeting students' needs?

Comparisons of US students with those of other countries continue to demonstrate the need for improvements in the ways science is taught in schools. Most US students are not scientifically literate by the time they graduate from high school. In addition, in some locations, students belonging to underrepresented minority groups, economically disadvantaged students and those considered "at risk" attain lower scores on standardized measures of science achievement than other student groups.

References:

National Center for Educational Statistics, National Assessment of Educational Progress. (2004). Retrieved 4-20-2004 from http://nces.ed.gov/nationsreportcard/

Schmidt, W.H., McKnight, C.C., Cogan, L.S., Jakwerth, P.M., Houang, R.T. (1999). *Facing the Consequences: Using the TIMSS for a Closer Look at US Mathematics and Science Education*. Boston: Kluwer Academic Publishers.



National Science Education Standards

Published in 1996, the National Science Education Standards present a vision of a scientifically literate population by outlining what students need to know, understand and be able to do. The standards are guided by the following principles.

Science is for all students. All students, regardless of age, sex or race/ethnicity, disabilities or interest should have opportunities to attain high levels of scientific literacy.

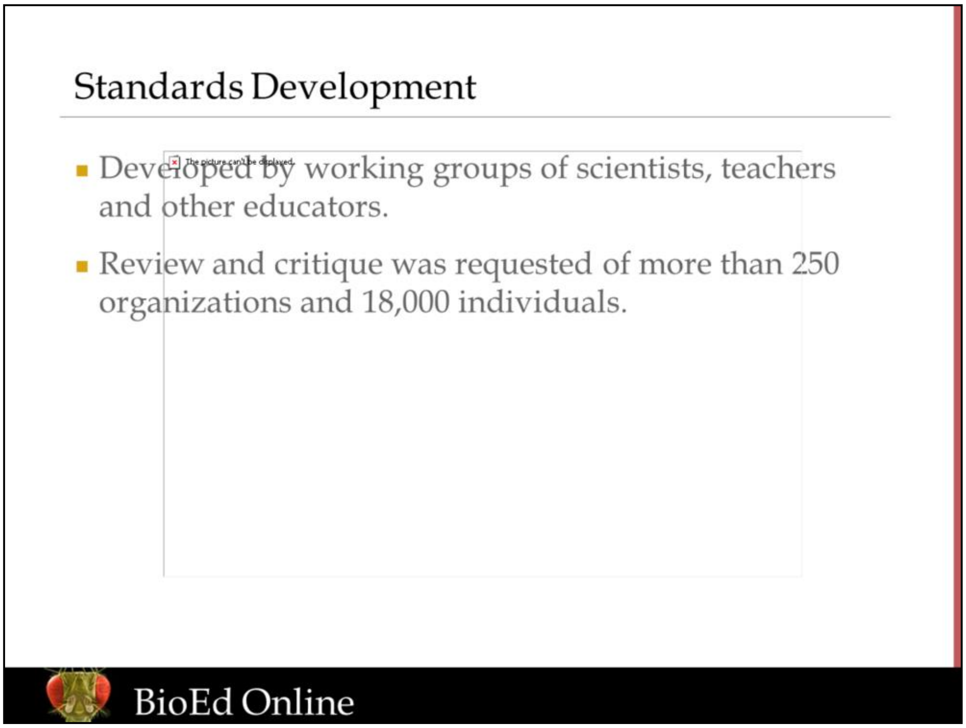
Learning science is an active process. Students need to do science to learn science. Therefore, they must have opportunities to ask questions, conduct investigations, make observations, construct and text explanations and communicate their ideas to others.

School science reflects traditions of contemporary science. To develop science knowledge, students must be familiar with and have conducted scientific investigations.

Improving science is part of system wide educational reform. Local, state and national education reform efforts should complement one another across disciplines and grade levels.

Reference:

National Research Council. (1996). *National Science Education Standards*. Washington, DC: National Academy Press.

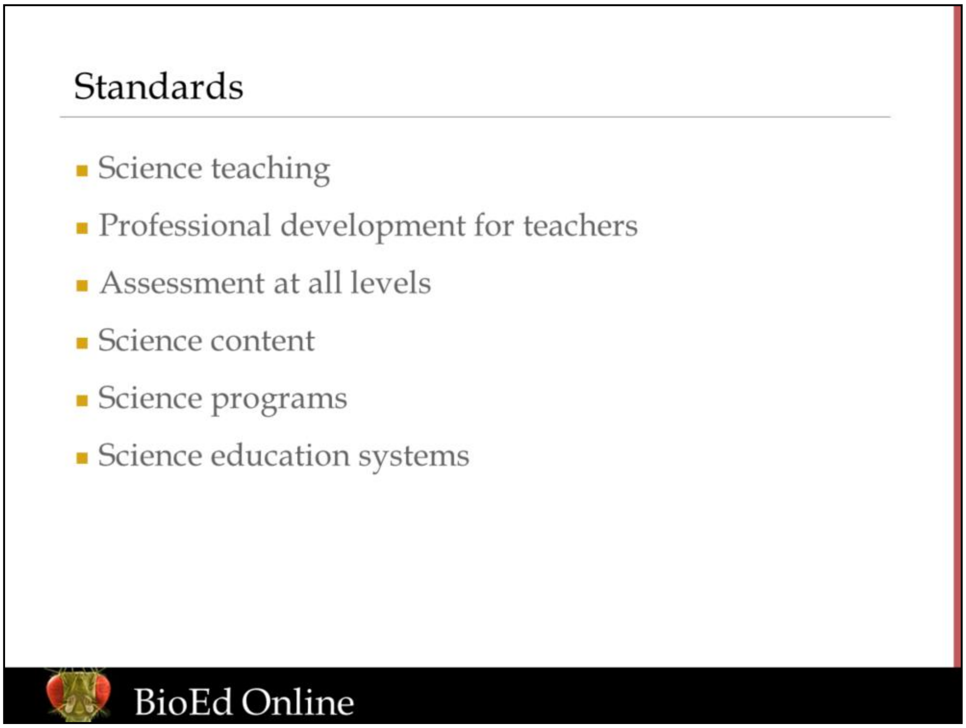


Standards Development

Development of the National Science Education Standards was overseen by the National Committee on Science Education Standards and Assessment of the National Research Council. This committee first met in May, 1992. Input to the Standards was requested of science teachers, scientists, science educators and many other contributors. The first complete pre-draft of the Standards was released in 1994. A draft version was released for nationwide review later that year. More than 40,000 copies were released to approximately 18,000 individuals and 250 groups.

Reference:

National Research Council. (1996). *National Science Education Standards*. Washington, DC: National Academy Press.

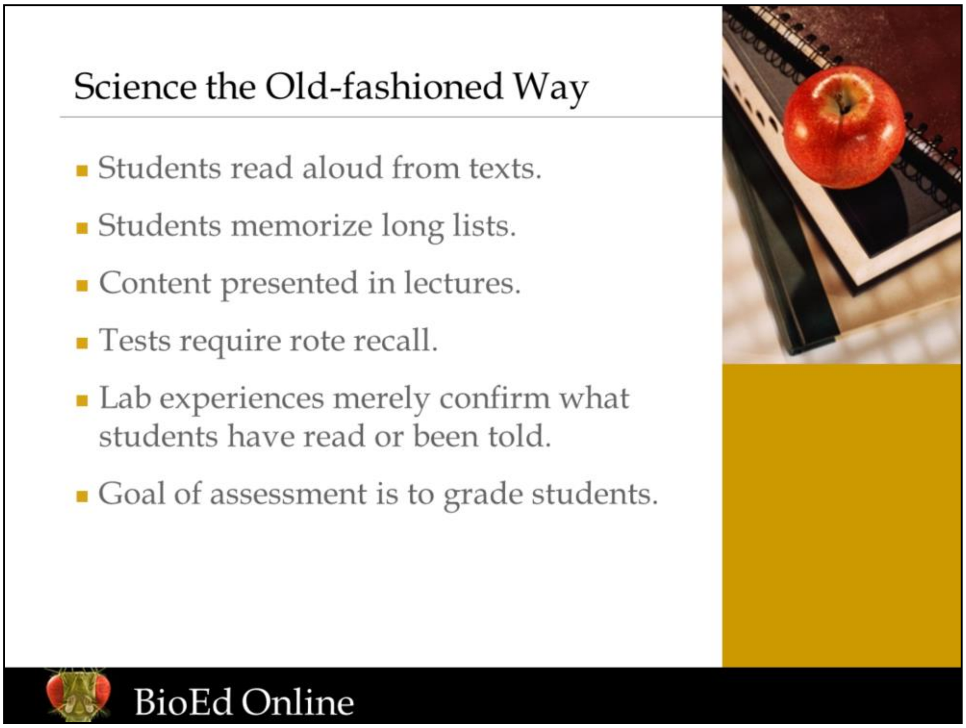


Standards

The National Science Education Standards provide recommendations not only for what students should know and be able to do, but also for science teaching, teacher professional development, assessment, science programs and science educational systems. Thus, the Standards provide a complete blueprint for effective science teaching and learning.

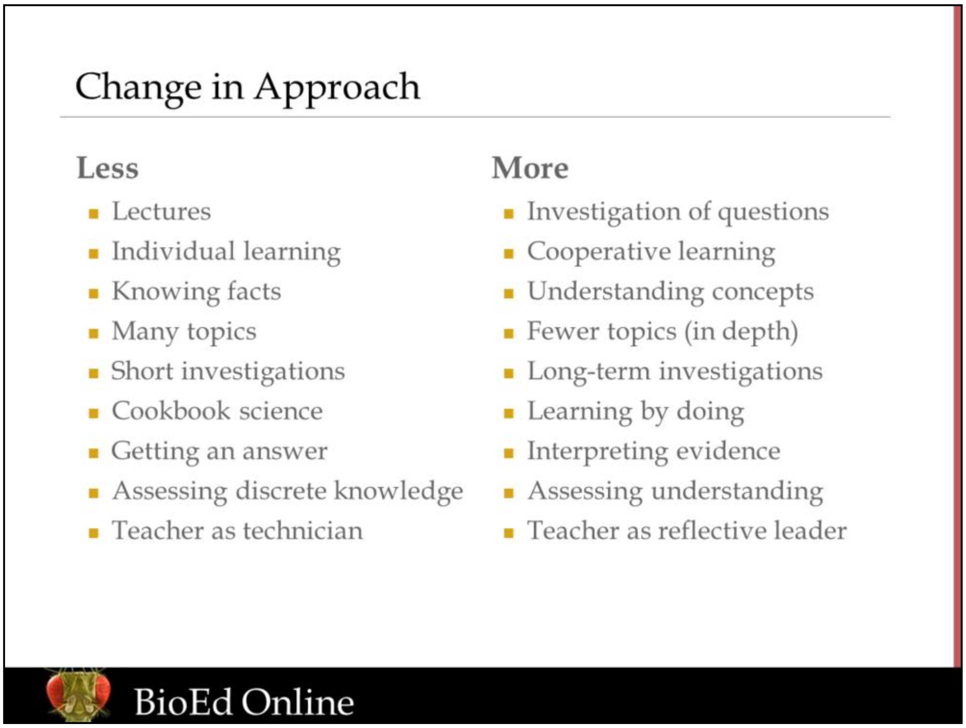
Reference:

National Research Council. (1996). National Science Education Standards. Washington, DC: National Academy Press.



Science the Old-fashioned Way

Traditional methods of teaching science often involve detailed lectures or lengthy readings from textbooks. Assessment often has emphasized the memorization of large numbers of facts. During laboratory exercises, students follow instructions “cookbook” style. Unfortunately, these methods often convince many students of all ages to pursue other areas of study. Furthermore, research is showing that these types of instructional approaches do not meet the needs of large numbers of learners.



Change in Approach

The National Science Education Standards, the National Science Foundation and Project 2061 (among others) promote dramatic changes in the ways science is taught. These changes reflect growing recognition of the need to engage students actively in the process of science through collaborative investigations; cover fewer topics, but with greater depth; and use evidence to formulate explanations. These approaches also imply important changes in the roles of teachers and in the ways that student learning is assessed.

For example, research is beginning to show that students benefit more from the study of fewer topics—with greater in-depth coverage of those topics—than from the superficial coverage of many seemingly unrelated topics. In fact, the typical US science curriculum has been criticized as being “a mile wide and an inch deep” (Schmidt *et al*., 1999).

In addition, science learning should build on earlier experiences as students move through grades K-12. As noted by the National Science Education Standards (1996), “in the early grades, instruction should establish the meaning and use of unifying concepts and processes—for example, what it means to measure and how to use measurement tools. At the upper grades, the standard should facilitate and enhance the learning of scientific concepts and principles by providing students with a big picture of scientific ideas—for example, how measurement is important in all scientific endeavors.” At the same time, it is important to acknowledge that students often will have their own ideas about natural phenomena that are inconsistent with accepted science knowledge. Since these ideas can be resistant to change, it is important to provide students with opportunities to challenge and change their own understandings through inquiry.

The Standards also note that relating science to students’ own experiences helps to demonstrate the relevance of science to everyday life and can be an important force in motivating students to learn.

When students investigate a scientific question, they develop content knowledge in addition to task-specific and critical thinking skills.

References:

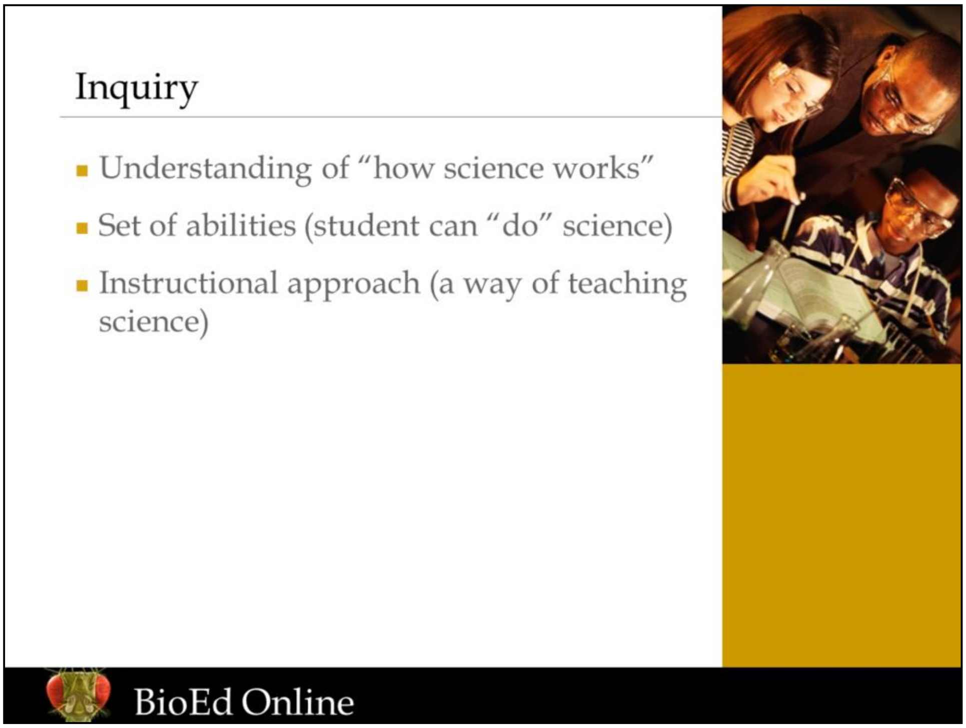
American Association for the Advancement of Science. (1993). *Project 2061: Benchmarks for Science Literacy*. New York: Oxford University Press.

National Research Council. (1996). *National Science Education Standards*. Washington, DC: National Academy Press.

National Science Foundation. (1997). *The Challenge and Promise of K-8 Science Education Reform. Foundations, Volume 1*. Arlington, VA.: National Science Foundation, 97-76.

Schmidt, W.H., McKnight, C.C., Cogan, L.S., Jakwerth, P.M., Houang, R.T. (1999). *Facing the Consequences: Using*

TIMSS for a Closer Look at US Mathematics and Science Education. Boston: Kluwer Academic Publishers

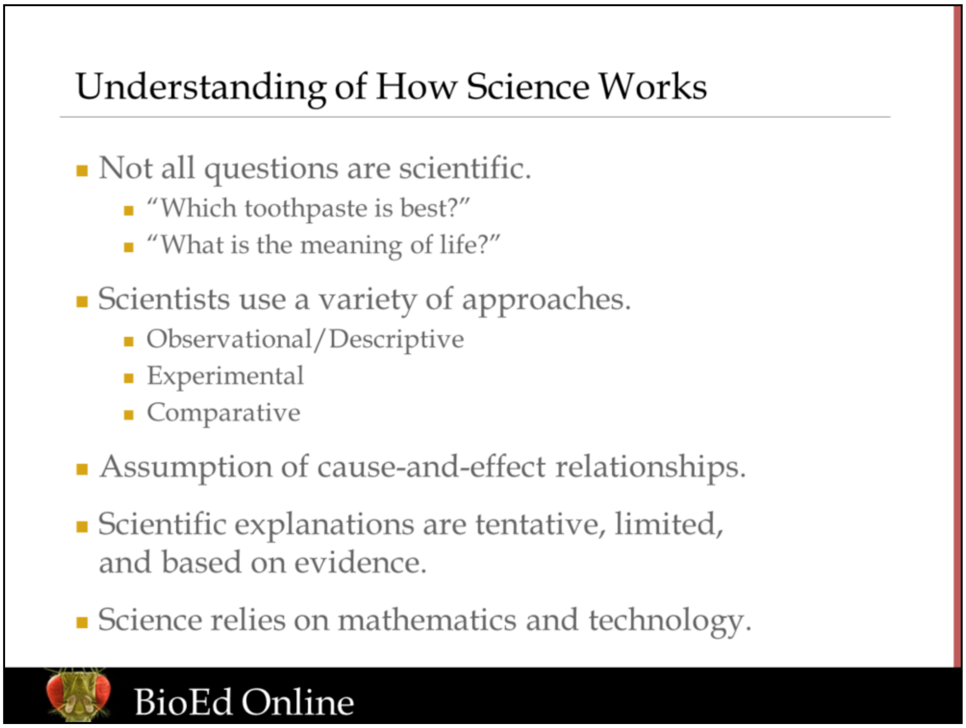


Inquiry

The term "inquiry" can be interpreted in three different ways in the context of science education. It can be thought of as understanding how scientists build knowledge about the natural world. It also can refer to the development of students' skills actually to investigate a scientific question, or to a way of teaching science based on the asking and investigation of questions about the natural world.

References:

National Research Council. (1996). *Inquiry and the National Science Education Standards*. Washington, DC: National Academy Press.



Understanding of how science works

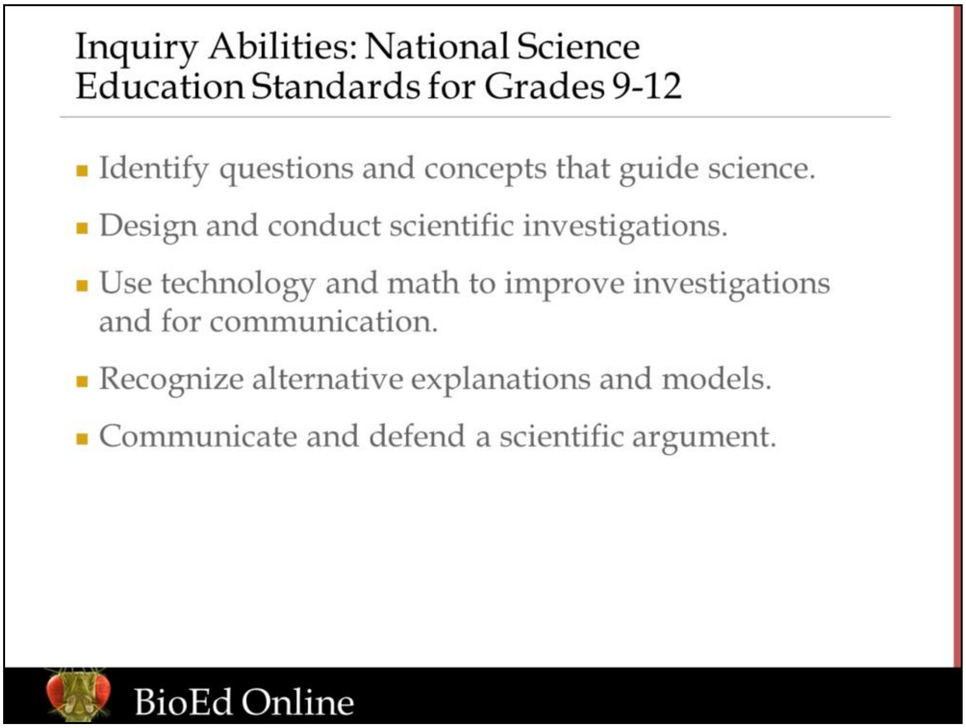
When students learn science through inquiry, they also develop understandings about the nature of science. In particular, students learn to distinguish between a scientific question that can be tested or investigated and questions that are not scientific. Some non-scientific questions can be reframed as questions that can be investigated scientifically. For example, the question, "which toothpaste is best?" is non-scientific because "best" cannot be measured. However, the question could be reformulated to focus on a measurable quality of toothpaste, such as tooth whitening, prevention of cavities, etc. "What is the meaning of life?" is a question that falls outside the realm of science.

Scientists use different approaches, depending on the questions they are investigating. Many scientists study natural phenomena instead of conducting controlled experiments. Geologists, epidemiologists and astronomers, for example, often must rely on detailed observations to uncover complex mechanisms or cause-and-effect relationships. Others, such as ecologists, frequently make comparisons between similar or dissimilar systems.

Even though the vast body of scientific knowledge is relatively stable, all scientific explanations are considered to be tentative. Each explanation is based on a specific set of evidence. There are no absolute scientific truths.

Reference:

National Academy of Sciences. (1998). *Teaching About Evolution and the Nature of Science*. Washington, DC: National Academy Press.



Inquiry Abilities: National Science Education Standards for Grades 9-12

The National Science Education Standards provide guidelines for the development of inquiry skills at all grade levels and note that even "from the earliest grades, students should experience science in a form that engages them in the active construction of ideas and explanations and enhances their opportunities to develop the abilities to do science." At the same time, students should "do science" in ways that are developmentally appropriate.

In the earliest grades, instruction focuses on the development of students' basic skills for science, such as learning to use simple measurement tools and making careful observations. Later, students develop their abilities to recognize patterns and cycles in nature. Usually, students in upper elementary school begin to use tools, such as microscopes, to extend the senses. Students in these grade levels also begin to understand cause-and-effects relationships among single variables. Middle school students are able to design, conduct and, most importantly, explain controlled experimental designs.

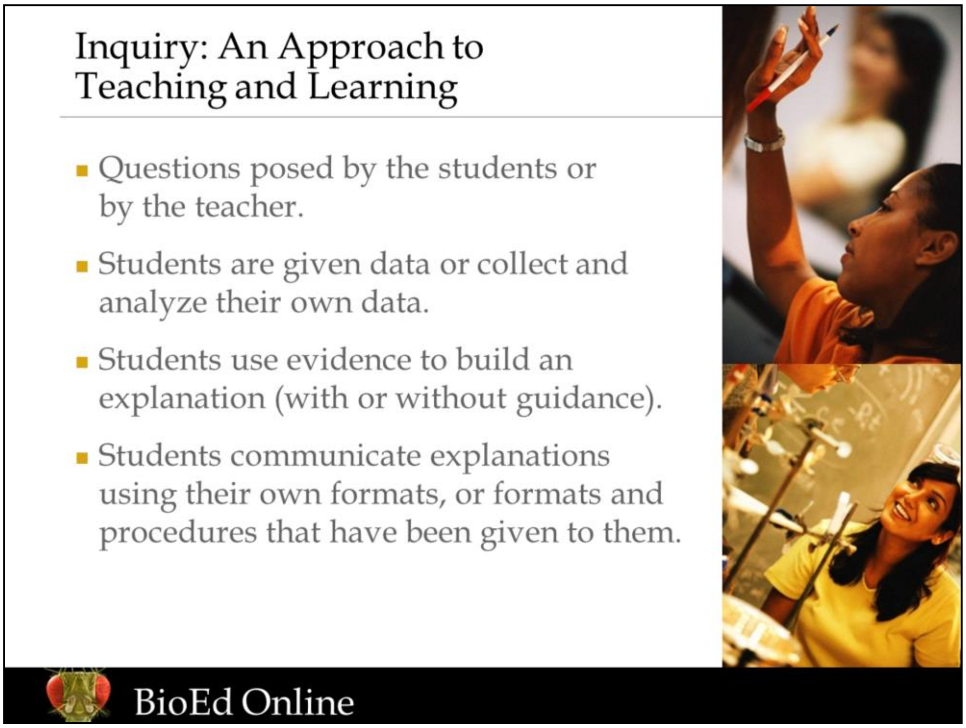
High school students should be able to formulate a testable hypothesis and design a simple investigation. They also should have opportunities to learn to analyze evidence, use mathematics and technology to interpret or communicate data and explanations, recognize alternative models, and be able to formulate and defend an evidence-based scientific explanation.

When students are allowed to build on previous knowledge and skills, they acquire more thorough understandings than if they are taught new skills and processes in isolation.

References:

Bransford, J.D., Brown, A.L., Cocking, R.R. (Eds). (1999). *How People Learn: Brain, Mind, Experience and School*. Washington, DC: National Academy Press.

National Research Council. (1996). *National Science Education Standards*. Washington, DC: National Academy Press.

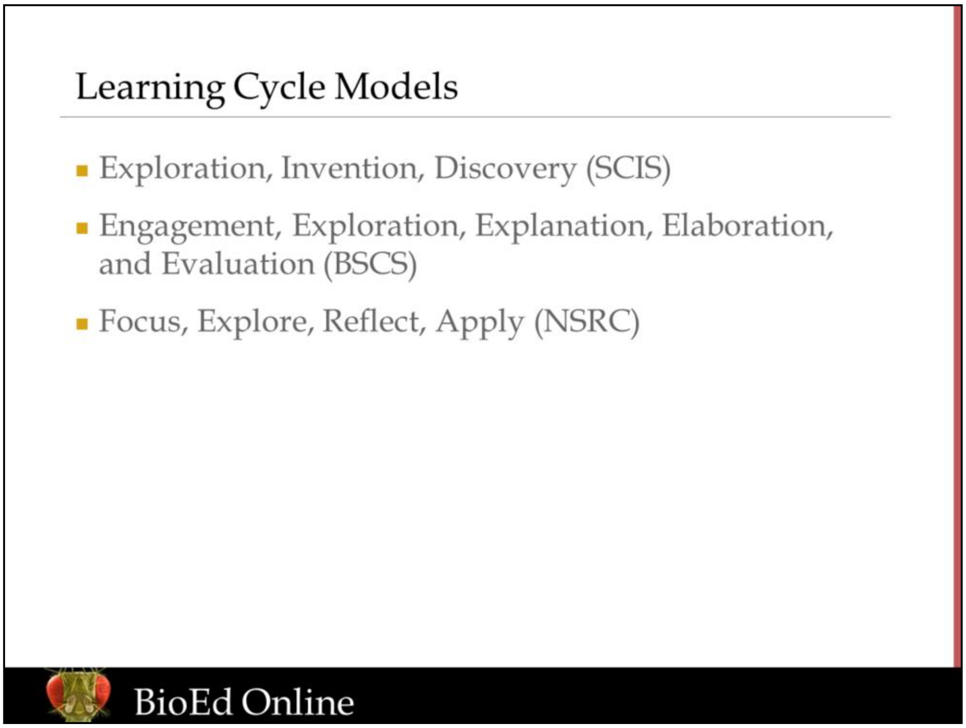


Inquiry: An approach to teaching and learning

There are many approaches to teaching inquiry. Questions can be posed by the teacher or by the students. Students can define what constitutes evidence and collect it themselves, or the teacher can give students data to analyze. Students can formulate their own explanations based on evidence, or the teacher can provide guidance about possible explanations. Students can create their own presentations based on their investigations, or the teacher can provide steps and procedures for communication.

Reference:

National Research Council. (1996). *Inquiry and the National Science Education Standards*. Washington, DC: National Academy Press.



Learning Cycle Models

Many effective instructional models for teaching science involve versions of the "learning cycle." Generally, learning cycle models are (USE? APPLY? REFLECT?) constructivist approaches. In other words, the learner builds his or her own understanding. Learning cycle models typically include a focus or discovery phase, which serves to pique student interest and allow teachers to assess existing student understandings. Next, students have opportunities to explore a question and collect evidence. Finally, students reflect on their investigations to build a new understanding. Learning cycle assessments usually have students applying their new knowledge to a unique situation. The teacher's role is that of facilitator or coach.

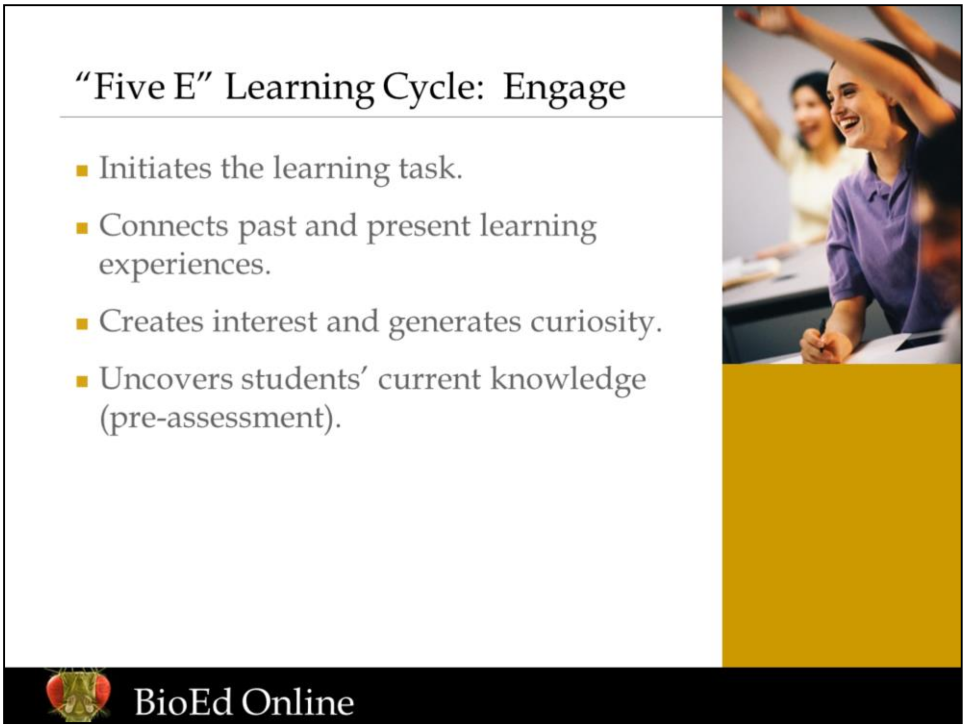
References:

Atkin, J.M., Karplus. (1962). Discovery or Invention. *The Science Teacher*, 29(2), 121-143.

Bybee, R.W. (1997). *Achieving Scientific Literacy: From Purposes to Practice*. Portsmouth, NH: Heinemann.

Marek, E.A., Cavallo, A.M.L. (1997). *The Learning Cycle: Elementary Science and Beyond*. Portsmouth, NH: Heinemann.

National Science Resources Center. (1997). *Science for All Children*. Washington, DC. National Academy Press.



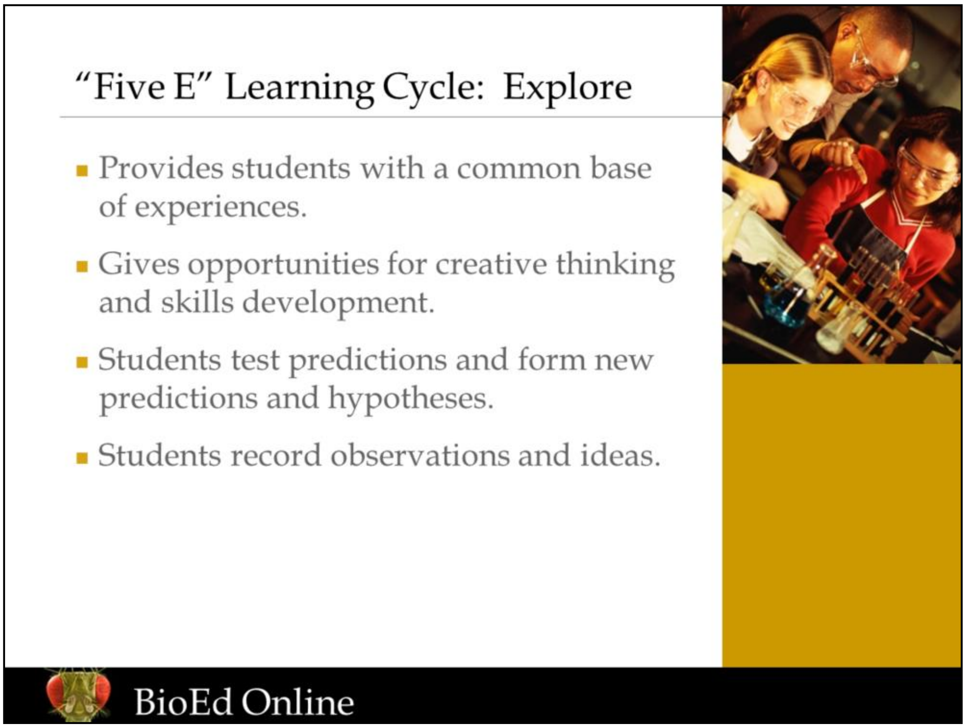
“Five E” Learning Cycle: Engage

The “Five E” Learning Cycle model consists of five stages. The first stage focuses student attention and allows the teacher to identify any preconceptions that will need to be addressed during the course of the lesson.

References:

Bybee, R.W. (1997). *Achieving Scientific Literacy: From Purposes to Practice*. Portsmouth, NH: Heinemann.

Trowbridge, L.W., Bybee, R.W. (2000). *Teaching Secondary School Science* (6th-7th ed.). Merrill.



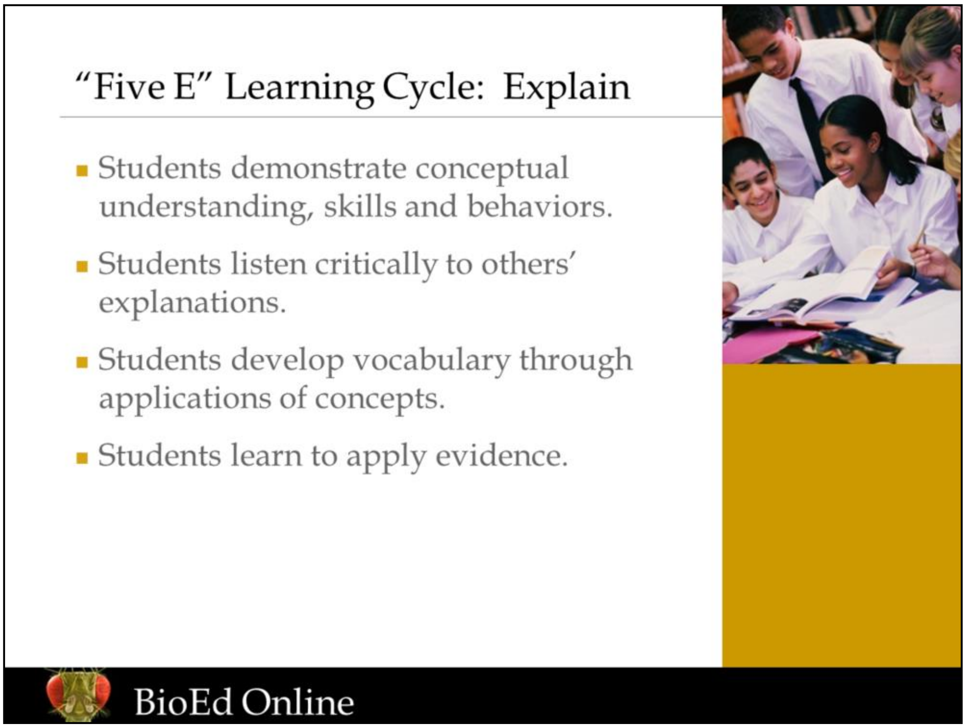
"Five E" Learning Cycle: Explore

During the Explore phase of the "Five E" Learning Cycle model, students work collaboratively to investigate a question. Students have opportunities to test hypotheses and predictions, record observations and develop skills.

References:

Bybee, R.W. (1997). *Achieving Scientific Literacy: From Purposes to Practice*. Portsmouth, NH: Heinemann.

Trowbridge, L.W., Bybee, R.W. (2000). *Teaching Secondary School Science* (6th-7th ed.). Merrill.



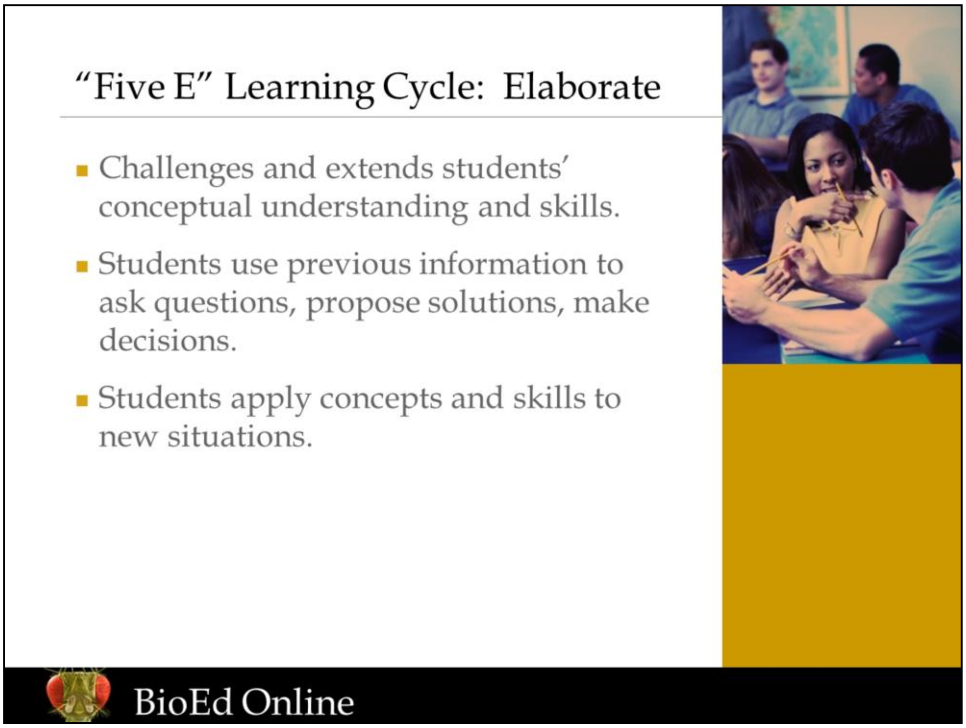
"Five E" Learning Cycle: Explain

In the Explain phase of the "5 E" Learning Cycle model, students provide possible solutions or answers and listen critically to other students' explanations. This phase also provides an opportunity for students to demonstrate their conceptual understanding and development of skills.

References:

Bybee, R.W. (1997). *Achieving Scientific Literacy: From Purposes to Practice*. Portsmouth, NH: Heinemann.

Trowbridge, L.W., Bybee, R.W. (2000). *Teaching Secondary School Science* (6th-7th ed.). Merrill.



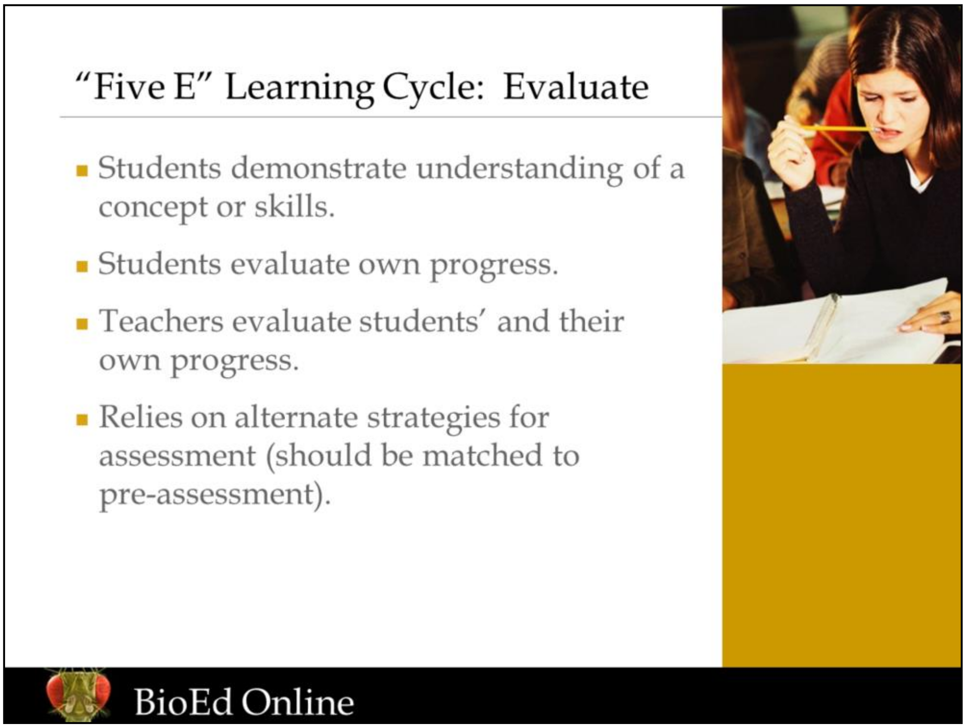
"Five E" Learning Cycle: Elaborate

The Elaborate phase of the "5 E" Learning Cycle model provides opportunities for students to extend their knowledge by providing them with new experiences. Students must apply previous information to ask questions, propose solutions and make decisions.

References:

Bybee, R.W. (1997). *Achieving Scientific Literacy: From Purposes to Practice*. Portsmouth, NH: Heinemann.

Trowbridge, L.W., Bybee, R.W. (2000). *Teaching Secondary School Science* (6th-7th ed.). Merrill.



"Five E" Learning Cycle: Evaluate

During the Evaluate phase of the "5 E" Learning Cycle model, students demonstrate an understanding or knowledge of a skill or concept. Usually, any questions posed to the learner are open-ended and require critical thinking. Self-assessment by students also should be encouraged.

Evaluations can focus on students' conceptual understandings, skills development or other learning outcomes. Appropriate assessment strategies might include performance assessments, evaluation of drawings or physical models made by students, interviews with groups of students or individuals, creative writing exercises using science concepts, creation of concept maps by students, or examination of student laboratory notebooks or portfolios.

References:

Bybee, R.W. (1997). *Achieving Scientific Literacy: From Purposes to Practice*. Portsmouth, NH: Heinemann.

Marek, E.A., Cavallo, A.M.L. (1997). *The Learning Cycle*. Portsmouth, NH: Heinemann.

Trowbridge, L.W., Bybee, R.W. (2000). *Teaching Secondary School Science* (6th-7th ed.). Merrill.