Human Genetic Variation

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Please contact the NIH Office of Science Education with questions about this supplement at *supplements@science.education.nih.gov*.

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 is dedicated to promoting scientific literacy and the knowledge and skills we need to secure a healthy future for all.

We designed this curriculum supplement to complement existing life science curricula at both the state and local levels and to be consistent with the *National Science Education Standards*.[1] It was developed and tested by a team of teachers, scientists, medical experts, and other professionals with relevant subject-area expertise from institutes and medical schools across the country, representatives from the National Human Genome Research Institute, and curriculum design experts from Biological Sciences Curriculum Study (BSCS) and Videodiscovery, Inc. 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. For the 2011 (third) printing, key sections of the supplement were updated, but the Student Lessons remain basically the same.

The curriculum supplements enable teachers to facilitate learning and stimulate student interest by applying scientific concepts to real-life scenarios. Design elements include a conceptual flow of lessons based on the BSCS 5E Instructional Model (page 3), 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 skills.

Each of our curriculum supplements comes with a complete set of materials for teachers, including extensive background and resource information, detailed lesson plans, masters for student worksheets, and a Web site with videos, interactive activities, updates, and corrections (as needed). The supplements are distributed at no cost to educators across the United States upon request. They may be copied for classroom use but may not be sold.

We welcome your comments. For a complete list of curriculum supplements and ordering information, or to submit feedback, please visit *http://science.education.nih.gov* or write to

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We appreciate the valuable contributions of the talented staff at BSCS and Videodiscovery, Inc. 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 materials are both engaging and effective.

I hope you find our series a valuable addition to your classroom and wish you a productive school year.

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

About the National Institutes of Health

Founded in 1887, NIH is the federal focal point for health research in the United States. Today, NIH is one of the agencies within the Department of Health and Human Services. Its 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. NIH works toward meeting the mission by providing leadership, direction, and grant support to programs designed to improve the health of the nation through research.

NIH's education programs contribute to ensuring the continued supply of well-trained basic research and clinical investigators, as well as the myriad professionals in the many allied disciplines who support the research enterprise. These efforts also help educate people about scientific results so that they can make informed decisions about their own—and the public's—health.

This curriculum supplement is one such education effort. It is a collaboration among the National Human Genome Research Institute, the NIH Office of Science Education, Biological Sciences Curriculum Study, and Videodiscovery, Inc.

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

About the National Human Genome Research Institute

The National Human Genome Research Institute (NHGRI) is leading the international effort to identify and characterize the estimated 20,000 to 25,000 genes that orchestrate a single cell's development into a human infant and then into an adult, and that govern whether that individual will be susceptible to diseases such as muscular dystrophy, cancer, Alzheimer disease, high blood pressure, and obesity.

Part of the National Institutes of Health, the Federal government's biomedical research arm, NHGRI set the year 2005 as its deadline for completing the DNA sequence of the human genome, our genetic blueprint. On April 14 of 2003, NHGRI, the Department of Energy, and their partners around the world announced the successful completion of the Human Genome Project.

Completing the sequence of the human genome and deciphering its functions are the first step toward "molecular medicine," the revolutionary approach to diagnosis and treatment that will create targeted, individualized health care in the early 21st century. Then, each person should be able to determine his or her risk for disease through genetic tests. If the tests indicate increased susceptibility to a disease, the individual will be able to obtain counseling on how to reduce that risk—perhaps by periodic medical check-ups, a special diet and other lifestyle changes, as well as drugs tailored to his or her genetic profile. Treatment of disease will also likely include gene therapies to replace, compensate for, or repair the genes that play a role in the disease.

In addition to genetics research, NHGRI sponsors research exploring the potential ethical, legal, and social consequences of the anticipated genetics revolution in medicine. By focusing now on preventing the potential misuses of genetic information in insurance and employment, NHGRI is helping ensure that genetic information will be used as it was intended: to promote human health and save lives.

For more information about the National Human Genome Research Institute, visit its Web site at *http://www.genome.gov*.

About Biological Sciences Curriculum Study

Headquartered in Colorado Springs, Colorado, BSCS was founded in 1958 as a curriculum study committed to an evidence- and inquiry-based approach to science education. BSCS instructional materials and professional development services are based on current research about teaching and learning for all science classrooms, kindergarten through college.

BSCS's materials are extensively field-tested in diverse settings across the country and evaluated for proven effectiveness. The BSCS 5E Instructional Model and inquiry are hallmarks of its materials, placing students at the center of their learning.

The BSCS mission is to transform science teaching and learning through research and development that strengthens learning environments and inspires a global community of scientifically literate citizens. BSCS is a 501(c)(3) nonprofit organization.

For more information, please visit *http://www.bscs.org*.

Introduction to *Human Genetic Variation*

This module has two central objectives. The first is to introduce students to major concepts related to human genetic variation. *Homo sapiens* comprises a single species, yet the more than 6.9 billion of us alive today, and the millions who preceded us following the emergence of fully modern humans some 150,000 years ago, are a diverse lot. One look at the students who sit in your class each day is all you need to confirm that fact. The module's first objective is to help students recognize and understand this variation.

The second objective is to convey to students the relationship between basic biomedical research and the improvement of personal and public health. The knowledge that scientists gained as they sequenced the human genome is changing the practice of medicine, and it is vital that citizens recognize these changes and are prepared to deal with them. Being prepared involves understanding the basic science that underlies new medical practices and therapies and recognizing the complex issues and questions that some of these procedures and therapies raise. Thus, students will have the chance to think about how the detailed analysis of human genetic variation is already changing their lives.

Figure 1. *Humans are a genetically diverse lot. How will understanding this diversity at the molecular level change our lives?*

If recognizing human variation is common, it is not new; certainly our ancestors realized that no two humans are identical. Nevertheless, biologists before Charles Darwin subscribed to what Ernst Mayr called essentialist thinking: the notion that each species is defined by an invariant type that limits the ability of its members to vary too much from the essential nature of the species. Among Darwin's great insights was the recognition that the essentialist view is incorrect—the members of any given species are actually highly variable—and that some variations within a species will confer selective advantage on those individuals that possess them. This variation within species makes differential selection, and therefore evolution, possible. Mayr called this view population thinking, and it pervades modern biology.

Darwin, however, even while working as Gregor Mendel's contemporary, was confounded by his inability to identify the root source of biological variation or the mechanisms by which those variations are transmitted to subsequent generations of organisms within the same species. The rediscovery of Mendel's work in the early 1900s provided those answers, and the reconciliation of Mendelism and Darwinism in the modern synthesis of evolution in the 1930s and 1940s formed the basis for the biology we practice and teach today.

The identification of DNA as the genetic material in the early 1940s and the elucidation of its structure about a decade later opened the way for an analysis of genetic variation at the molecular level. That analysis proceeds at breakneck speed today, propelled by a host of powerful new techniques in molecular biology.

This module focuses on our progress in analyzing human genetic variation and the impact of that analysis on individuals and society. There are many concepts we could have addressed, but we have chosen, with the help of a variety of experts in this field, a relatively small number for exploration by your students. Those concepts follow.

- Humans share many basic characteristics, but there is a wide range of variation in human traits. Most human traits are multifactorial: They are influenced by multiple genes and environmental factors.
- The ultimate source of genetic variation is differences in DNA sequences. Most of those genetic differences do not affect how individuals function. Some genetic variation, however, is associated with disease, and some improves the ability of the species to survive changes in the environment. Genetic variation, therefore, is the basis for evolution by natural selection.
- One of the benefits of understanding human genetic variation at a molecular level is its practical value for helping us understand and treat disease. The development of effective gene-based therapies is an exciting outcome of human genetic research. These therapies, however, are potentially many years away for many diseases.
- Studying the genetic and environmental factors involved in multifactorial diseases will lead to improved diagnosis, prevention, and treatment of disease.
- Our growing understanding of human genetic variation will allow us to identify genes associated with common diseases such as cancer. Genetic testing to identify individuals who have variations that make them susceptible to certain diseases can help people make decisions in uncertain circumstances and holds the prospect for more effective prevention and treatment. However, this capability also raises difficult questions about the uses of genetic information—questions that illustrate the personal and social implications of biological research.

We hope the module's five lessons will be effective vehicles for carrying these concepts to your students. Although the activities contain much interesting information about various aspects of human genetics, we suggest that you focus your students' attention on the major concepts the module was designed to convey. The concluding steps in each lesson are intended to focus the students' attention on those concepts as the lesson draws to a close.

Implementing the Module

The five lessons in this module are designed to be taught either in sequence, as a supplement to your standard curriculum, or as individual activities that support or enhance your treatment of specific concepts in biology. The following pages offer general suggestions about using these materials in the classroom; you will find specific suggestions in the support material provided for each lesson.

What Are the Goals of the Module?

Human Genetic Variation is designed to help students reach the following major goals associated with biological literacy:

- to understand a set of basic scientific principles related to human genetic variation,
- to experience the process of inquiry and develop an enhanced understanding of the nature and methods of science, and
- to recognize the role of science in society and the relationship between basic science and personal and public health.

What Are the Science Concepts and How Are They Organized?

We have organized the activities to form a conceptual whole that moves students from an introduction to human genetic variation (*Alike, But Not the Same*), to an investigation of its biological significance (*The Meaning of Genetic Variation*), to a discussion of some of the practical implications of human

Table 1. Conceptual flow of the lessons.

Lesson	Learning Phase	Major Concepts
Lesson 1 *Alike, But Not the Same*	Engage	Humans share many basic characteristics, but there is a wide range of variation in human traits. Most human traits are multifactorial: They are influenced by multiple genes and environmental factors.
Lesson 2 *The Meaning of Genetic Variation*	Explore	The ultimate source of genetic variation is differences in DNA sequences. Most of those genetic differences do not affect how individuals function. Some genetic variation, however, is associated with disease, and some improves the ability of the species to survive changes in the environment. Genetic variation, therefore, is the basis for evolution by natural selection.
Lesson 3 *Molecular Medicine Comes of Age*	Explain	One of the benefits of understanding human genetic variation at a molecular level is its practical value for helping us understand and treat disease. The development of effective gene-based therapies is an exciting outcome of human genetic research. These therapies, however, are potentially many years away for many diseases.
Lesson 4 *Are You Susceptible?*	Elaborate	Studying the genetic and environmental factors involved in multifactorial diseases will lead to increased diagnosis, prevention, and treatment of disease.
Lesson 5 *Making Decisions in the Face of Uncertainty*	Evaluate	Our growing understanding of human genetic variation will allow us to identify genes associated with common diseases such as cancer. Genetic testing to identify individuals who have variations that make them susceptible to certain diseases can help people make decisions in uncertain circumstances and holds the prospect for more effective prevention and treatment. However, this capability also raises difficult questions that illustrate the personal and social implications of biological research.

genetic variation for the treatment of disease (*Molecular Medicine Comes of Age* and *Are You Susceptible?*), and, finally, to a consideration of how understanding human genetic variation can affect the decisions we make about our own health (*Making Decisions in the Face of Uncertainty*). Table 1 summarizes the sequence of major concepts addressed by the five lessons.

Although we encourage you to use the lessons in the sequence outlined in Table 1, many of the lessons can be taught individually, to replace or enhance a more traditional approach to the same or related content. Table 2 provides recommendations for inserting the lessons into a standard high school curriculum in biology.

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

Human Genetic Variation supports teachers in their efforts to reform science education in the spirit of the National Research Council's 1996 *National Science Education Standards (NSES)*. Table 3 lists the content and teaching standards that this module primarily addresses.

How Does the BSCS 5E Instructional Model Promote Active, Collaborative, Inquiry-Based Learning?

The activities in this module are designed to offer students the opportunity to participate in active, collaborative, and inquiry-based learning in biology. But what do these terms mean?

Despite their current popularity, many teachers think of active, collaborative, and inquiry-based learning rather generically. Defining these three key terms specifically will provide a foundation on which we can build a detailed description of the instructional approach that the five lessons in this module advocate and implement.

Conceptually the broadest of the three, **active learning** means that students are involved in "doing things and thinking about the things they are doing" (Bonwell and Eison, 1991, p. 2). These authors elaborate by listing the following characteristics typically associated with strategies that deserve to be labeled "active":

- Students are involved in more than listening.
- Instructors place less emphasis on transmitting information and more emphasis on developing students' skills.
- Students are involved in higher-order thinking (for example, analysis, synthesis, and evaluation).
- Students are engaged in activities (for example, reading, discussing, and writing).
- Instructors encourage students' exploration of their own understandings, attitudes, and values.

Most teachers endorse the use of active learning. We know intuitively, if not experientially and explicitly, that learning does not occur through passive absorption. But often, we do not realize how active students must be for real learning to occur. Typically, the answer to this question is more active than we might expect.

Table 2. Correlation between lessons and high school biology topics.

High School Biology Topic	Lesson 1	Lesson 2	Lesson 3	Lesson 4	Lesson 5
evolution and natural selection		✔			
ethical issues related to genetic testing and screening		✔	✔	✔	✔
human genetic variation including genetic disorders		✔			
multifactorial traits	✔	✔	✔	✔	✔

Table 3. Correlation to the *National Science Education Standards*.
A. The Content Standards

Standard A: As a result of activities in grades 9–12, all students should develop abilities necessary to do scientific inquiry and understandings about scientific inquiry.	**Correlation to *Human Genetic Variation***
• Identify questions and concepts that guide scientific investigations.	Lessons 1, 2 ,and 3
• Use technology and mathematics to improve investigations and communications.	Lesson 2
• Formulate and revise scientific explanations and models using logic and evidence.	Lessons 2 and 3
• Recognize and analyze alternative explanations and models.	Lessons 2 and 3
• Communicate and defend a scientific argument.	Lesson 3
• Understanding scientific inquiry.	Lessons 2 and 3
Standard C: As a result of their activities in grades 9–12, all students should develop understanding of the cell and the molecular basis of heridity.	**Correlation to *Human Genetic Variation***
• Cells store and use information to guide their functions.	Lessons 2, 3, and 5
• Cells can differentiate, and complex multicellular organisms are formed as a highly organized arrangement of differentiated cells.	Lessons 2 and 5
• In all organisms, the instructions for specifying the characteristics of the organism are carried in the DNA.	Lessons 2, 3, and 5
• Changes in DNA occur spontaneously at low rates.	Lessons 2, 3, and 5
• Species evolve over time.	Lesson 2
Standard E: As a result of activities in grades 9–12, all students should develop abilities of technological design and understandings about science and technology.	**Correlation to *Human Genetic Variation***
• Scientists in different disciplines ask different questions, use different methods of investigation, and accept different types of evidence to support these explanations.	Lesson 3
• Science often advances with the introduction of new technologies.	Lesson 5
• Creativity, imagination, and a good knowledge base are all required in the work of science and engineering.	Lessons 1–5
• Science and technology are pursued for different purposes.	Lesson 5
Standard F: As a result of activities in grades 9–12, all students should develop understanding of	**Correlation to *Human Genetic Variation***
• personal and community health.	Lessons 2, 3, 4, and 5
• natural and human-induced hazards.	Lessons 2, 3, 4, and 5
• science and technology in local, national, and global challenges.	Lesson 5
Standard G: As a result of activities in grades 9–12, all students should develop understanding of	**Correlation to *Human Genetic Variation***
• science as a human endeavor.	Lesson 3
• nature of scientific knowledge.	Lessons 1–5
• historical perspectives.	Lesson 2

Table 3. Correlation to the *National Science Education Standards*. B. The Teaching Standards

Standard A: Teachers of science plan an inquiry-based science program for their students. In doing this, teachers	**Correlation to *Human Genetic Variation***
• develop a framework of yearlong and short-term goals for students.	Each lesson provides short-term objectives for students. Tables 1, Conceptual Flow of the Lessons, and 6, Suggested Timeline for Teaching the Module, also help teachers plan.
• select science content and adapt and design curriculum to meet the interests, knowledge, understanding, abilities, and experiences of students.	Using the modules helps teachers update their curriculum in response to their students' interest in this topic.
• select teaching and assessment strategies that support the development of student understanding and nurture a community of science learners.	The focus on active, collaborative, and inquiry-based learning in the activities helps teachers meet this standard.
Standard B: Teachers of science guide and facilitate learning. In doing this, teachers	**Correlation to *Human Genetic Variation***
• focus and support inquiries while interacting with students.	All of the activities in the module encourage and support student inquiry.
• orchestrate discourse among students about scientific ideas.	All of the activities in the module promote discourse among students.
• challenge students to accept and share responsibility for their own learning.	All of the activities in the module challenge students to accept and share responsibility for their learning.
• recognize and respond to student diversity and encourage all students to participate fully in science learning.	Combining the BSCS 5E Instructional Model with active, collaborative learning is an effective way of responding to the diversity of student backgrounds and learning styles.
• encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science.	Annotations for the teacher throughout the activities provide many suggestions for how teachers can model these attributes.
Standard C: Teachers of science engage in ongoing assessment of their teaching and of student learning. In doing this, teachers	**Correlation to *Human Genetic Variation***
• use multiple methods and systematically gather data about student understanding and ability.	Each lesson has a variety of assessment components embedded within its structure. Annotations draw teachers' attention to these opportunities for assessment.
• analyze assessment data to guide teaching.	Annotations provide answers to questions that can help teachers analyze student feedback. The annotations also suggest ways for teachers to change their approach to students, based on that feedback.
Standard E: Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning. In doing this, teachers	**Correlation to *Human Genetic Variation***
• display and demand respect for the diverse ideas, skills, and experiences of all students.	The answers provided for teachers model these qualities.
• nurture collaboration among students.	All the activities are designed to be completed by students working in collaborative groups.
• structure and facilitate ongoing formal and informal discussion based on a shared understanding of rules of scientific discourse.	All the discussions in the lessons model the rules of scientific discourse.
• model and emphasize the skills, attitudes, and values of scientific inquiry.	The annotations for teachers provide many suggestions about how to model these skills, attitudes, and values.

The activities in this module were designed with the following assumptions about active learning (BSCS, 1999):

- An activity promotes active learning to the degree to which *all students*, not simply a vocal few, are involved in mental processing related to the content.
- An activity promotes active learning to the degree that it offers *extended opportunities* for students to become personally engaged with the content.
- An activity promotes active learning to the degree that it involves students in thinking *deeply* about content.

The activities also make extensive use of **collaborative learning**. Most often occurring within the context of group work, collaborative and cooperative learning currently enjoy "favorite child" status among the many strategies available to teachers.

Teachers are using group approaches across disciplines, for in- and out-of-class assignments, with large and small classes, and with beginning and advanced students. In fact, you will often find that collaborative activities go hand-in-hand with active learning.

Collaborative learning and cooperative learning, which have long theoretical and empirical histories, come out of different academic traditions, operate on different premises, and use different strategies. But both approaches share a fundamental commitment to the notion that students learn from and with each other—"learning through joint intellectual effort," according to one expert (Brody, 1995, p. 134). In the interest of brevity, we will leave undiscussed the finer distinctions between the two, offering in this curriculum a mix of strategies that put students together and engage them in tasks that encourage learning together.

Finally, the activities in the module use **inquiry-based strategies**. All truly inquiry-based activities share the characteristics of active learning. In addition, inquiry-based strategies emphasize discovery: the process of observation, followed by analysis, that leads to explanation, to conclusion, or to the next question. Note that an activity need not involve students in active experimentation to be fundamentally an inquiry experience.

More than active or collaborative learning, inquiry-based strategies attempt to teach students how biologists see the world, how they think about what they see, and how they draw conclusions that are consistent with observations and current knowledge. Such strategies say to the student, in effect, "This is science as a way of knowing."

The BSCS 5E Instructional Model

The lessons in the module were designed using an instructional model to organize and sequence the experiences offered to students. This model, called the BSCS 5E Instructional Model, is based on constructivism, a term that expresses a view of the student as an active agent who "constructs" meaning out of his or her interactions with events (Perkins, 1992). According to this view, rather than passively absorbing information, the student redefines, reorganizes, elaborates, and changes his or her initial understandings through interactions with phenomena, the environment, and other individuals. In short, the student interprets objects and phenomena and then internalizes this interpretation in terms of previous experiences.

A constructivist view of learning recognizes that the development of ideas and the acquisition of lasting understandings take time and experience (Saunders, 1992). In the typical classroom, this means that fewer concepts and subjects can be covered during the school year or, in this case, in five days of instruction. Nevertheless, research suggests that students who are given time and opportunity to thoroughly grasp a small number of important concepts do better on traditional tests than students who are exposed briefly to a large number of ideas (Sizer, 1992; Knapp et al., 1995). In fact, the intensive thinking involved in constructing a thorough understanding of a few major ideas appears to benefit all students, regardless of ability.

Table 4 illustrates the key components of the BSCS 5E Instructional Model, so-called because it takes students through five phases of learning that are easily described using five words that begin with the letter "E": Engage, Explore, Explain, Elaborate, and Evaluate.

Table 4. The key components of the BSCS 5E Model: *What the teacher does.*

Phase	What the teacher does that's *consistent* with the 5E Model	What the teacher does that's *inconsistent* with the 5E Model
Engage	• Creates interest • Generates curiosity • Raises questions • Elicits responses that uncover what students know or think about the concept or subject	• Explains concepts • Provides definitions and answers • States conclusions • Provides premature answers to students' questions • Lectures
Explore	• Encourages students to work together without direct instruction from teacher • Observes and listens to students as they interact • Asks probing questions to redirect students' investigations when necessary • Provides time for students to puzzle through problems • Acts as a consultant for students	• Provides answers • Tells or explains how to work through the problem • Tells students they are wrong • Gives information or facts that solve the problem • Leads students step-by-step to a solution
Explain	• Encourages students to explain concepts and definitions in their own words • Asks for justification (evidence) and clarification from students • Formally provides definitions, explanations, and new labels • Uses students' previous experiences as the basis for explaining concepts	• Accepts explanations that have no justification • Neglects to solicit students' explanations • Introduces unrelated concepts or skills
Elaborate	• Expects students to use formal labels, definitions, and explanations provided previously • Encourages students to apply or extend concepts and skills in new situations • Reminds students of alternative explanations • Refers students to existing data and evidence and asks, "What do you already know?" "Why do you think … ?"	• Provides definitive answers • Tells students they are wrong • Lectures • Leads students step-by-step to a solution • Explains how to work through the problem
Evaluate	• Observes students as they apply new concepts and skills • Assesses students' knowledge and/or skills • Looks for evidence that students have changed their thinking or behaviors • Allows students to assess their own learning and group-process skills • Asks open-ended questions, such as, "Why do you think . . . ?" "What evidence do you have?" "What do you know about x?" "How would you explain x?"	• Tests vocabulary words, terms, and isolated facts • Introduces new ideas or concepts • Creates ambiguity • Promotes open-ended discussion unrelated to concept or skill

Table 5. The key components of the BSCS 5E Model: *What the students do*.

Phase	What the students do that is *consistent* with the 5E Model	What the students do that is *inconsistent* with the 5E Model
Engage	• Become interested in and curious about the concept/topic • Express current understanding of a concept or idea • Raise questions such as, What do I already know about this? What do I want to know about this? How could I find out?	• Ask for the "right" answer • Offer the "right" answer • Insist on answers or explanations • Seek closure
Explore	• "Mess around" with materials and ideas • Conduct investigations in which they observe, describe, and record data • Try different ways to solve a problem or answer a question • Acquire a common set of experiences so they can compare results and ideas • Compare their ideas with those of others	• Let others do the thinking and exploring (passive involvement) • Work quietly with little or no interaction with others (only appropriate when exploring ideas or feelings) • Stop with one solution • Demand or seek closure
Explain	• Explain concepts and ideas in their own words • Base their explanations on evidence acquired during previous investigations • Become involved in student-to-student conversations in which they debate their ideas • Record their ideas and current understanding • Reflect on and perhaps revise their ideas • Express their ideas using appropriate scientific language • Compare their ideas with what scientists know and understand	• Propose explanations from "thin air" with no relationship to previous experiences • Bring up irrelevant experiences and examples • Accept explanations without justification • Ignore or dismiss other plausible explanations • Propose explanations without evidence to support their ideas
Elaborate	• Make conceptual connections between new and former experiences • Use what they have learned to explain a new object, event, organism, or idea • Use scientific terms and descriptions • Draw reasonable conclusions from evidence and data • Communicate their understanding to others	• Ignore previous information or evidence • Draw conclusions from "thin air" • Use terminology inappropriately and without understanding
Evaluate	• Demonstrate what they understand about the concept(s) and how well they can implement a skill • Compare their current thinking with that of others and perhaps revise their ideas • Assess their own progress by comparing their current understanding with their prior knowledge • Ask new questions that take them deeper into a concept or topic area	• Disregard evidence or previously accepted explanations in drawing conclusions • Offer only yes-or-no answers or memorized definitions or explanations as answers • Fail to express satisfactory explanations in their own words • Introduce new, irrelevant topics