IEA TIMSS 2019

CHAPTER 2

TIMSS 2019 Science Framework

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Overview

Children have a natural curiosity about the world and their place in it. Science education in the primary grades capitalizes on this curiosity and starts young students on a path of systematic inquiry about the world in which they live. As their understanding of science develops, students in the lower-secondary grades become increasingly able to make informed decisions about themselves and their world so that, as adults, they can become informed citizens capable of distinguishing scientific fact from fiction and understanding the scientific basis of important social, economic, and environmental issues. Across the world, there is an increased demand for those qualified to pursue the careers in science, technology, and engineering that drive the innovation necessary for economic growth and for improving quality of life. To meet this demand, it is increasingly important to prepare students to enter advanced study in these areas.

This chapter presents the assessment frameworks for the two TIMSS 2019 science assessments:

- TIMSS Science—Fourth Grade
- TIMSS Science—Eighth Grade

The TIMSS 2019 Science Frameworks for the fourth and eighth grades extend the 24-year history of TIMSS assessments, beginning in 1995 and taking place every four years since. TIMSS 2019 is the seventh assessment in the series.

In general, the TIMSS 2019 science frameworks are similar to those used in TIMSS 2015. However, there have been minor updates to particular topics to better reflect the curricula of the participating countries as reported in the *TIMSS 2015 Encyclopedia* (Mullis, Martin, Goh, and Cotter, 2016). TIMSS 2019 marks the transition to eTIMSS, and the science frameworks have also been updated to take advantage of both digital and paper assessment formats. eTIMSS provides an avenue for expanding the range of assessment methods included in TIMSS and capitalizes especially on new and improved computer-based approaches to the assessment of inquiry and investigation in science.

At each grade, the science assessment framework for TIMSS 2019 is organized around two dimensions:

- Content dimension, specifying the subject matter to be assessed
- Cognitive dimension, specifying the thinking processes to be assessed

Exhibit 2.1 shows the target percentage of testing time devoted to each content and cognitive domain for the TIMSS 2019 fourth and eighth grade assessments.

Exhibit 2.1: Target Percentages of the TIMSS 2019 Science Assessment Devoted to Content and Cognitive Domains at the Fourth and Eighth Grades

Fourth Grade

Content Domains	Percentages
Life Science	45%
Physical Science	35%
Earth Science	20%

Eighth Grade

Content Domains	Percentages
Biology	35%
Chemistry	20%
Physics	25%
Earth Science	20%

Cognitive Domains	Percentages	
	Fourth Grade	Eighth Grade
Knowing	40%	35%
Applying	40%	35%
Reasoning	20%	30%

The content domains differ for the fourth and eighth grades, reflecting the nature and difficulty of the science taught at each grade. There is more emphasis at the fourth grade on life science than its counterpart, biology, at the eighth grade. At the eighth grade, physics and chemistry are assessed as separate content domains and receive more emphasis than at fourth grade, where they are assessed as one content domain (physical science). The three cognitive domains (knowing, applying, and reasoning) are the same at both grades, encompassing the range of cognitive processes involved in learning science concepts, and then applying these concepts and reasoning with them.

In 2019, TIMSS Science also will assess science practices. These practices include skills from daily life and school studies that students use in a systematic way to conduct scientific inquiry and

investigation and that are fundamental to all science disciplines. Increasing emphasis has been placed on science practices and science inquiry in many countries' current science curricula, standards, and frameworks (Mullis, Martin, Goh, and Cotter, 2016).

The practice of science is, by its very nature, strongly connected to the area of science under study and, therefore, cannot be assessed in isolation. Some items in the TIMSS 2019 science assessment at both the fourth and eighth grades will assess one or more of these important science practices together with content specified in the content domains and thinking processes specified in the cognitive domains.

The next two sections of this chapter present the TIMSS 2019 science content domains for fourth and eighth grades, followed by a description of the cognitive domains, which are applicable to both grades. The chapter concludes with a description of the science practices.

Science Content Domains—Fourth Grade

Three major content domains define the science content for the TIMSS Science fourth grade assessment: life science, physical science, and Earth science. Exhibit 2.2 shows the target percentages of testing time for each of the three content domains in the TIMSS 2019 Science assessment.

Exhibit 2.2: Target Percentages of the TIMSS 2019 Science Assessment Devoted to Content Domains at the Fourth Grade

Fourth Grade Content Domains	Percentages
Life Science	45%
Physical Science	35%
Earth Science	20%

Each of these content domains includes several major topic areas, and each topic area in turn includes one or more topics. Each topic is further described by specific objectives that represent the students' expected knowledge, abilities, and skills assessed within each topic. Across the fourth grade assessment, each objective receives approximately equal weight in terms of the number of assessment items. The verbs used in the objectives are intended to represent typical performances expected of fourth grade students, but are not intended to limit performances to a particular cognitive domain. Each objective can be assessed drawing on any of the three cognitive domains (knowing, applying, and reasoning).

Life Science

The study of life science at the fourth grade provides students with an opportunity to capitalize on their innate curiosity and begin to understand the living world around them. In TIMSS 2019, life science is represented by five topic areas:

- Characteristics and life processes of organisms
- Life cycles, reproduction, and heredity
- Organisms, environment, and their interactions
- Ecosystems
- Human health

By the fourth grade, students are expected to be building a base of knowledge about general characteristics of organisms, how they function, and how they interact with other organisms and with their environment. Students also should be familiar with fundamental science concepts related to life cycles, heredity, and human health that in later grades will lead to a more sophisticated understanding of how the human body functions.

Characteristics and Life Processes of Organisms

1. Differences between living and non-living things and what living things require to live:
   A. Recognize and describe differences between living and non-living things (i.e., all living things can reproduce, grow and develop, respond to stimuli, and die; and non-living things cannot).
   B. Identify what living things require in order to live (i.e., air, food, water, and an environment in which to live).
2. Physical and behavioral characteristics of major groups of living things:
   A. Compare and contrast physical and behavioral characteristics that distinguish major groups of living things (i.e., insects, birds, mammals, fish, reptiles, and flowering plants).
   B. Identify or provide examples of members of major groups of living things (i.e., insects, birds, mammals, fish, reptiles, and flowering plants).
   C. Distinguish groups of animals with backbones from groups of animals without backbones.
3. Functions of major structures in living things:
   A. Relate major structures in animals to their functions (e.g., teeth break down food, bones support the body, lungs take in air, the heart circulates blood, the stomach digests food, muscles move the body).
   B. Relate major structures in plants to their functions (i.e., roots absorb water and nutrients and anchor the plant, leaves make food, the stem transports water and food, petals attract pollinators, flowers produce seeds, and seeds produce new plants).

Life Cycles, Reproduction, and Heredity

1. Stages of life cycles and differences among the life cycles of common plants and animals:
   A. Identify stages of the life cycles of plants (i.e., germination, growth and development, reproduction, and seed dispersal).
   B. Recognize, compare, and contrast the life cycles of familiar plants and animals (e.g., trees, beans, humans, frogs, butterflies).
2. Inheritance and reproduction strategies:
   A. Recognize that plants and animals reproduce with their own kind to produce offspring with features that closely resemble those of the parents.
   B. Distinguish between features of plants and animals that are inherited from their parents (e.g., number of petals, color of petals, eye color, hair color), and those that are not (e.g., some broken branches in a tree, length of human hair).
   C. Identify and describe different strategies that increase the number of offspring that survive (e.g., a plant producing many seeds, mammals caring for their young).

Organisms, Environment, and Their Interactions

1. Physical features or behaviors of living things that help them survive in their environment:
   A. Associate physical features of plants and animals with the environments in which they live and describe how these features help them to survive (e.g., a thick stem, a waxy coating, and a deep root help a plant survive in an environment with little water; the coloring of an animal helps camouflage it from predators).
   B. Associate behaviors of animals with the environments in which they live and describe how these behaviors help them to survive (e.g., migration or hibernation helps an animal to stay alive when food is scarce).
2. Responses of living things to environmental conditions:
   A. Recognize and describe how plants respond to environmental conditions (e.g., amount of available water, amount of sunlight).
   B. Recognize and describe how different animals respond to changes in environmental conditions (e.g., light, temperature, danger); recognize and describe how the human body responds to high and low temperatures, exercise, and danger.
3. The impact of humans on the environment:
   A. Recognize that human behavior has negative and positive effects on the environment (e.g., negative effects of air and water pollution, the benefits of reducing air and water pollution); provide general descriptions and examples of the effects of pollution on humans, plants, and animals, and their environments.

Ecosystems

1. Common ecosystems:
   A. Relate common plants and animals (e.g., evergreen trees, frogs, lions) to common ecosystems (e.g., forests, ponds, grasslands).
2. Relationships in simple food chains:
   A. Recognize that all plants and animals need food to provide energy for activity and need raw materials for growth and repair; explain that plants need sunlight to make their food, while animals eat plants or other animals to get their food.
   B. Complete a model of a simple food chain using common plants and animals from familiar ecosystems, such as a forest or a desert.
   C. Describe the roles of living things at each link in a simple food chain (e.g., plants produce their own food; some animals eat plants, while other animals eat the animals that eat plants).
   D. Identify and describe common predators and their prey.
3. Competition in ecosystems:
   A. Recognize and explain that some living things in an ecosystem compete with others for food or space.

Human Health

1. Transmission, prevention, and symptoms of communicable diseases:
   A. Relate the transmission of common communicable diseases to human contact (e.g., touching, sneezing, coughing).
   B. Identify or describe some methods of preventing disease transmission (e.g., vaccination, washing hands, avoiding people who are sick); recognize common signs of illness (e.g., high body temperature, coughing, stomachache).
2. Ways of maintaining good health:
   A. Describe everyday behaviors that promote good health (e.g., a balanced diet, exercising regularly, brushing teeth, getting enough sleep, wearing sunscreen); identify common food sources included in a balanced diet (e.g., fruits, vegetables, grains).

Physical Science

At the fourth grade, students learn how many physical phenomena that they observe in their everyday lives can be explained through an understanding of physical science concepts. The topic areas for the physical science content domain at fourth grade are:

- Classification and properties of matter and changes in matter
- Forms of energy and energy transfer
- Forces and motion

Fourth grade students should have an understanding of physical states of matter (solid, liquid, and gas), as well as common changes in the state and form of matter; this forms a foundation for the study of both chemistry and physics in the middle and upper grades. At this level, students also should know common forms and sources of energy and their practical uses, and understand basic concepts about light, sound, electricity, and magnetism. The study of forces and motion emphasizes an understanding of forces as they relate to movements students can observe, such as the effect of gravity or pushing and pulling.

Classification and Properties of Matter and Changes in Matter

1. States of matter and characteristic differences of each state:
   A. Identify and describe three states of matter (i.e., a solid has a definite shape and volume, a liquid has a definite volume but not a definite shape, and a gas has neither a definite shape nor a definite volume).
2. Physical properties as a basis for classifying matter:
   A. Compare and sort objects and materials on the basis of physical properties (e.g., weight/mass, volume, state of matter, ability to conduct heat or electricity, ability to float or sink in water, ability to be attracted by a magnet). [Note: Students in the fourth grade are not expected to differentiate between mass and weight.]
   B. Identify properties of metals (i.e., conducting electricity and conducting heat) and relate these properties to uses of metals (e.g., a copper electrical wire, an iron cooking pot).
   C. Describe examples of mixtures and how they can be physically separated (e.g., sifting, filtration, evaporation, magnetic attraction).
3. Magnetic attraction and repulsion:
   A. Recognize that magnets have two poles and that like poles repel and opposite poles attract.
   B. Recognize that magnets can be used to attract some metal objects.
4. Physical changes observed in everyday life:
   A. Identify observable changes in materials that do not result in new materials with different properties (e.g., dissolving, crushing an aluminum can).
   B. Recognize that matter can be changed from one state to another by heating or cooling; describe changes in the state of water (i.e., melting, freezing, boiling, evaporation, and condensation).

C. Identify ways of increasing how quickly a solid material dissolves in a given amount of water (i.e., increasing the temperature, stirring, and breaking the solid into smaller pieces); distinguish between strong and weak concentrations of simple solutions.

5. Chemical changes observed in everyday life:

   A. Identify observable changes in materials that make new materials with different properties (e.g., decaying, such as food spoiling; burning; rusting).

Forms of Energy and Energy Transfer

1. Common sources and uses of energy:

   A. Identify sources of energy (e.g., the Sun, flowing water, wind, coal, oil, gas), and recognize that energy is needed to move objects and for heating and lighting.

2. Light and sound in everyday life:

   A. Relate familiar physical phenomena (i.e., shadows, reflections, and rainbows) to the behavior of light.

   B. Relate familiar physical phenomena (i.e., vibrating objects and echoes) to the production and behavior of sound.

3. Heat transfer:

   A. Recognize that warmer objects have a higher temperature than cooler objects; describe what will happen when a hot object and a cold object are brought into contact (i.e., the temperature of the hot object decreases and the temperature of the cold object increases).

4. Electricity and simple electrical systems:

   A. Recognize that electrical energy in a circuit can be transformed into other forms of energy (e.g., heat, light, sound).

   B. Explain that simple electrical systems (e.g., a flashlight) require a complete (unbroken) electrical pathway.

Forces and Motion

1. Familiar forces and the motion of objects:

   A. Identify gravity as the force that draws objects to Earth.

   B. Recognize that forces (i.e., pushing and pulling) may cause an object to change its motion; compare the effects of these forces of different strengths in the same or opposite directions acting on an object; and recognize that friction force works against the direction of motion (e.g., friction working against a push or a pull makes it more difficult to move an object along a surface).

2. Simple machines:

   A. Recognize that simple machines, (e.g., levers, pulleys, gears, ramps) help make motion easier (e.g., make lifting things easier, reduce the amount of force required, change the distance, change the direction of the force).

Earth Science

Earth science is the study of Earth and its place in the Solar System, and at fourth grade focuses on the study of phenomena and processes that students can observe in their everyday lives. While there is no single picture of what constitutes an Earth science curriculum that applies to all countries, the three topic areas included in this domain are generally considered to be important for students at the fourth grade to understand as they learn about the planet on which they live and its place in the Solar System:

- Earth's physical characteristics, resources, and history
- Earth's weather and climates
- Earth in the Solar System

At this level, students should have some general knowledge about the structure and physical characteristics of Earth's surface, and about the use of Earth's most important resources. Students also should be able to describe some of Earth's processes in terms of observable changes and understand the time frame over which such changes have occurred. Fourth grade students should also demonstrate some understanding about Earth's place in the Solar System based on observations of patterns of change on Earth and in the sky.

Earth's Physical Characteristics, Resources, and History

1. Physical characteristics of the Earth system:

   A. Recognize that Earth's surface is made up of land and water in unequal proportions (more water than land) and is surrounded by air; describe where fresh and salt water are found, and recognize that water in rivers or streams flows from mountains to oceans or lakes.

2. Earth's resources:

   A. Identify some of Earth's resources that are used in everyday life (e.g., water, wind, soil, forests, oil, natural gas, minerals).

   B. Explain the importance of using Earth's renewable and non-renewable resources responsibly (e.g., fossil fuels, forests, water).

3. Earth's history:

   A. Recognize that wind and water change Earth's landscape and that some features of Earth's landscape (e.g., mountains, river valleys) result from changes that happen very slowly over a long time.

B. Recognize that some remains (fossils) of animals and plants that lived on Earth a long time ago are found in rocks and make simple deductions about changes in Earth's surface from the location of these remains.

Earth's Weather and Climates

1. Weather and climates on Earth:
   A. Apply knowledge of changes of state of water to common weather events (e.g., cloud formation, dew formation, the evaporation of puddles, snow, rain).
   B. Describe how weather (i.e., daily variations in temperature, humidity, precipitation in the form of rain or snow, clouds, and wind) can vary with geographic location.
   C. Describe how average temperature and precipitation can change with the seasons and location.

Earth in the Solar System

1. Objects in the Solar System and their movements:
   A. Identify the Sun as a source of heat and light for the Solar System; describe the Solar System as the Sun and the planets that revolve around it.
   B. Recognize that the Earth has a moon that revolves around it, and from Earth the Moon looks different at different times of the month.
2. Earth's motion and related patterns observed on Earth:
   A. Explain how day and night are related to Earth's daily rotation about its axis, and provide evidence of this rotation from the changing appearance of shadows during the day.
   B. Describe how seasons in Earth's northern and southern hemispheres are related to Earth's annual movement around the Sun.

Science Content Domains—Eighth Grade

Four major content domains define the science content for the TIMSS Science eighth grade assessment: biology, chemistry, physics, and Earth science. Exhibit 2.3 shows the target percentages for each of the four content domains in the TIMSS 2019 science assessment.

Exhibit 2.3: Target Percentages of the TIMSS 2019 Science Assessment Devoted to Content Domains at the Eighth Grade

Eighth Grade Content Domains	Percentages
Biology	35%
Chemistry	20%
Physics	25%
Earth Science	20%

Each of these content domains includes several major topic areas, and each topic area in turn includes one or more topics. Each topic is further described by specific objectives that represent the students' expected knowledge, abilities, and skills assessed within each topic. Across the eighth grade assessment, each objective receives approximately equal weight in terms of assessment items. The verbs used in the objectives are intended to represent typical performances expected of eighth grade students, but are not intended to limit performances to a particular cognitive domain. Each objective can be assessed drawing on each of the three cognitive domains (knowing, applying, and reasoning).

Biology

At the eighth grade, students build on the foundational life science knowledge they learned in the primary grades, and develop an understanding of many of the most important concepts in biology. The biology domain includes six topic areas:

- Characteristics and life processes of organisms
- Cells and their functions
- Life cycles, reproduction, and heredity
- Diversity, adaptation, and natural selection
- Ecosystems
- Human health

Concepts learned in each of these topic areas are essential for preparing students for more advanced study. Eighth grade students are expected to understand how structure relates to function in organisms. They also should have a foundational understanding of cell structure and function and the processes of

photosynthesis and cellular respiration. At this level, the study of reproduction and heredity provides a foundation for later, more advanced study of molecular biology and molecular genetics. Learning the concepts of adaptation and natural selection provides a foundation for understanding evolution, and an understanding of processes and interactions in ecosystems is essential for students to begin to think about how to develop solutions to many environmental challenges. Finally, developing a science-based understanding of human health enables students to improve the condition of their lives and the lives of others.

Characteristics and Life Processes of Organisms

1. Differences among major taxonomic groups of organisms:
   A. Identify the defining characteristics that differentiate among major taxonomic groups of organisms (i.e., plants, animals, fungi, mammals, birds, reptiles, fish, amphibians, and insects).
   B. Recognize and categorize organisms that are examples of major taxonomic groups of organisms (i.e., plants, animals, fungi, mammals, birds, reptiles, fish, amphibians, and insects).
2. Structures and functions of major organ systems:
   A. Locate and identify major organs (e.g., lungs, stomach, brain) and the components of major organ systems (e.g., respiratory system, digestive system) in the human body.
   B. Compare and contrast major organs and major organ systems in humans and other vertebrates.
   C. Explain the role of major organs and major organ systems in sustaining life, such as those involved in circulation and respiration.
3. Physiological processes in animals:
   A. Recognize responses of animals to external and internal changes that work to maintain stable body conditions (e.g., increased heart rate during exercise, feeling thirsty when dehydrated, feeling hungry when requiring energy, sweating in heat, shivering in cold).

Cells and Their Functions

1. The structures and functions of cells:
   A. Explain that living things are made of cells that both carry out life functions and reproduce by division.
   B. Identify major cell structures (i.e., cell wall, cell membrane, nucleus, chloroplast, vacuole, and mitochondria) and describe the primary functions of these structures.
   C. Recognize that cell walls and chloroplasts differentiate plant cells from animal cells.

D. Explain that tissues, organs, and organ systems are formed from groups of cells with specialized structures and functions.

2. The processes of photosynthesis and cellular respiration:

   A. Describe the basic process of photosynthesis (i.e., requires light, carbon dioxide, water, and chlorophyll; produces glucose/sugar; and releases oxygen).

   B. Describe the basic process of cellular respiration (i.e., requires oxygen and glucose/sugar; produces energy; and releases carbon dioxide and water).

Life Cycles, Reproduction, and Heredity

1. Life cycles and patterns of development:

   A. Compare and contrast the life cycles and patterns of growth and development of different types of organisms (i.e., mammals, birds, amphibians, insects, and plants).

2. Sexual reproduction and inheritance in plants and animals:

   A. Recognize that sexual reproduction involves the fertilization of an egg cell by a sperm cell to produce offspring that are similar but not identical to either parent; relate the inheritance of traits to organisms passing on genetic material to their offspring.

   B. Recognize that an organism's traits are encoded in its DNA; recognize that DNA is genetic information found in chromosomes located in the nucleus of each cell.

   C. Distinguish inherited characteristics from acquired or learned characteristics.

Diversity, Adaptation, and Natural Selection

1. Variation as the basis for natural selection:

   A. Recognize that variations in physical and behavioral characteristics among individuals in a population give some individuals an advantage in surviving and passing on their characteristics to their offspring.

   B. Relate species survival or extinction to reproductive success in a changing environment (natural selection).

2. Evidence for changes in life on Earth over time:

   A. Draw conclusions about the relative length of time major groups of organisms have existed on Earth using fossil evidence.

   B. Describe how similarities and differences among living species and fossils provide evidence of the changes that occur in living things over time, and recognize that the degree of similarity of characteristics provides evidence of common ancestry.

Ecosystems

1. The flow of energy in ecosystems:
   A. Identify and provide examples of producers, consumers, and decomposers; draw or interpret food web diagrams.
   B. Describe the flow of energy in an ecosystem (i.e., energy flows from producers to consumers, and only part of the energy is passed from one level to the next); draw or interpret energy pyramids.
2. The cycling of water, oxygen, and carbon in ecosystems:
   A. Describe the role of living things in cycling water through an ecosystem (i.e., plants take in water from the soil and give off water through their leaves; and animals take in water and release water during respiration and as waste).
   B. Describe the role of living things in cycling oxygen and carbon through an ecosystem (i.e., plants take in carbon dioxide from the air and release oxygen into the air as part of photosynthesis and store carbon in their cells; and animals take in oxygen from the air and release carbon dioxide into the air as part of respiration).
3. Interdependence of populations of organisms in an ecosystem:
   A. Describe and provide examples of competition among populations or organisms in an ecosystem.
   B. Describe and provide examples of predation in an ecosystem.
   C. Describe and provide examples of symbiosis among populations of organisms in an ecosystem (e.g., birds or insects pollinating flowers, birds eating insects on deer or cattle).
4. Factors affecting population size in an ecosystem:
   A. Describe factors that affect the growth of plants and animals; identify factors that limit population size (e.g., disease, predators, food resources, drought).
   B. Predict how changes in an ecosystem (e.g., changes in the water supply, the introduction of a new population, hunting, migration) can affect available resources, and thus the balance among populations.
5. Human impact on the environment:
   A. Describe and explain ways in which human behavior (e.g., re-planting forests, reducing air and water pollution, protecting endangered species) can have positive effects on the environment.

B. Describe and explain ways in which human behavior (e.g., allowing factory waste water to enter water systems, burning fossil fuels that release greenhouse gases and pollutants into the air) can have negative effects on the environment; describe and provide examples of the effects of air, water, and soil pollution on humans, plants, and animals (e.g., water pollution can reduce plant and animal life in the water system).

Human Health

1. Causes, transmission, and prevention of, and resistance to diseases:
   A. Describe causes, transmission, and prevention of common diseases (e.g., influenza, measles, malaria, HIV).
   B. Describe the role of the body's immune system in resisting disease and promoting healing (i.e., antibodies in the blood help the body resist infection and white blood cells fight infection).
2. The importance of diet, exercise, and other lifestyle choices:
   A. Explain the importance of diet, exercise, and other lifestyle choices in maintaining health and preventing illness (e.g., heart disease, high blood pressure, diabetes, skin cancer, lung cancer).
   B. Identify the dietary sources and roles of nutrients in a healthy diet (i.e., vitamins, minerals, proteins, carbohydrates, and fats).

Chemistry

At the eighth grade, students' study of chemistry extends beyond developing an understanding of everyday phenomena to learning the central concepts and principles that are needed for understanding practical applications of chemistry and undertaking later, more advanced study. The chemistry domain includes three topic areas:

- Composition of matter
- Properties of matter
- Chemical change

The composition of matter topic area focuses on differentiating elements, compounds, and mixtures and understanding the particulate structure of matter. Included in this area also is the use of the periodic table as an organizing principle for the elements. At a more macroscopic level, the properties of matter topic area focuses on distinguishing between physical and chemical properties of matter and understanding the properties of mixtures and solutions and the properties of acids and bases. The study of chemical change focuses on the characteristics of chemical changes and the conservation of matter during chemical changes.

Composition of Matter

1. Structure of atoms and molecules:
   A. Describe atoms as composed of subatomic particles (i.e., negatively charged electrons surrounding a nucleus containing positively charged protons and neutrons with no charge).
   B. Describe the structure of matter in terms of particles (i.e., atoms and molecules) and describe molecules as combinations of atoms (e.g., H_2O, O_2, CO_2).
2. Elements, compounds, and mixtures:
   A. Describe the differences among elements, compounds, and mixtures; differentiate between pure substances (i.e., elements and compounds) and mixtures (homogeneous and heterogeneous) on the basis of their formation and composition.
3. The periodic table of elements:
   A. Recognize that the periodic table is an arrangement of the known elements; recognize and describe that the elements are arranged in order of the number of protons in the nuclei of the atoms of each element.
   B. Recognize that an element's properties (e.g., metal or non-metal, reactivity) can be predicted from its location in the periodic table (i.e., row, or period, and column, or group/family) and that elements in the same group have some properties in common.

Properties of Matter

1. Physical and chemical properties of matter:
   A. Distinguish between physical and chemical properties of matter.
   B. Relate uses of materials to their physical properties (e.g., melting point, boiling point, solubility, thermal conductivity).
   C. Relate uses of materials to their chemical properties (e.g., tendency to rust, flammability).
2. Physical and chemical properties as a basis for classifying matter:
   A. Classify substances according to physical properties that can be demonstrated or measured (e.g., density, melting or boiling point, solubility, magnetic properties, electrical or thermal conductivity).
   B. Classify substances according to their chemical properties (e.g., whether the substance is a metal or a nonmetal).
3. Mixtures and solutions:
   A. Explain how physical methods can be used to separate mixtures into their components.

B. Describe solutions in terms of substance(s) (i.e., solid, liquid, or gas solutes) dissolved in a solvent and relate the concentration of a solution to the amounts of solute and solvent present.

C. Explain how temperature, stirring, and surface area in contact with the solvent affect the rate at which solutes dissolve.

4. Properties of acids and bases:

A. Recognize everyday substances as acids or bases based on their properties (e.g., acids have pH less than 7; acidic foods usually have a sour taste; bases usually do not react with metals; bases feel slippery).

B. Recognize that both acids and bases react with indicators to produce different color changes.

C. Recognize that acids and bases neutralize each other.

Chemical Change

1. Characteristics of chemical changes:

A. Differentiate chemical from physical changes in terms of the transformation (reaction) of one or more pure substances (reactants) into different pure substances (products).

B. Provide evidence (i.e., temperature changes, gas production, precipitate formation, color change, or light emission) that a chemical change has taken place.

C. Recognize that oxygen is needed in oxidation reactions (i.e., combustion, rusting, and tarnishing) and relate these reactions to everyday activities (e.g., burning wood, preserving metal objects).

2. Matter and energy in chemical reactions:

A. Recognize that matter is conserved during a chemical reaction and that all of the atoms present at the beginning of the reaction are present at the end of the reaction, but they are rearranged to form new substances.

B. Recognize that some chemical reactions release energy (heat) while others absorb it, and classify familiar chemical reactions (e.g., burning, neutralization, the mixing of substances in a chemical cold pack) as either releasing heat or absorbing energy (heat).

C. Recognize that chemical reactions occur at different rates and that the rate of reaction can be affected by changing the conditions under which the reaction is taking place (i.e., surface area, temperature, and concentration).

3. Chemical bonds:

A. Recognize that a chemical bond results from the attraction between atoms in a compound and that the atoms' electrons are involved in this bonding.

Physics

As in the chemistry domain, students' study of physics at the eighth grade extends beyond understanding the scientific basis of common everyday observations to learning many of the central physics concepts that are needed for understanding practical applications of physics or for undertaking advanced study later in their education. The physics domain includes five topic areas:

- Physical states and changes in matter
- Energy transformation and transfer
- Light and sound
- Electricity and magnetism
- Motion and forces

Eighth grade students are expected to be able to describe processes involved in changes in the state of matter and relate states of matter to the distance and movement among particles. They also should be able to identify different forms of energy, describe simple energy transformations, apply the principle of conservation of total energy in practical situations, and understand the difference between thermal energy (heat) and temperature. Students at this level also are expected to know some basic properties of light and sound, relate these properties to observable phenomena, and solve practical problems involving the behavior of light and sound. In the topic area of electricity and magnetism, students should be familiar with the electrical conductivity of common materials, current flow in electric circuits, and the difference between simple series and parallel circuits. They also should be able to describe properties and uses of permanent magnets and electromagnets. Students' understanding of motion and forces should include knowing general types and characteristics of forces and how simple machines function. They should understand the concepts of pressure and density and be able to predict qualitative changes in motion based on the forces acting on an object.

Physical States and Changes in Matter

1. Motion of particles in solids, liquids, and gases:
   A. Recognize that atoms and molecules in matter are in constant motion and recognize the differences in relative motion and distance between particles in solids, liquids, and gases; apply knowledge about the movement of and distance between atoms and molecules to explain the physical properties of solids, liquids, and gases (i.e., volume, shape, density, and compressibility).
   B. Relate changes in temperature of a gas to changes in its volume and/or pressure and changes in the average speed of its particles; relate expansion of solids and liquids to temperature change in terms of the average spacing between particles.

2. Changes in states of matter:
   A. Describe changes of state (i.e., melting, freezing, boiling, evaporation, condensation, and sublimation) as resulting from an increase or decrease of thermal energy.
   B. Relate the rate of change of state to physical factors (e.g., surface area, the temperature of the surroundings).
3. Physical changes:
   A. Recognize that physical changes do not involve the formation of new substances.
   B. Explain that mass remains constant during physical changes (e.g., change of state, dissolving solids, thermal expansion).

Energy Transformation and Transfer

1. Forms of energy and the conservation of energy:
   A. Identify different forms of energy (e.g., kinetic, potential, light, sound, electrical, thermal, chemical).
   B. Describe the energy transformations that take place in common processes (e.g., combustion in an engine to move a car, photosynthesis, the production of hydroelectric power); recognize that the total energy of a closed system is conserved.
2. Thermal energy transfer and thermal conductivity of materials:
   A. Recognize that temperature remains constant during melting, boiling, and freezing, but thermal energy increases or decreases during a state change.
   B. Relate the transfer of thermal energy from an object or an area at a higher temperature to one at a lower temperature to cooling and heating; recognize that hot objects cool off and cold objects warm up until they reach the same temperature as their surroundings.
   C. Recognize that conduction, convection, and radiation are all types of thermal energy transfer; compare the relative thermal conductivity of different materials.

Light and Sound

1. Properties of light:
   A. Describe or identify basic properties of light (i.e., speed; transmission through different media; reflection, refraction, absorption, and splitting of white light into its component colors); relate the apparent color of objects to reflected or absorbed light.
   B. Solve practical problems involving the reflection of light from plane mirrors and the formation of shadows; interpret simple ray diagrams to identify the path of light.

2. Properties of sound:

   A. Recognize that sound is a wave phenomenon caused by vibration and is characterized by loudness (amplitude) and pitch (frequency); describe some basic properties of sound (i.e., the need for a medium for transmission, reflection and absorption by surfaces, and relative speed through different media which is always slower than light).

   B. Relate common phenomena (e.g., echoes, hearing thunder after seeing lightning) to the properties of sound.

Electricity and Magnetism

1. Conductors and the flow of electricity in electrical circuits:

   A. Classify materials as electrical conductors or insulators; identify electrical components or materials that can be used to complete circuits.

   B. Identify diagrams representing complete circuits; describe factors that affect electrical current in series or parallel circuits (e.g., the number of batteries and/or bulbs).

2. Properties and uses of permanent magnets and electromagnets:

   A. Relate properties of permanent magnets (i.e., two opposite poles, attraction/repulsion, and strength of the magnetic force varies with distance) to uses in everyday life (e.g., a directional compass).

   B. Describe the properties that are unique to electromagnets (i.e., the strength varies with current, number of coils, and type of metal in the core; the magnetic attraction can be turned on and off; and the poles can switch) and relate properties of electromagnets to uses in everyday life (e.g., doorbell, recycling factory).

Motion and Forces

1. Motion:

   A. Recognize the speed of an object as change in position (distance) over time and acceleration as change in speed over time.

2. Common forces and their characteristics:

   A. Describe common mechanical forces (e.g., gravitational, normal, friction, elastic, buoyant); recognize and describe weight as a force due to gravity; differentiate between contact and non-contact forces (e.g., friction, gravity).

   B. Recognize that forces have strength and direction; recognize that for every action force there is an equal and opposite reaction force; recognize and describe the difference in the force of gravity on an object when it is located on different planets (or moons).

3. Effects of forces:
   A. Describe the functioning of simple machines (e.g., levers, inclined planes, pulleys, gears).
   B. Explain floating and sinking in terms of density differences and the effect of buoyant force.
   C. Describe pressure in terms of force and area; describe effects related to pressure (e.g., water pressure increasing with depth, a balloon expanding when inflated).
   D. Predict qualitative one-dimensional changes in motion (speed and direction) of an object based on the forces acting on it; recognize and describe how the force of friction affects motion (e.g., the contact area between surfaces can increase friction and impede motion).

Earth Science

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, chemistry, and physics. 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. The TIMSS 2019 Science Framework identifies the following topic areas that are universally considered to be important for students at the eighth grade to understand as they learn about the planet on which they live and its place in the universe:

- Earth's structure and physical features
- Earth's processes, cycles, and history
- Earth's resources, their use, and conservation
- Earth in the Solar System and the universe

Eighth grade students are expected to have some general knowledge about the structure and physical features of Earth, including Earth's structural layers, and the atmosphere. Students also should have a conceptual understanding of processes, cycles, and patterns, including geological processes that have occurred over Earth's history, the water cycle, and patterns of weather and climate. Students should demonstrate knowledge of Earth's resources and their use and conservation, and relate this knowledge to practical solutions to resource management issues. At this level, the study of Earth and the Solar System includes understanding how observable phenomena relate to the movements of Earth and the Moon, and describing the features of Earth, the Moon, and other planets.

Earth's Structure and Physical Features

1. Earth's structure and physical characteristics:
   A. Describe the structure of the Earth (i.e., crust, mantle, and core) and the physical characteristics of these distinct parts.

B. Describe the distribution of water on Earth in terms of its physical state (i.e., ice, water, and water vapor), and fresh versus salt water.

2. Components of Earth's atmosphere and atmospheric conditions:

A. Recognize that Earth's atmosphere is a mixture of gases; identify the relative abundance of its main components (i.e., nitrogen, oxygen, water vapor, and carbon dioxide), relate these components to everyday processes.

B. Relate changes in atmospheric conditions (i.e., temperature and pressure) to changes in altitude.

Earth's Processes, Cycles, and History

1. Geological processes:

A. Describe the general processes involved in the rock cycle (e.g., the cooling of lava, heat and pressure transforming sediment into rock, weathering, erosion).

B. Identify or describe changes to Earth's surface (e.g., mountain building), resulting from major geological events (e.g., glaciation, the movement of tectonic plates and subsequent earthquakes and volcanic eruptions).

C. Explain the formation of fossils and fossil fuels; use evidence from the fossil record to explain how the environment has changed over long periods of time.

2. Earth's water cycle:

A. Describe the processes in Earth's water cycle (i.e., evaporation, condensation, transportation, and precipitation) and recognize the Sun as the source of energy for the water cycle.

B. Describe the role of cloud movement and water flow in the circulation and renewal of fresh water on Earth's surface.

3. Weather and climate:

A. Distinguish between weather (i.e., day-to-day variations in temperature, humidity, precipitation in the form of rain or snow, clouds, and wind) and climate (i.e., long-term typical weather patterns in a geographic area).

B. Interpret data or maps of weather patterns to identify climate types.

C. Relate the climate and seasonal variations in weather patterns to global and local factors (e.g., latitude, altitude, geography).

D. Identify or describe evidence for climate changes (e.g., changes that occur during ice ages, changes that are related to global warming).

Earth's Resources, Their Use and Conservation

1. Managing Earth's resources:
   A. Provide examples of Earth's renewable and nonrenewable resources.
   B. Discuss advantages and disadvantages of different energy sources (e.g., sunlight, wind, flowing water, geothermal, oil, coal, gas, nuclear).
   C. Describe methods of conservation of Earth's resources and methods of waste management (e.g., recycling).
2. Land and water use:
   A. Explain how common methods of land use (e.g., farming, logging, mining) can affect land and water resources.
   B. Explain the importance of water conservation, and describe methods for ensuring that fresh water is available for human activities (e.g., desalination, purification).

Earth in the Solar System and the Universe

1. Observable phenomena on Earth resulting from movements of Earth and the Moon:
   A. Describe the effects of the Earth's annual revolution around the Sun, given the tilt of its axis (e.g., different seasons, different constellations visible at different times of the year).
   B. Recognize that tides are caused by the gravitational pull of the Moon, and relate phases of the Moon and eclipses to the relative positions of Earth, the Moon, and the Sun.
2. The Sun, stars, Earth, Moon, and planets:
   A. Recognize that the Sun is a star and provides light and heat to each member of the Solar System; explain that the Sun and other stars produce their own light, but that other members of the Solar System are visible because of light reflected from the Sun.
   B. Compare and contrast certain physical features of Earth with those of the Moon and other planets (e.g., presence and composition of an atmosphere, average surface temperature, presence of water, mass, gravity, distance from the Sun, period of revolution and rotation, ability to support life); recognize that the force of gravity keeps planets and moons in their orbits.

Science Cognitive Domains—Fourth and Eighth Grades

The cognitive dimension is divided into three domains that describe the thinking processes students are expected to engage in when encountering the science items developed for TIMSS 2019. The first domain, knowing, addresses the student's ability to recall, recognize, describe, and provide examples of facts, concepts, and procedures that are necessary for a solid foundation in science. The second domain, applying, focuses on using this knowledge to compare, contrast, and classify groups of objects or materials; relating knowledge of a science concept to a specific context; generating explanations; and solving practical problems. The third domain, reasoning, includes using evidence and science understanding to analyze, synthesize, and generalize, often in unfamiliar situations and complex contexts.

These three cognitive domains are used at both grades, however, the target percentages for each domain vary between fourth and eighth grade in accordance with the increased cognitive ability, instruction, experience, and breadth and depth of understanding of students at the higher grade level. The percentage of items that involve knowing is higher at the fourth grade compared to the eighth grade, while the percentage of items that ask students to engage in reasoning is higher at the eighth grade compared to the fourth grade. While there is some hierarchy in the thinking processes across the three cognitive domains (from knowing to applying to reasoning), each cognitive domain contains items representing a full range of difficulty. Exhibit 2.4 shows the target percentages in terms of assessment time for each of the three cognitive domains at the fourth and eighth grades.

Exhibit 2.4: Target Percentages of the TIMSS 2019 Science Assessment Devoted to Cognitive Domains at the Fourth and Eighth Grades

Cognitive Domains	Percentages	
	Fourth Grade	Eighth Grade
Knowing	40%	35%
Applying	40%	35%
Reasoning	20%	30%

For the fourth and eighth grades, each content domain includes items developed to address each of the three cognitive domains. For example, the life science content domain includes knowing, applying, and reasoning items, as do the other content domains. The following sections further describe the thinking processes that define the cognitive domains.

Knowing

Items in this domain assess students' knowledge of facts, relationships, processes, concepts, and equipment. Accurate and broad-based factual knowledge enables students to successfully engage in the more complex cognitive activities essential to the scientific enterprise.

Recall/Recognize	Identify or state facts, relationships, and concepts; identify the characteristics or properties of specific organisms, materials, and processes; identify the appropriate uses for scientific equipment and procedures; and recognize and use scientific vocabulary, symbols, abbreviations, units, and scales.
Describe	Describe or identify descriptions of properties, structures, and functions of organisms and materials, and relationships among organisms, materials, and processes and phenomena.
Provide Examples	Provide or identify examples of organisms, materials, and processes that possess certain specified characteristics; and clarify statements of facts or concepts with appropriate examples.

Applying

Items in this domain require students to engage in applying knowledge of facts, relationships, processes, concepts, equipment, and methods in contexts likely to be familiar in the teaching and learning of science.

Compare/Contrast/ Classify	Identify or describe similarities and differences between groups of organisms, materials, or processes; and distinguish, classify, or sort individual objects, materials, organisms, and processes based on characteristics and properties.
Relate	Relate knowledge of an underlying science concept to an observed or inferred property, behavior, or use of objects, organisms, or materials.
Use Models	Use a diagram or other model to demonstrate knowledge of science concepts, to illustrate a process, cycle, relationship, or system, or to find solutions to science problems.
Interpret Information	Use knowledge of science concepts to interpret relevant textual, tabular, pictorial, and graphical information.
Explain	Provide or identify an explanation for an observation or a natural phenomenon using a science concept or principle.

Reasoning

Items in this domain require students to engage in reasoning to analyze data and other information, draw conclusions, and extend their understandings to new situations. In contrast to the more direct applications of science facts and concepts exemplified in the applying domain, items in the reasoning domain involve unfamiliar or more complicated contexts. Answering such items can involve more than one approach or strategy. Scientific reasoning also encompasses developing hypotheses and designing scientific investigations.

Analyze	Identify the elements of a scientific problem and use relevant information, concepts, relationships, and data patterns to answer questions and solve problems.
Synthesize	Answer questions that require consideration of a number of different factors or related concepts.
Formulate Questions/ Hypothesize/Predict	Formulate questions that can be answered by investigation and predict results of an investigation given information about the design; formulate testable assumptions based on conceptual understanding and knowledge from experience, observation, and/or analysis of scientific information; and use evidence and conceptual understanding to make predictions about the effects of changes in biological or physical conditions.
Design Investigations	Plan investigations or procedures appropriate for answering scientific questions or testing hypotheses; and describe or recognize the characteristics of well-designed investigations in terms of variables to be measured and controlled and cause-and-effect relationships.
Evaluate	Evaluate alternative explanations; weigh advantages and disadvantages to make decisions about alternative processes and materials; and evaluate results of investigations with respect to sufficiency of data to support conclusions.
Draw Conclusions	Make valid inferences on the basis of observations, evidence, and/or understanding of science concepts; and draw appropriate conclusions that address questions or hypotheses, and demonstrate understanding of cause and effect.
Generalize	Make general conclusions that go beyond the experimental or given conditions; apply conclusions to new situations.
Justify	Use evidence and science understanding to support the reasonableness of explanations, solutions to problems, and conclusions from investigations.

Science Practices in TIMSS 2019

Scientists engage in scientific inquiry by following key science practices that enable them to investigate the natural world and answer questions about it. Students of science must become proficient at these practices to develop an understanding of how the scientific enterprise is conducted. These practices include skills from daily life and school studies that students use in a systematic way to conduct scientific inquiry. The science practices are fundamental to all science disciplines. Five practices that are fundamental to scientific inquiry are represented in TIMSS 2019:

1. **Asking questions based on observations**—Scientific inquiry includes observations of phenomena in the natural world. These observations, when considered together with theory, lead to questions, which are used to formulate testable hypotheses to help answer those questions.
2. **Generating evidence**—Testing hypotheses requires designing and executing systematic investigations and controlled experiments in order to generate evidence to support or refute the hypothesis. Scientists relate their theories to properties that can be observed or measured in order to determine the evidence to be gathered, the equipment and procedures needed to collect the evidence, and the measurements to be recorded.

3. **Working with data**—Once the data are collected, scientists summarize it in various types of visual displays and describe or interpret patterns in the data and explore relationships between variables.
4. **Answering the research question**—Scientists use evidence from observations and investigations, together with their theories to answer questions and support or refute hypotheses.
5. **Making an argument from evidence**—Scientists use evidence together with science knowledge to construct explanations, justify and support the reasonableness of their explanations and conclusions, and extend their conclusions to new situations.

These science practices are assessed in the context of one of the science content domains, and by drawing upon the range of thinking processes specified in the cognitive domains. Some items in the TIMSS 2019 science assessment at both the fourth and eighth grades assess one or more of these important science practices as well as content specified in the content domains and thinking processes specified in the cognitive domains.

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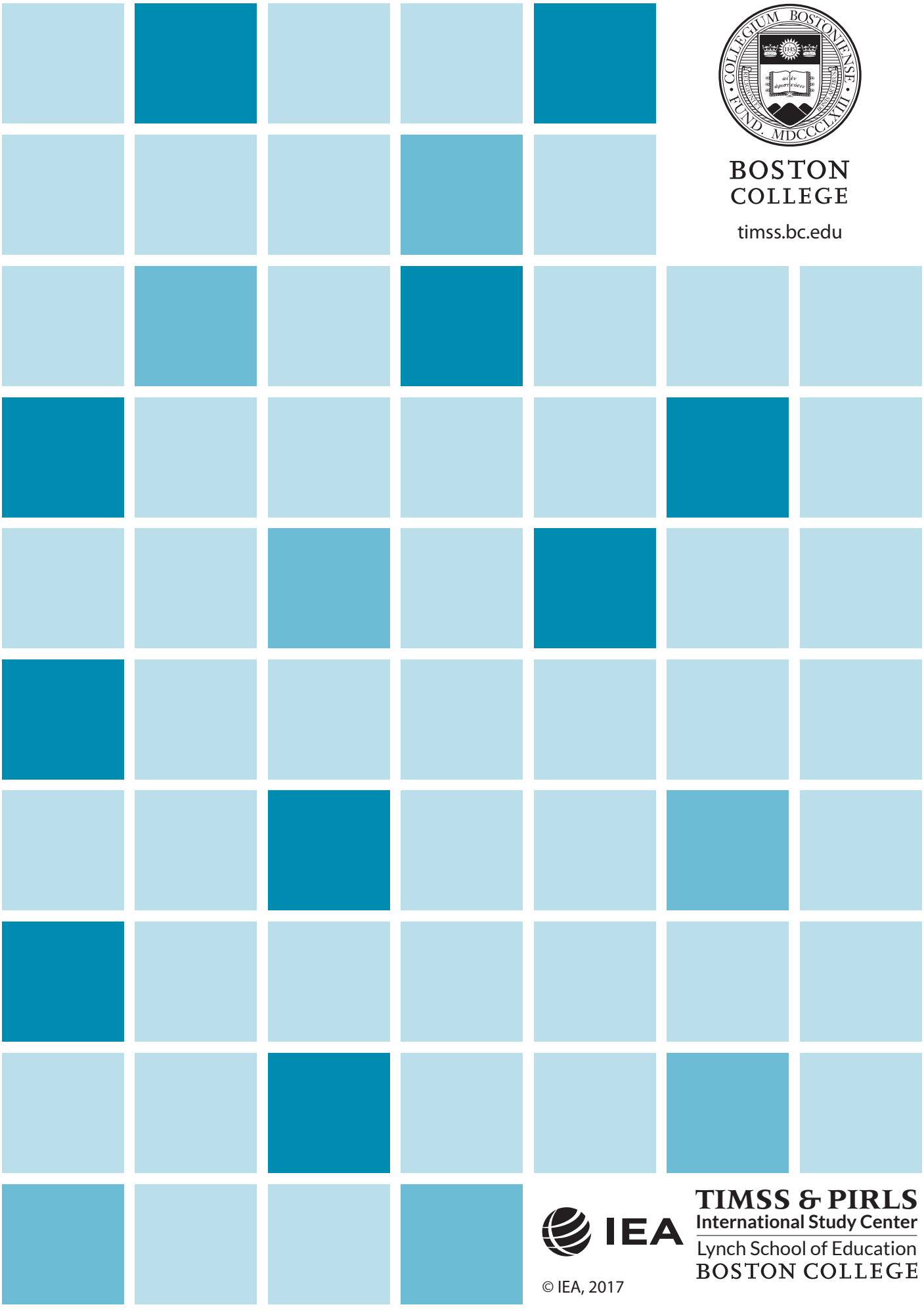

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