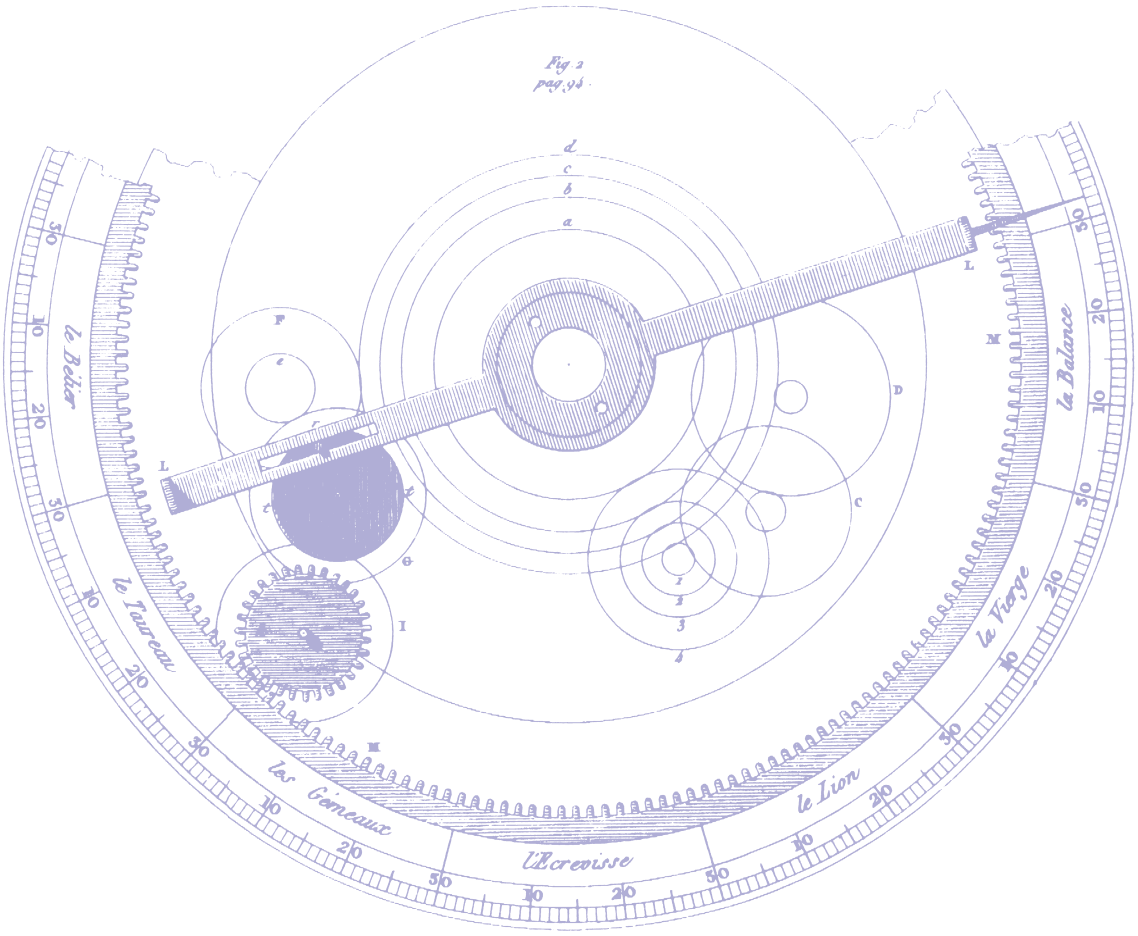
Science Framework



Science Framework

Overview

In parallel with mathematics, the science assessment framework for TIMSS 2003 is based on two main organizing dimensions, a content dimension and a cognitive dimension.[1] Each of these two dimensions has several domains:

Science Content Domains

- Life Science
- Chemistry
- Physics
- Earth Science
- Environmental Science

Science Cognitive Domains

- Factual Knowledge
- Conceptual Understanding
- Reasoning and Analysis

The content domains define the specific science subject matter covered by the assessment, and the cognitive domains define the sets of behaviors expected of students as they engage with the science content. Each content domain has several main topic areas (e.g., the earth science domain is comprised of the topic areas of the earth's structure and physical features; the earth's processes, cycles and history; and the earth in the solar system and the universe). Each topic area is presented as a list of specific assessment objectives that are appropriate for either the fourth or eighth grade and reflect what is covered in the science curriculum in a majority of participating countries by those grade levels.[2]

Exhibit 3 shows the target percentages of testing time devoted to each science content and cognitive domain for both the fourth and eighth grade assessments, and indicates the content reporting categories for each grade level. At the eighth grade, the reporting categories correspond to the five content domains of Life Science, Chemistry, Physics, Earth Science, and Environmental Science. At the fourth grade, only three reporting categories are planned due to the combined reporting of chemistry and physics topics as Physical Science and a reduced emphasis on topics in Environmental Science.

Exhibit 3: Target Percentages of TIMSS 2003 Science Assessment Devoted to Content and Cognitive Domains by Grade Level

	Fourth Grade	Eighth Grade
Science Content Domains		
Life Science	45%	30%
Physical Science	35%	*
Chemistry	*	15%
Physics	*	25%
Earth Science	20%	15%
Environmental Science	*	15%
Science Cognitive Domains		
Factual Knowledge	40%	30%
Conceptual Understanding	35%	35%
Reasoning and Analysis	25%	35%

*At fourth grade, Physical Science will be assessed as one content area including both physics and chemistry topics. Some understandings related to Environmental Science will be assessed as part of the Life Science and Earth Science content domains at fourth grade.

1 These two dimensions are comparable to the content and performance expectations aspects defined in the TIMSS curriculum frameworks for the 1995 and 1999 assessments (Robitaille, D.F., et al (1993), *TIMSS Monograph No.1: Curriculum Frameworks for Mathematics and Science*, Vancouver, BC: Pacific Educational Press.)

2 More information about the factors considered in finalizing the topics and assessment objectives is provided in the Introduction.

In addition to the content and cognitive domains, the TIMSS 2003 science framework also includes Scientific Inquiry as a separate assessment strand. Scientific inquiry is treated as an overarching dimension that includes knowledge, skills, and abilities assessed by items or tasks set in different content-related contexts that cover a range of cognitive demands. The items and tasks developed to assess understandings and abilities related to scientific inquiry will, therefore, be associated with both a content and a cognitive domain as well as with assessment areas related specifically to scientific inquiry. From the entire set of items and tasks developed to draw on understandings and abilities across the content and cognitive domains, a portion also will engage students in the process of scientific inquiry and permit the assessment of their performance in this area. Many of the outcomes related to scientific inquiry will be assessed primarily in the problem solving and inquiry tasks and will represent up to 15 percent of the total assessment time.[3] The content domains, cognitive domains, and scientific inquiry assessment strand for the science assessment are discussed in detail in the following sections. Example science items and tasks are presented in Appendix C.

Science Content Domains

While TIMSS recognizes the importance of the teaching and learning of unified concepts and topics that bridge the domains of science, the following major content domains are used to define the science content covered in the fourth and eighth grade assessments in TIMSS 2003:

- Life Science
- Chemistry
- Physics
- Earth Science
- Environmental Science

The organization of topics across these domains is in general the same as that used to define the reporting categories in the 1995 and 1999 assessments, although there are some differences in the definition of the areas of environmental science and scientific inquiry.[4] Direct mapping of the trend items from 1995 and/or 1999 onto the science content domains defined in this frameworks document will permit the analysis and reporting of content domains appropriate for each grade level. It is important to note that in an international assessment such as TIMSS the organization of science topics into these content domains may not correspond to the structure of science instruction in all countries. In fact, some of the topics included in the TIMSS 2003 science framework may be taught in some countries in other courses, such as health education, social studies, or geography.

3 See the Assessment Design chapter for further discussion of the assessment design and the allocation of items/tasks and assessment time to blocks.

4 In TIMSS 1995, a combined reporting category of Environmental Issues and the Nature of Science was included at both the fourth and eighth grades. In the 1999 eighth grade assessment, this combined category was replaced with two reporting categories: Environmental and Resource Issues, and Scientific Inquiry and the Nature of Science. Trend items in these categories will be mapped to the appropriate content domain in the science framework for 2003.

The following sections describe each of the science content domains. They give an overview of the topics to be covered in the TIMSS assessment, focusing on the difference in student understandings expected at the fourth and eighth grades. In defining the assessment outcomes expected at the two grade levels, TIMSS assumes a development of conceptual understanding across the grades, progressing from the observable at the fourth grade to somewhat more abstract concepts by the eighth grade. Understandings specified at the eighth grade are focused on describing what the students at that level know and can do beyond what is expected at the fourth grade.

Following the general description of each content domain is a table indicating a set of assessment outcomes for the fourth and eighth grades. The assessment outcomes are organized into main topic areas and then into a set of subtopics defining specific understandings and abilities in conceptually related areas. These assessment outcomes are written in terms of behaviors to be elicited by items that exemplify the understandings and abilities expected of students at each grade level. The main topic areas in each content domain are basically the same at the fourth and eighth grades, but the specific assessment outcomes are appropriate for each grade level, and some of the more advanced topics are not assessed at the fourth grade. Further discussion of the range of behaviors assessed to measure student understandings and abilities is included in the section of the science framework describing the cognitive domains.

Life Science

The life sciences include understandings of the nature and function of living organisms, the relationships between them, and their interaction with the environment. At the fourth and eighth grades, it is expected that in some curricula, many of the essential biological concepts may be approached through a study of human biology. While TIMSS recognizes the importance of human biology in the science curriculum of fourth- and eighth-grade students, a separate human biology topic area is not specified in the science framework. Rather, understandings related to human biology are included within the following major life science topic areas that address both humans and other organisms and include a separate topic area devoted to human health:

- Types, characteristics, and classification of living things
- Structure, function, and life processes in organisms
- Cells and their functions
- Development and life cycles of organisms
- Reproduction and heredity
- Diversity, adaptation, and natural selection
- Ecosystems
- Human health

The classification of organisms by physical and behavioral characteristics is fundamental to life science, and is expected of both fourth- and eighth-grade students. At the fourth grade, students may be assessed on their understanding of general characteristics that distinguish between living and nonliving things, and their ability to compare and contrast characteristics of major groups of common organisms, including humans. At the eighth grade, students are expected to know the defining characteristics of major taxonomic groups and classify organisms according to these characteristics.

Understanding of structure and function in organisms at the fourth grade begins with knowledge of the basic bodily functions and relating major body structures in humans and other organisms to their functions. By the eighth grade, students should have developed an understanding of tissues, organs, and organ systems, and be able to explain how certain biological processes are necessary to sustain life. Basic understanding of cells and their functions is expected at the eighth grade but not the fourth grade.

Understandings in development, reproduction, and heredity are expected to increase substantially from the fourth to eighth grade. At the fourth grade, students are expected to know and compare the life cycles of familiar organisms. Knowledge of reproduction and heredity at this grade level is restricted to a very basic understanding that organisms of the same kind reproduce and that offspring closely resemble their parents. By the eighth grade, students should start developing a more mechanistic understanding that includes the comparison of growth and development in different organisms. They also are expected to compare sexual and asexual reproduction in terms of biological processes at the cellular level, including ideas about heredity that involve the passing of genetic material from parent(s) to offspring.

The development of some understandings related to diversity, adaptation, and natural selection among organisms is expected at both the fourth and eighth grades. At the fourth

grade, students are expected to provide examples of physical and behavioral characteristics that make some plants and animals better suited for different environments. At the eighth grade, it is expected that students are beginning to develop an understanding of populations and a working definition of modern species in terms of similarity of characteristics and reproduction capabilities in a population of related organisms. They are making more connections, relating the diversity of characteristics to the survival or extinction of species in changing environments. It is not until the eighth grade that students are expected to start considering evidence for the history and changes in the earth's life forms over time by the comparison of living species and fossil records.

The study of ecosystems is essential to understanding the interdependence of living organisms and their relationship to the physical environment. Basic concepts related to ecosystems, including energy flow and the interaction of biotic and abiotic factors, are expected to be introduced in the primary school science curriculum and further developed throughout middle and secondary school. At the fourth grade, students' understandings may be demonstrated through descriptions of specific relationships between plants and animals in common ecosystems. At the eighth grade, students should show introductory-level understanding of the interdependence between populations of organisms that maintains balance in an ecosystem. They are expected to represent the flow of energy in an ecosystem, recognize the role of organisms in the cycling of materials, and predict the effects of changes in ecosystems. The effect of human activity on ecosystems is an important aspect of understanding the interdependence of living organisms and the environment. Students' understandings related to the impact of humans are described in the Environmental Science section.

Both fourth- and eighth-grade students are expected to demonstrate understandings related to human health, nutrition, and disease. At the fourth grade, students should demonstrate familiarity with common communicable diseases and relate diet and personal habits to their effect on health. At the eighth grade, students are expected to know some causes of disease, communicate more in-depth knowledge about the mechanisms of infection and transmission, and know the importance of the immune system. They should also be able to describe the role of specific nutrients in the normal functioning of the human body.

Life Science: Types, Characteristics, and Classification of Living Things

Grade 4

- Explain differences between living and nonliving things based on common features (movement, basic needs for air/food/water, reproduction, growth, response to stimuli).
- Compare and contrast physical and behavioral characteristics of humans and other major groups of organisms (e.g., insects, birds, mammals, plants), and identify/provide examples of plants and animals belonging to these groups.

Grade 8

- State the defining characteristics that are used to differentiate among the major taxonomic groups and organisms within these groups, and classify organisms on the basis of a variety of physical and behavioral characteristics.

Life Science: Structure, Function, and Life Processes in Organisms

Grade 4

- Relate major body structures in humans and other organisms (plants and animals) to their functions (e.g., digestion takes place in the stomach, plant roots absorb water, teeth break down food, bones support the body, lungs take in oxygen).
- Demonstrate knowledge of bodily actions in response to outside conditions (e.g., heat, cold, danger) and activities (e.g., exercise).

Grade 8

- Locate major organs in the human body; identify the components of organ systems; and compare/contrast organs and organ systems in humans and other organisms.
- Relate the structure and function of organs and organ systems to the basic biological processes required to sustain life (sensory, digestive, skeletal/muscular, circulatory, nervous, respiratory, reproductive).
- Explain how biological actions in response to specific external/internal changes work to maintain stable bodily conditions (e.g., sweating in heat, shivering in cold, increased heart rate during exercise).

Life Science: Cells and Their Functions

Grade 4

- Not Assessed

Grade 8

- Describe the cellular make-up of all living organisms (both single-celled and multi-cellular), demonstrating knowledge that cells carry out life functions and undergo cell division during growth/repair in organisms, and that tissues, organs, and organ systems are formed from groups of cells with specialized structures and functions.
- Identify cell structures and some functions of cell organelles (cell wall, cell membrane, nucleus, cytoplasm, chloroplast, mitochondria, vacuoles), including a comparison of plant and animal cells.
- Provide a general description of the process of photosynthesis that takes place in plant cells (the need for light, carbon dioxide, water, and chlorophyll, production of food, and release of oxygen).
- Describe the process of respiration that takes place in plant and animal cells (the need for oxygen, breaking down of food to produce energy, and release of carbon dioxide).

Life Science: Development and Life Cycles of Organisms

Grade 4

- Trace the general steps in the life cycle of organisms (birth, growth and development, reproduction, and death); know and compare life cycles of familiar organisms (e.g., humans, butterflies, frogs, plants, mosquitos).

Grade 8

- Compare and contrast how different organisms grow and develop (e.g., humans, plants, birds, insects).

Life Science: Reproduction and Heredity

Grade 4

- Recognize that plants and animals reproduce with their same kind to produce offspring with features that closely resemble those of the parents.

Grade 8

- Explain that reproduction (asexual or sexual) occurs in all living organisms and is important for the survival of species; compare/contrast biological processes in asexual and sexual reproduction in general terms (e.g., cell division to produce an identical offspring versus combination of egg and sperm from female/male parents to produce offspring that are similar but not identical to either parent); state advantages and disadvantages of each type of reproduction.
- Relate the inheritance of traits to the passing on of genetic material contained in the cells of the parent(s) to their offspring; distinguish inherited characteristics from physical/behavioral features that are acquired/learned.

Life Science: Diversity, Adaptation, and Natural Selection

Grade 4

- Associate physical features and patterns of behavior of plants and animals with the environments in which they live; identify/provide examples of certain physical or behavioral characteristics of plants/animals that make them better suited for survival in different environments and explain why (e.g., camouflage, color change, fur thickness).

Grade 8

- Relate the survival/extinction of different species to variation in physical/behavioral characteristics in a population and reproductive success in changing environments.
- Demonstrate knowledge of the relative time major groups of organisms have existed on the earth (e.g., humans, reptiles, fish, plants); describe how similarities and differences among living species and fossils provide evidence of the changes that occur in living things over time.

Life Science: Ecosystems[5]

Grade 4

- Explain that all plants and animals need food to provide fuel for activity and material for growth and repair; understand that plants need the sun to make their own food, while animals consume plants and/or other animals as food.
- Explain relationships in a given community (e.g., forest, tidepool) based on simple food chains, using common plants and animals and predator/prey relationships.

Grade 8

- Demonstrate knowledge of the flow of energy in an ecosystem (the role of photosynthesis and respiration and the storage of food/energy products in organisms); identify different organisms as producers, consumers, and decomposers; draw/interpret food pyramids or food web diagrams.
- Describe the role of organisms in the cycling of materials through the earth's surface (e.g., oxygen/carbon dioxide, water) and the decomposition of organisms and recycling of elements back into the environment.
- Discuss the interdependence of populations of organisms in an ecosystem in terms of the effects of competition and predation; identify factors that can limit population size (e.g., disease, predators, food resources, drought); predict effects of changes in an ecosystem (e.g., climate, water supply, food supply, population changes, migration) on the available resources and the balance among populations.

Life Science: Human Health

Grade 4

- Recognize ways that common communicable diseases (e.g., colds, influenza) are transmitted; identify signs of health/illness and some methods of preventing and treating illness.
- Describe ways of maintaining good health, including the need for a balanced/varied diet, identification of common food sources (e.g., fruits and vegetables, grains), and the effect of personal habits on health (e.g., using sunscreen, preventing injury, personal hygiene, exercise, drug, alcohol, and tobacco use).

Grade 8

- Describe causes of common infectious diseases, methods of infection/transmission, prevention, and the importance of the body's natural resistance (immunity) and healing capabilities.
- Explain the importance of diet, hygiene, exercise, and lifestyle in maintaining health and preventing illness (e.g., heart disease, diabetes, skin cancer, lung cancer); identify the dietary sources and role of nutrients in a healthy diet (vitamins, minerals, proteins, carbohydrates, fats).

5 Assessment objectives related to the effects of human behavior on environments are described in the Environmental Science section. At grade 4 these objectives may be reported in Life Science.

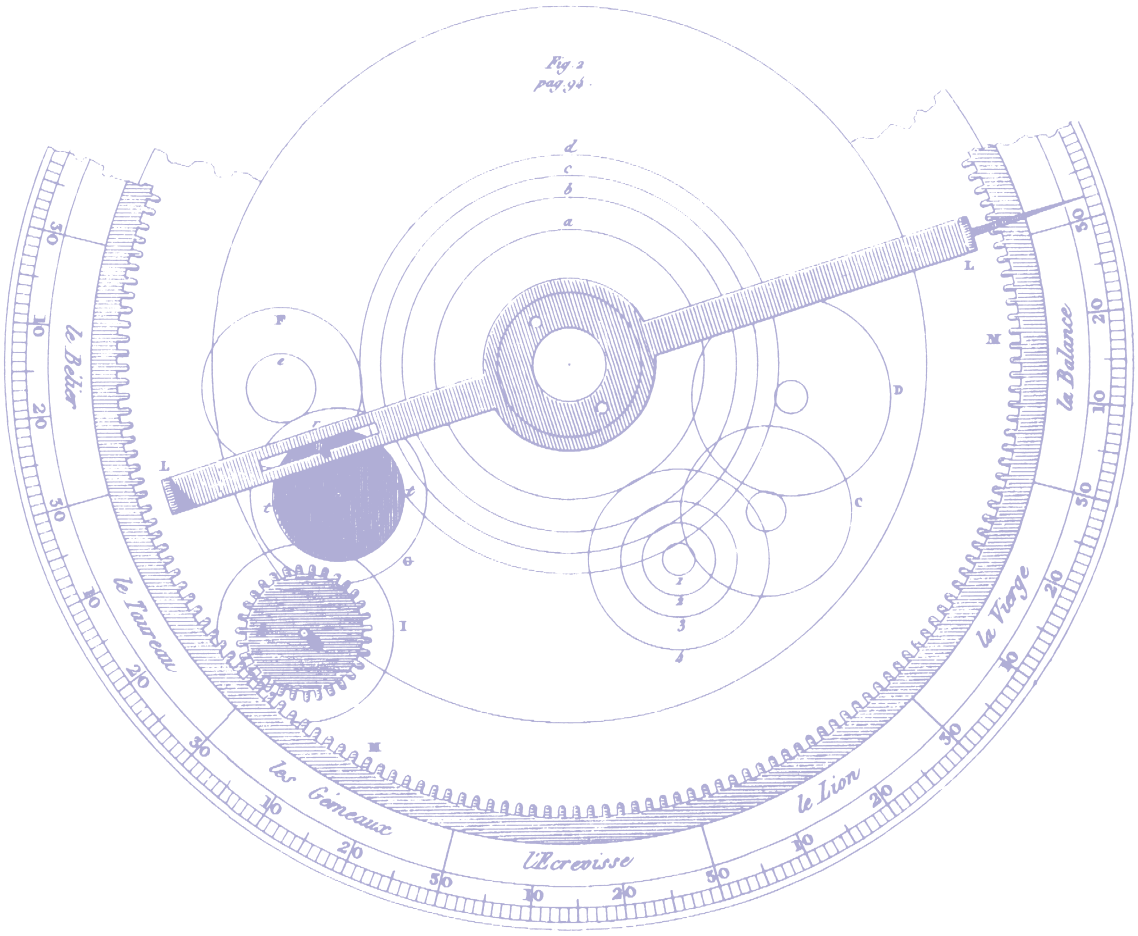


Fig 2
pag. 95
le Bélier
le Taureau
les Gémeaux
l'Ecrevisse
le Lion
le Vierge
la Balance

Physical Sciences

The physical sciences include concepts related to matter and energy and cover topics in the areas of both chemistry and physics. At the eighth grade, these two main content areas will be assessed and reported separately, although there is overlap of some of the understandings related to chemical and physical properties and changes in matter. While some of the physical science topics are appropriate in either physics or chemistry courses in different science curricula, the TIMSS 2003 science framework treats topics related to the properties, composition, classification, and particulate structure of matter as part of the chemistry domain and topics related to general physical states of matter and their transformation as part of the physics domain. The organization of topics in the assessment framework for 2003 is consistent with the classification of items in the reporting categories for the earlier TIMSS assessments. At the fourth grade, where the understandings of both chemical and physical concepts are considerably less developed, physical science will be reported as a single content domain combining understandings related to both chemical and physical concepts, with less emphasis on chemistry topics. Although the reporting of the physical sciences will differ for the fourth and eighth grades, student understandings and abilities related to the topics in each of the physical science content areas are specified separately at both grade levels.

Chemistry

In the area of chemistry, students will be assessed on their understanding of concepts related to the following topic areas:

- Classification and composition of matter
- Particulate structure of matter
- Properties and uses of water
- Acids and bases
- Chemical change

At the fourth grade, understandings related to the classification, composition, and properties of matter are focused on comparing or classifying objects and materials on the basis of observable physical properties and relating these properties to their uses. Students at the fourth grade are also expected to have a beginning practical knowledge of the formation of mixtures and water solutions. At the eighth grade, students should be able to classify substances on the basis of characteristic properties and differentiate between elements, compounds, and mixtures in terms of their composition. Their understanding of mixtures and solutions is expected to be more sophisticated, including ideas related to heterogeneous and homogeneous mixtures and the preparation, concentration, and components of solutions. They are also expected to have a beginning understanding of the particulate structure of matter in terms of atoms and molecules; this area is not assessed at the fourth grade. While students at both grades may be assessed on their knowledge of some properties and uses of metals and water, by the eighth grade a beginning knowledge of acids and bases is also expected.

At the fourth grade, students should identify some familiar changes in materials that produce other materials with different properties, but they are not expected to know how these changes are related to chemical transformations. At the eighth grade, students should have a clear understanding of the difference between physical and chemical changes and demonstrate basic knowledge of conservation of matter during these changes. Eighth-grade students are also expected to recognize the need for oxygen in rusting and burning and the relative tendency of familiar substances to undergo these types of reactions, and to identify common reactions that absorb or give off heat/energy.

Chemistry: Classification and Composition of Matter

Grade 4

- Compare/classify/order different objects and materials on the basis of observable physical properties (e.g., weight/mass, shape, volume, color, hardness, texture, odor, taste, magnetic attraction).
- Identify some properties of metals and relate them to their use (e.g., conduct heat and electricity, are hard, are shiny, can be molded).
- Identify/describe mixtures on the basis of physical appearance; demonstrate understanding that mixtures can be separated based on the observable properties of their parts (e.g., particle size, shape, color, magnetic attraction).
- Give examples of some materials that will dissolve in water and some that will not, and identify common conditions that increase the amount of material that will dissolve or the speed at which materials dissolve (hot water, stirring, small particles).

Grade 8

- Classify/compare substances on the basis of characteristic physical properties that can be demonstrated or measured (e.g., density, thermal/electrical conductivity, solubility, melting/boiling point, magnetic properties).
- Recognize that substances may be grouped according to similar chemical and physical properties; describe properties of metals that distinguish them from other common substances (nonmetals).
- Differentiate between pure substances (elements and compounds) and mixtures (homogeneous and heterogeneous) on the basis of their formation and composition, and provide/identify examples of each (solid, liquid, gas).
- Select/describe physical methods for separating mixtures into their components (e.g., filtration, distillation, sedimentation, magnetic separation, flotation, dissolution).
- Define solutions in terms of substance(s) (solid, liquid, or gas solutes) dissolved in a solvent; apply knowledge of the relationship between concentration/dilution and the amounts of solute/solvent and the effect of factors such as temperature, stirring, and particle size.

Chemistry: Particulate Structure of Matter

Grade 4

- Not Assessed

Grade 8

- Describe the structure of matter in terms of particles, including molecules as combinations of atoms and atoms as being composed of subatomic particles (electrons surrounding a nucleus containing protons and neutrons).

Chemistry: Properties and Uses of Water

Grade 4

- Identify common uses of water in each of its forms (e.g., solvent, coolant, heat source).

Grade 8

- Identify water as a compound with molecules composed of one oxygen atom and two hydrogen atoms; relate the behavior/uses of water to its physical properties (e.g., melting point and boiling point, ability to dissolve many substances, thermal properties, expansion upon freezing).

Chemistry: Acids and Bases

Grade 4

- Not Assessed

Grade 8

- Compare the properties and uses of common acids and bases (acids have a sour taste and react with metals; bases usually have a bitter taste and slippery feel; strong acids and bases are corrosive; both acids and bases dissolve in water and react with indicators to produce different color changes; acids and bases neutralize each other).

Chemistry: Chemical Change

Grade 4

- Identify some familiar changes in materials that produce other materials with different characteristics (e.g., decaying of animal/plant matter, burning, rusting, cooking).

Grade 8

- Differentiate chemical from physical changes in terms of the transformation (reaction) of one or more substances (reactants) into different substances (products); provide evidence that a chemical change has taken place based on common examples (e.g., temperature change, gas production, color change, light emission).
- Recognize that although matter changes form during chemical change, its total amount is conserved.
- Recognize the need for oxygen in common oxidation reactions (combustion, rusting); compare the relative tendency of familiar substances to undergo these reactions (e.g., combustion of gasoline versus water, corrosion of steel versus aluminum).
- Demonstrate understanding that some chemical reactions give off while others absorb heat/energy; classify familiar chemical transformations as either releasing or absorbing heat/energy (e.g., burning, neutralization, cooking).

Physics

In physics, students' understandings of concepts related to energy and physical processes will be assessed in the following topic areas:

- Physical states and changes in matter
- Energy types, sources, and conversions
- Heat and temperature
- Light
- Sound and vibration
- Electricity and magnetism
- Forces and motion

At the fourth grade, students have a limited understanding of physical states and changes based on observable differences between matter in its three forms – solid, liquid, and gas. While general knowledge about changes of state is not expected at the fourth grade, students at this level are expected to know that water can exist in all three forms and can change from one form to another by being heated or cooled. In contrast, by the eighth-grade students should be able to describe processes involved in changes of state and begin to relate the states of matter to the distance and movement among particles. They also demonstrate understanding that matter is conserved during physical changes.

Concepts related to energy, heat, and temperature are assessed at some level at both the fourth and eighth grade, but these concepts are more formalized at the higher grade. While students at the fourth grade are able to identify common energy sources, those at the eighth grade are expected to compare different forms of energy, describe simple energy transformations, and apply the principle of conservation of total energy in practical situations. Eighth-grade students are also expected to recognize heat as the transfer of energy, and to relate temperature to the movement or speed of particles. At the fourth grade, assessment of students' understandings about heat is restricted to observable physical processes.

Understandings of light and sound are expected to develop substantially from fourth to eighth grade. Fourth-grade students' knowledge of light includes the identification of common sources and recognition of some familiar physical phenomena related to light. Students at the eighth grade are expected to know some basic properties/behavior of light and its interaction with matter; to use simple geometrical optics to solve practical problems; and to relate the appearance and color of objects to light properties. Students at the eighth grade also are expected to demonstrate practical knowledge of the nature/source of sound as caused by vibrations, while fourth-grade students will not be assessed in this area.

In the area of electricity and magnetism, fourth-grade students are expected to have some experience with the idea of a complete electrical circuit and practical knowledge of magnets and their uses. At the eighth grade, assessment of students' understanding of electricity is expanded to include the idea of current flow in complete circuits, simple circuit diagrams, and the relationship between current and voltage in circuits. They can also describe properties and forces of permanent magnets, as well as the essential features and uses of electromagnets.

Students at the fourth grade are expected to have an intuitive grasp of the idea of forces as they relate to movement, such as gravity acting on falling objects and push/pull forces. Knowledge about the measurement of the weight of objects may also be assessed at the fourth grade in the context of floating objects or objects on a scale. At the eighth grade, more quantitative knowledge of mechanics is expected. At this level, students are expected to represent motion, compute speed, interpret/use distance versus time graphs, and predict changes in the motion of an object based on the forces acting upon it. They should also demonstrate commonsense understanding of density and pressure as they relate to familiar physical phenomena, although more formalized knowledge is not expected.

Physics: Physical States and Changes in Matter

Grade 4

- Describe that all objects/materials are made up of matter that exists in three major states (solid, liquid, gas), and describe differences in the observable physical properties of solids, liquids, and gases in terms of shape and volume.
- Demonstrate knowledge that water exists in different physical states and can be changed from one state to another by heating or cooling, and describe these changes in familiar terms (melting, freezing, boiling).

Grade 8

- Use knowledge about the movement of and distance between particles to explain differences in the physical properties of solids, liquids, and gases (volume, shape, density, compressibility).
- Describe the processes of melting, freezing, evaporation, and condensation as changes of state resulting from the supplying or removing of heat/energy; relate the rate/extent of these processes to common physical factors (surface area, dissolved substances, temperature, altitude/pressure).
- Demonstrate understanding of the melting/boiling point of substances; explain why temperature remains constant during phase change (melting, boiling, freezing).
- Illustrate understanding that matter (mass) is conserved during familiar physical changes (e.g., change of state, dissolving solids, thermal expansion).

Physics: Energy Types, Sources, and Conversions

Grade 4

- Identify common energy sources and forms (e.g., wind, sun, electricity, burning fuel, water wheel, food); know some practical uses of energy.

Grade 8

- Identify different forms of energy (e.g., mechanical, light, sound, electrical, thermal, chemical); describe simple energy transformations (e.g., combustion in an engine to move a car, electrical energy to power a lamp, hydroelectric power, changes between potential and kinetic energy); and apply knowledge of the concept of conservation of total energy.

Physics: Heat and Temperature

Grade 4

- Demonstrate knowledge that heat flows from a hot object to a cold object and causes materials to change temperature and volume; identify common materials that conduct heat better than others; recognize the relationship between temperature measurements and how hot/cold an object is.

Grade 8

- Relate heat to the transfer of energy from an object at a high temperature to one at a lower temperature; compare the relative thermal conductivity of different materials; and compare/contrast methods of heat transfer (conduction, convection, and radiation).
- Explain thermal expansion in terms of change in volume and/or pressure (e.g., thermometers, balloons).
- Relate temperature and changes in volume and/or pressure to the movement/speed of particles.

Physics: Light

Grade 4

- Identify common sources of light (e.g., bulb, flame, sun); and relate familiar physical phenomena to the presence/absence and behavior of light (e.g., appearance of rainbows; colors produced from prisms, oil slicks, soap bubbles, etc.; formation of shadows; visibility of objects; mirrors).

Grade 8

- Describe/identify some basic properties/behaviors of light (transmission from a source through different media; speed of light compared to sound; reflection, refraction (bending), absorption, and transmission by different materials; splitting of white light into its component colors by prisms and other dispersive media).
- Relate the appearance/color of objects to the properties of reflected/absorbed light.
- Solve practical problems involving the reflection of light from plane mirrors and the formation of shadows; use/interpret ray diagrams to identify the path of light and locate reflected/projected images.

Physics: Sound and Vibration

Grade 4

- Not assessed.

Grade 8

- Explain how sound with varying loudness (intensity) and pitch is produced by vibrations with different properties (amplitude, frequency);* recognize that sound is transmitted away from a source through different materials and can be reflected by surfaces.

* Knowledge/use of the specific terms amplitude and frequency is not expected at grade 8.

Physics: Electricity and Magnetism

Grade 4

- Know common uses of electricity; identify a complete electrical circuit using batteries, bulbs, wires, and other common components that conduct electricity.
- Know that magnets have north and south poles, that like poles repel and opposite poles attract, and that magnets can be used to attract some other materials/objects.

Grade 8

- Describe the flow of current in an electrical circuit; draw/identify diagrams representing complete circuits (series and parallel); classify materials as electrical conductors or insulators; and recognize that there is a relationship between current and voltage in a circuit.
- Demonstrate knowledge of the properties of permanent magnets and the effects of magnetic force; identify essential features and practical uses of electromagnets.

Physics: Forces and Motion

Grade 4

- Identify familiar forces that cause objects to move (e.g., gravity acting on falling objects, push/pull forces).
- Describe how the relative weight of objects can be determined using a balance; relate the weight* of different objects to their ability to float or sink.

* Although buoyancy is a function of density, knowledge of the term and concept of density and the distinction between weight and mass is not expected at grade 4. At this level, students may be assessed on their knowledge of flotation using objects of comparable size but different weight/mass.

Grade 8

- Represent the motion of an object in terms of its position, direction, and speed in a given reference frame; compute speed from time and distance using standard units; and use/interpret information in distance versus time graphs.
- Describe general types of forces (e.g., weight as a force due to gravity, contact force, buoyant force, friction); predict changes in motion (if any) of an object based on the forces acting on it; demonstrate basic knowledge of work and the function of simple machines (e.g., levers) using common examples.
- Explain observable physical phenomena in terms of density differences (e.g., floating/sinking objects, rising balloons, ice layers).
- Demonstrate knowledge of effects related to pressure (e.g., atmospheric pressure as a function of altitude, ocean pressure as a function of depth, evidence of gas pressure in balloons, spreading force over a large/small area, fluid levels).

Earth Science

Earth science is concerned with the study of the earth and its place in the solar system and the universe. Topics covered in the teaching and learning of earth science draw on the fields of geology, astronomy, meteorology, hydrology, and oceanography, and are related to concepts in biology, physics, and chemistry. Although separate courses in earth science covering all of these topics are not taught in all countries, it is expected that understandings related to earth science topic areas will have been included in a science curriculum covering the physical and life sciences or in separate courses such as geography and geology. While there is no single picture of what constitutes an earth science curriculum at different grade levels that applies to all countries, the TIMSS framework identifies the following topic areas that are universally considered to be important for students at the fourth and eighth grades to understand about the planet on which they live and its place in the universe:

- Earth's structure and physical features (lithosphere, hydrosphere and atmosphere)
- Earth's processes, cycles, and history
- Earth in the solar system and the universe

Both fourth- and eighth-grade students are expected to have some general knowledge about the structure and composition of the earth. At the fourth grade, students should know that solid earth is composed of rocks, sand, and soil, and that most of the earth's surface is covered by water. At this level, assessment of students' understandings of the atmosphere is limited to evidence for the presence of water and the importance of air for the survival of living things. Eighth-grade students' understandings in these areas are more directly connected to underlying concepts in the life and physical sciences. Students are expected to compare physical characteristics of the earth's crust, mantle, and core, and to describe the distribution of water on the earth, including comparisons with respect to physical state, composition, and movement. Their understanding of the atmosphere includes the relative abundance of the main components of air, and changes in atmospheric conditions in relation to altitude. While students at the fourth grade are expected to know common features of the earth's landscape, those at the eighth grade should be able to use/interpret topographic maps and diagrams representing these structural features.

An understanding of the earth's processes, cycles, and history is expected at substantially different levels for fourth- and eighth-grade students. At the fourth grade, students are expected to be able to describe some of the earth's processes in terms of observable changes, including the movement of water, cloud formation, and changes in daily or seasonal weather conditions. In comparison, eighth-grade students are expected to provide more complete descriptions based on the concept of cycles and patterns. They use words and/or diagrams to describe the rock and water cycle, and interpret/use data or maps related to global and local factors affecting weather patterns. They can also differentiate between daily weather changes and general climate in different regions of the world. Assessing the understanding of the earth's history is fairly limited at the fourth grade. Students at that level should know that the earth is quite old and that fossils of plants and animals that lived a long time ago can be found in rocks. By the eighth grade, students are expected to start to develop a sense of the magnitude of time scales, and to be able to describe some physical processes and geological events that have taken place on the earth over billions of years.

By the fourth grade, students are expected to demonstrate some understandings about the earth's place in the solar system based on observations of changes in the earth and sky. In particular, they should be familiar with the motions of the earth, and relate daily changes on the earth to its rotation on its axis and relationship to the sun. By the eighth grade, students are expected to have a more complete knowledge of the solar system in terms of the relative distances, sizes, and motions of the sun, the planets, and their moons, and of how phenomena on the earth relate to the motion of bodies in the solar system. Students at the eighth grade are also expected to compare the physical features of the earth, the moon, and the other planets with respect to their ability to support life.

Assessment of knowledge of the universe outside the solar system is focused on a developing understanding of stars by the eighth grade. Eighth-grade students are expected to identify the sun as an "average" star and recognize that billions of other stars are observed in the night sky that are outside and very distant from our solar system. This area is not assessed at the fourth grade.

Earth Science: Earth's Structure and Physical Features[6]

Grade 4

- Know that the surface of the earth is composed of rocks, minerals, sand, and soil; and compare physical properties, locations, and uses of these materials.
- Recognize that most of the earth's surface is covered with water; describe the locations/types of water found on the earth (e.g., salt water in oceans, fresh water in lakes and rivers, clouds, snow, ice caps, icebergs).
- Provide evidence for the existence/nature of air, including the fact that air contains water (e.g., cloud formation, dew drops, evaporation of ponds), examples of the uses of air, and the importance of air for supporting life.
- Identify/describe common features of the earth's landscape (e.g., mountains, plains, rivers, deserts) and relate them to human use (e.g., farming, irrigation, land development).

Grade 8

- Demonstrate knowledge of the structure and physical characteristics of the earth's crust, mantle, and core; use/interpret topographic maps; describe the formation, characteristics, and/or uses of soil, minerals, and basic rock types.
- Compare the physical state, movement, composition and relative distribution of water on the earth (e.g., oceans, rivers, ground water, glaciers, ice caps, clouds).
- Know that the earth's atmosphere is a mixture of gases, and identify the relative abundance of its main components; relate changes in atmospheric conditions (temperature, pressure, composition) to altitude.

6 Assessment objectives related to the use and conservation of earth's natural resources are described in the Environmental Science section. At grade 4, these objectives may be reported in Earth Science.

Earth Science: Earth's Processes, Cycles, and History

Grade 4

- Draw/describe the movement of water on the earth's surface (e.g., flowing in rivers/streams from mountains to oceans/lakes); relate the formation of clouds and rain/snow to a change of state of water.
- Describe changes in weather conditions from day to day or over the seasons in terms of observable properties such as temperature, precipitation (rain/snow), clouds, and wind.
- Recognize that fossils of animals and plants that lived on the earth a long time ago can be found in rocks and provide evidence that the earth is very old.

Grade 8

- Demonstrate knowledge of the general processes involved in the rock cycle (weathering/erosion, deposition, heat/pressure, melting/cooling, lava flow) resulting in the continuous formation of igneous, metamorphic, and sedimentary rock.
- Diagram/describe the steps in the earth's water cycle (evaporation, condensation, and precipitation), referencing the sun as the source of energy and the role of cloud movement and water flow in the circulation and renewal of fresh water on the earth's surface.
- Interpret weather data/maps, and relate changing weather patterns to global and local factors in terms of temperature, pressure, precipitation, wind speed/direction, cloud types/formation, and storm fronts.
- Compare seasonal climates of major regions on the earth, considering effects of latitude, altitude and geography (e.g., mountains and oceans); identify/describe long- and short-term climatic changes (e.g., ice ages, global warming trends, volcanic eruptions, changes in ocean currents).
- Identify/describe physical processes and major geological events that have occurred over billions of years (e.g., weathering, erosion, deposition, volcanic activity, earthquakes, mountain building, plate movement, continental drift); explain the formation of fossils and fossil fuels.

Earth Science: Earth in the Solar System and the Universe

Grade 4

- Describe the solar system as a group of planets (including earth) each revolving around the sun, and identify the sun as the source of heat and light for the solar system.
- Relate daily patterns observed on the earth to the earth's rotation on its axis and its relationship to the sun (e.g., day/night, appearance of shadows).
- Draw/describe the phases of the moon.

Grade 8

- Explain phenomena on the earth (day/night, tides, year, phases of the moon, eclipses, seasons in the northern/southern hemisphere, appearance of sun, moon, planets, and constellations) in terms of the relative movements, distances, and sizes of the earth, moon, and other bodies in and outside the solar system.
- Recognize the role of gravity in the solar system (e.g., tides, keeping the planets and moons in orbit, pulling us to the earth's surface).
- Compare and contrast the physical features of the earth with the moon and other planets (e.g., atmosphere, temperature, water, distance from sun, period of revolution/rotation, ability to support life).
- Recognize the sun as an "average" star, and know that there are billions of other stars in the universe outside and very distant from the earth's solar system.

Environmental Science

Environmental science is a field of applied science concerned with environmental and resource issues. As such, it involves concepts from the life, earth, and physical sciences, and considerable overlap with these content areas. While environmental science typically is not offered as a separate science course until at least the upper secondary or post-secondary level, its inclusion in the TIMSS framework as a separate content domain reflects the relative importance placed internationally on educating students about factors affecting the environment and ecosystems. Both fourth- and eighth-grade students are expected to have attained some understandings related to environmental science. However, because these are more limited at the fourth grade, environmental science will be reported separately at the eighth grade but not the fourth, where items measuring these understandings will be included in the Earth Science or Life Science reporting categories as indicated below. In addition, a number of assessment objectives appropriate to each grade level that are related to a basic understanding of the functioning of and relationships in ecosystems, fundamental to environmental science, are described in the Life Science section.

The environmental science category in TIMSS is defined primarily by understandings related to the interaction of humans with ecosystems, changes in the environment from manmade or natural events, and protection of the environment. An underlying theme throughout is the roles and responsibilities of science, technology, and society in maintaining the environment and conserving resources. The main topic areas in environmental science are:

- Changes in population
- Use and conservation of natural resources
- Changes in environments

Eighth-grade but not fourth-grade students are expected to demonstrate some understanding of the consequences of rapid growth in the human population. They should be able to analyze trends in world population, and be able to discuss some effects of increasing population on the environment, demonstrating a link to underlying science concepts related to biodiversity, sustainable populations, and carrying capacity of environments.

Fourth-grade students are expected to have practical knowledge of human use of the earth's natural resources and may identify some physical resources used in everyday life, their common sources, and the need to conserve these resources. At the eighth grade, students are expected to demonstrate an increased understanding of limiting resources in environments and the impact of science and technology on the use and conservation of these resources.

As described in the Life Science section, students at the fourth and eighth grades are expected to have some understanding of balance in ecosystems in terms of interactions between organisms and their relationship to the physical environment. An important understanding in environmental science is how changes in environments, whether resulting from natural processes or from human activity, can affect both living and nonliving components and shift this balance. At both grade levels, students are expected to demonstrate understanding that human activity can affect the environment positively or negatively and to cite examples. At the eighth grade, it is expected that students will be able to discuss both short- and long-term effects and the role of science and technology in environmental issues. Students at the fourth grade are expected to know the effects of some common types of pollution and how humans can prevent or reduce them. At the eighth grade, a broader knowledge of pollution is expected, and students should be able to relate some global environmental concerns to their possible causes and/or effects. They should be able to discuss the impact of environmental changes in terms of changes to habitat, resources, food webs, and life cycles.

Environmental Science: Changes in Population

Grade 4

- Not Assessed.

Grade 8

- Analyze trends in human population, identifying that the world population is growing at an increasing rate, and comparing the population distribution, growth rate, and consumption/availability of resources in different regions.
- Discuss effects of population growth on the environment (e.g., use of natural resources, food supply/demand, health, water supply/demand, growth of cities/suburbs, land use/development, hunting/fishing).

Environmental Science: Use and Conservation of Natural Resources

Grade 4

- Identify some of the earth's physical resources that are used in everyday life and their common sources (e.g., water, soil, wood, minerals, fuel, food); explain the importance of using these resources wisely.

Note: Environmental Science is not reported separately at Grade 4. Items measuring understandings related to the use and conservation of natural resources are reported in Life Science or Earth Science.

Grade 8

- Know common examples of renewable and nonrenewable resources; discuss advantages and disadvantages of different types of energy sources (e.g., fossil fuels, wood, solar, wind, geothermal, nuclear, hydroelectric, chemical batteries); and describe methods of conservation and waste management (e.g., recycling/reuse, use of biodegradable materials).
- Relate effects of human use of land/soil resources (e.g., farming, ranching, mining, tree harvesting) to methods used in agriculture and land management (e.g., crop rotation, terracing/contour farming, fertilization, irrigation, pest control, grazing management, reclamation/recycling, reforesting).
- Discuss factors related to the supply/demand of fresh water and use of water resources (e.g., renewable but limited supply of fresh water, purification, desalination, irrigation, water treatment/reuse, conservation, use of dams, fishing practices).

Environmental Science: Changes in Environments

Grade 4

- Present ways in which human behavior can have a positive or a negative effect on environments; provide general descriptions and examples of the effects of pollution on humans, plants, animals, and their environments, and ways of preventing or reducing pollution.

Note: Environmental Science is not reported separately at grade 4. Items measuring understandings related to changes in environments are reported in Life Science or Earth Science.

Grade 8

- Discuss ways in which human activity can both contribute to and help solve environmental problems, including both short- and long-term effects on ecosystems; describe sources, effects, and ways of preventing/reducing air, water, and land pollution; and explain the role of science and technology in addressing environmental issues.
- Relate some global environmental concerns to their possible causes and/or effects (e.g., global warming, acid rain, depletion of the ozone layer, deforestation, desertification); present ways in which science and technology can be used to address these concerns.
- Describe some natural hazards and their impact on humans, wildlife, and the environment in terms of changes to habitat, resources, food webs, and life cycles (e.g., earthquakes, landslides, wildfires, volcanic eruptions, floods, storms).

Science Cognitive Domains

The TIMSS science framework is based on the idea of science as a process used to learn about the physical world that involves observation, description, investigation, and explanation of natural phenomena. As such, it includes both demonstration of content knowledge and the ability to apply and communicate understanding of concepts in solving problems, developing explanations, and conducting and reporting results of investigations. In addition to defining the specific science topics that will be assessed, the assessment outcomes for each science content domain include descriptions of illustrative skills and cognitive abilities that the items on the TIMSS test are designed to assess. In this section, the cognitive dimension is further described, and the skills and abilities that illustrate student understandings are classified into three broad cognitive domains that will be assessed across the science content domains:

- Factual Knowledge
- Conceptual Understanding
- Reasoning and Analysis

The development of scientific understanding and reasoning builds on previous knowledge, expanding and revising the knowledge base as it progresses. It requires the ability to determine how facts and concepts are related to each other. In order to participate in the scientific endeavor, it is important to have a firm grasp of basic science concepts and be able to support them with facts. Therefore, in TIMSS it is relevant to include a measure of the extent and accuracy of students' factual knowledge base as well as their understanding, use, and application of science concepts in problem situations. In a problem-solving situation, students may fail to solve the problem either because they lack the factual or procedural knowledge required or because they are unable to analyze the problem to identify the relevant facts and concepts to apply and/or to develop an effective strategy. Determining the impact of each of these factors is important in identifying areas where education and learning can be improved.

Including the cognitive dimension in the frameworks will ensure that balanced tests are produced that provide adequate coverage of each cognitive domain at each grade level. The distribution of items across *factual knowledge*, *conceptual understanding*, and *reasoning and analysis* will vary between fourth and eighth grade in accordance with the increased cognitive ability, maturity, instruction, experience, and breadth and depth of conceptual understanding of students at the higher grade level (see Exhibit 3). While some hierarchy is imposed in the division of behaviors into the three cognitive categories, there is still a range of complexity in the cognitive skills elicited by items aligned with each category. In addition, a range of difficulty levels is expected for items developed in each of the cognitive domains. While an individual item may elicit behaviors that correspond to more than one cognitive domain, an item will be categorized into a cognitive domain on the basis of the most complex cognitive ability required and the primary contribution of the item to the interpretation of results from the assessment. The following sections further describe the student skills and abilities defining the cognitive domains. The general descriptions are followed by tables indicating specific behaviors to be elicited by items that are aligned with each category.

Factual Knowledge

The cognitive domain of *factual knowledge* refers to students' knowledge base of relevant science facts, information, tools, and procedures. In order to solve problems and develop explanations in science, students must possess a strong knowledge base. Accurate and broad-based factual knowledge enables students to engage successfully in the more complex cognitive activities essential to the scientific enterprise. Demonstrating factual knowledge involves more than just rote memorization and recall of isolated bits of information. For example, being able to make comparisons, classify/order, and differentiate among materials and organisms hinges on basic knowledge of physical characteristics and the application of science concepts. In addition, students' knowledge and use of the definitions of scientific terms is linked to their understanding of underlying concepts and relationships. Knowledge of vocabulary, facts, information, symbols, units, and procedures may be assessed through their proper usage in a given context. The selection of the appropriate apparatus, equipment, measurement devices, and experimental operations to use in conducting investigations also depends on students' basic knowledge of the tools and procedures of science.

Factual Knowledge

Recall/Recognize	Make or identify accurate statements about science facts, relationships, processes, and concepts; identify the characteristics or properties of specific organisms, materials, and processes.
Define	Provide or identify definitions of scientific terms; recognize and use scientific vocabulary, symbols, abbreviations, units, and scales in relevant contexts.
Describe	Recognize or describe organisms, physical materials, and science processes that demonstrate knowledge of properties, structure, function, and relationships.
Use Tools and Procedures	Demonstrate knowledge of the use of science apparatus, equipment, tools, procedures, and measurement devices/scales.

Conceptual Understanding

Conceptual understanding in science means having a grasp of the relationships that explain the behavior of the physical world and relating the observable to more abstract or more general scientific concepts. It increases in sophistication as students progress through school and develop cognitively, and the evidence of understanding will vary across grades. Conceptual understanding, then, is not something that will be measured directly. Rather, students must show evidence of it through its use and application in performing specific tasks appropriate for each grade level. To measure conceptual understanding, TIMSS items will be included that require students to extract and use scientific information and use and apply their understanding of science concepts and principles to find solutions and develop explanations. This cognitive domain also includes the selection of illustrative examples in support of statements of facts or concepts. Items aligned with this cognitive domain will involve the direct application or demonstration of relationships, equations, and formulas in contexts likely to be familiar in the teaching and learning of science concepts. Both quantitative problems requiring a numerical solution and qualitative problems requiring a written descriptive response are included. In providing explanations, students should be able to use models to illustrate structures and relationships and demonstrate knowledge of scientific concepts. The problems in this cognitive domain are designed to involve more straightforward applications of concepts and require considerably less analysis and integration than the items aligned with the reasoning and analysis domain.

Conceptual Understanding

Illustrate with Examples	Support or clarify statements of facts/concepts with appropriate examples; identify or provide specific examples to illustrate knowledge of general concepts.
Compare/Contrast/ Classify	Identify or describe similarities and differences between groups of organisms, materials, or processes; distinguish, classify, or order individual objects, materials, organisms, and processes based on characteristics and properties.
Represent/Model	Use/draw diagrams and/or models to demonstrate understanding of science concepts, structures, relationships, processes, and biological/physical systems and cycles (e.g., food webs, electrical circuits, water cycle, solar system, atomic structure).
Relate	Relate knowledge of underlying biological and physical concepts to the observed or inferred properties/behaviors/uses of objects, organisms, and materials.
Extract/ Apply Information	Identify/extract/apply relevant textual, tabular, or graphical information in light of science concepts/principles.

Find Solutions	Identify/use science relationships, equations, and formulas to find qualitative or quantitative solutions involving the direct application/demonstration of concepts.
Explain	Provide or identify reasons/explanations for observations or natural phenomena, demonstrating understanding of the underlying science concept, principle, law, or theory.

Reasoning and Analysis

Reasoning and analysis is involved in all of the more complex tasks related to science. A major purpose of science education is to prepare students to engage in scientific reasoning to solve problems, develop explanations, draw conclusions, make decisions, and extend their knowledge to new situations. In addition to the more direct applications of science concepts exemplified in the conceptual understanding domain, some problem-solving situations involve unfamiliar or more complicated contexts that require students to reason from scientific principles to provide an answer. Solutions may involve breaking down the problem into component parts, each involving the application of a science concept or relationship. Students may be required to analyze the problem to determine what underlying principles are involved; interpret/use diagrams and graphs; devise and explain strategies for problem solving; select and apply the appropriate equations, formulas, relationships, and analytical techniques; and evaluate their solutions. Correct solutions to such problems may stem from a variety of approaches or strategies, and developing the ability to consider alternative strategies is an important educational goal in the teaching and learning of science.

Students may be required to draw conclusions from scientific data and facts, providing evidence of both inductive and deductive reasoning and an understanding of the investigation of cause and effect. They are expected to evaluate and make decisions based on conceptual understanding, including weighing advantages and disadvantages of alternative materials and processes, considering the impact of different scientific endeavors, and evaluating solutions to problems. By the eighth grade, in particular, they also start to consider and evaluate alternative explanations, extend conclusions to new situations, and justify explanations based on evidence and scientific understanding. Considerable scientific reasoning is also involved in developing hypotheses and designing scientific investigations to test them, and in analyzing and interpreting data. Abilities in this area are introduced at a very basic level in primary school and then further developed throughout students' science education in middle and secondary school.

Some items in this cognitive domain may focus on unified concepts and major conceptual themes, requiring students to bring together knowledge and understanding from different areas and apply it to new situations. As such, they may involve the integration of mathematics and science and/or the integration and synthesis of concepts across the domains of science. Fourth-grade students may be expected to demonstrate some of the abilities needed for scientific reasoning, but at a less sophisticated level than eighth-grade students. Items included to assess these areas at the fourth grade will be more structured and less open-ended than items for eighth-grade students. Due to the more sophisticated cognitive abilities required, less weight will be placed on this cognitive domain at the fourth grade.

Reasoning and Analysis

Analyze/Interpret/ Solve Problems	Analyze problems to determine the relevant relationships, concepts, and problem-solving steps; develop/explain problem-solving strategies; interpret/use diagrams and graphics to visualize and/or solve problems; give evidence of deductive and inductive reasoning processes used to solve problems.
Integrate/Synthesize	Provide solutions to problems that require consideration of a number of different factors or related concepts; make associations/connections between concepts in different areas of science; demonstrate understanding of unified concepts and themes across the domains of science; integrate mathematical concepts/procedures in the solutions to science problems.
Hypothesize/Predict	Combine knowledge of science concepts with information from experience or observation to formulate questions that can be answered by investigation; formulate hypotheses as testable assumptions using knowledge from observation and/or analysis of scientific information and conceptual understanding; make predictions about the effects of changes in biological or physical conditions in light of evidence and scientific understanding.
Design/Plan	Design/plan investigations appropriate for answering scientific questions or testing hypotheses; describe/recognize the characteristics of well-designed investigations in terms of variables to be measured and controlled and cause-and-effect relationships; make decisions about measurements/procedures to use in conducting investigations.
Collect/Analyze/ Interpret Data	Make and record systematic observations and measurements, demonstrating appropriate applications of apparatus, equipment, tools, procedures, and measurement devices/scales; represent scientific data in tables, charts, graphs, and diagrams using appropriate format, labeling, and scales; select/apply appropriate mathematical computations/techniques to data to obtain derived values necessary to draw conclusions; detect patterns in data, describe/summarize data trends, and interpolate/extrapolate from data or given information.
Draw Conclusions	Make valid inferences on the basis of evidence and/or understanding of science concepts; draw appropriate conclusions that address questions/hypotheses, and demonstrate understanding of cause and effect.

Reasoning and Analysis

Generalize	Make/evaluate general conclusions that go beyond the experimental or given conditions, and apply conclusions to new situations; determine general formulas for expressing physical relationships.
Evaluate	Weigh advantages and disadvantages to make decisions about alternative processes, materials, and sources; consider scientific and social factors to evaluate the impact/consequences of science and technology in biological and physical systems; evaluate alternative explanations and problem-solving strategies and solutions; evaluate results of investigations with respect to sufficiency of data to support conclusions.
Justify	Use evidence and scientific understanding to justify explanations and problem solutions; construct arguments to support the reasonableness of solutions to problems, conclusions from investigations, or scientific explanations.

Scientific Inquiry

In the contemporary science curricula of many countries, considerable emphasis is placed on engaging students in scientific inquiry. The goal of scientific inquiry is to provide explanations of scientific phenomena that help us understand the underlying principles governing the natural world. At the fourth- and eighth-grade level, students are not expected to be formulating and testing fundamental theories, but they should be able to pose scientific questions or hypotheses of limited scope that can be investigated. At these grade levels, scientific inquiry involves students in the process of questioning, planning, and conducting investigations to gather evidence, and formulating explanations based on observations and in light of scientific understanding. The understandings and abilities required to engage in this type of scientific investigation are important in developing citizens that are literate in the methods, processes, and products of science. They are also precursors of the more advanced types of inquiry directed at furthering scientific knowledge that are important in preparing future scientists. Given that the scientific inquiry process is an integral part of learning and doing science, it is important to assess students' understandings and abilities required to engage in this process successfully.

Scientific inquiry is treated as an overarching assessment strand in the TIMSS framework that overlaps all of the fields of science and has both content- and skills-based components. Assessment of scientific inquiry includes items and tasks requiring students to demonstrate knowledge of the tools, methods, and procedures necessary to do science, to apply this knowledge to engage in scientific investigations, and to use scientific understanding to propose explanations based on evidence. These processes of scientific inquiry promote a broader understanding of science concepts as well as reasoning and problem-solving skills.

It is expected that students at both grade levels will possess some general knowledge of the nature of science and scientific inquiry, including the fact that scientific knowledge is subject to change, the importance of using different types of scientific investigations in verifying/testing scientific knowledge, the use of basic "scientific methods," communication of results, and the interaction of science, mathematics, and technology. In addition to this general knowledge, students are expected to demonstrate the skills and abilities involved in the following five major phases of the scientific inquiry process:[7]

- Formulating questions and hypotheses
- Designing investigations
- Collecting and representing data
- Analyzing and interpreting data
- Drawing conclusions and developing explanations

These phases of scientific inquiry are appropriate for both fourth- and eighth-grade students, but the understandings and abilities to be demonstrated increase in complexity across grades, reflecting the cognitive development of students. The learning of science in the fourth grade is focused on observing and describing, and students at this level are expected to be able to formulate questions that can be answered based on observations or information obtained about the natural world. To obtain evidence to answer these questions, they should demonstrate a grasp of what constitutes a "fair test," and be able to describe and conduct an investigation based on making systematic observations or

7 The order of the phases of scientific inquiry is imposed primarily for organizational purposes, reflecting the logical sequence consistent with the convention used in reporting the results of investigations. While real scientific inquiry may not proceed in a strict order, some aspect of each of these phases will be part of any scientific investigation.

measurements using simple tools, equipment, and procedures. They are also expected to represent their findings using simple charts and diagrams, apply routine mathematical computations of measured values, identify simple relationships, and briefly describe the results of their investigations. Conclusions drawn from investigations at the fourth grade are expected to be written as an answer to a specific question.

By the eighth grade, students should demonstrate a more quantitative and formalized approach to scientific investigation that involves more evaluation and decision-making. They are expected to be able to formulate a hypothesis or prediction based on observation or scientific knowledge that can be tested by investigation. They are expected to demonstrate an understanding of cause and effect and the importance of specifying variables to be controlled and varied in well-designed investigations. They may also be required to make more decisions about the measurements to be made and the equipment and procedures to use. In collecting and representing data, students at this level are expected to use appropriate terminology, units, precision, format, and scales. They should also demonstrate more advanced data analysis skills in selecting and applying appropriate mathematical techniques and describing patterns in data. Eighth-grade students may be expected to evaluate the results of their investigation with respect to the sufficiency of their data for supporting conclusions that address the question or hypothesis under investigation.

The assessment of both fourth- and eighth-grade students' ability to provide explanations based on evidence from scientific investigations provides another measure of their understanding and application of related science concepts. By the eighth grade, it is expected that students will be able to formulate explanations in terms of cause-and-effect relationships between variables and in light of scientific understanding. At this level, students may also begin to consider alternative explanations and apply/extend their conclusions to new situations.

Students' understandings and abilities related to scientific inquiry will be assessed primarily through items or tasks that require students to apply knowledge and process skills in a practical context. The tasks, while not intended to be full scientific investigations, will be designed to require a basic understanding of the processes of scientific investigation and elicit some of the skills that are essential to the scientific inquiry process. As such, they will be used to assess whether students have some of the key understandings and abilities necessary to engage in scientific inquiry.