

# TIMSS assessment frameworks and specifications 2003

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Chestnut Hill, MA: International Study Center, Lynch School of Education, Boston College, 2003

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# TIMSS

Trends in Mathematics  
and Science Study



The International Association for the  
Evaluation of Educational Achievement

BOSTON  
COLLEGE



The International Study Center  
Lynch School of Education

## Assessment Frameworks and Specifications 2003

2nd Edition

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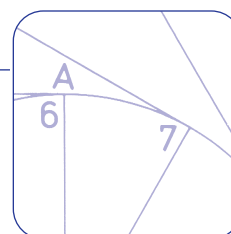
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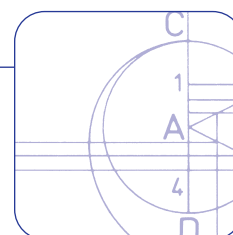
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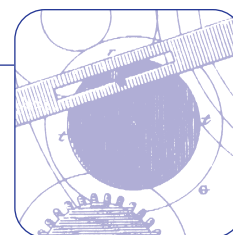
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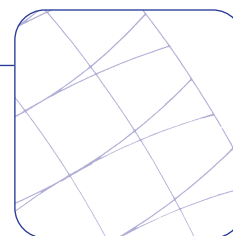
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Example Science Items



# Preface

## Background

Advancing science and mathematics education has long been the focus of studies by the IEA, the International Association for the Evaluation of Educational Achievement. Reflecting the seminal place that these two key curriculum areas hold in all educational systems as fundamental to developing technologically proficient societies, IEA has been measuring student achievement and collecting contextual information to facilitate student learning in mathematics and science for nearly 40 years.

The conduct of the First International Mathematics Study (FIMS) dates back to 1964, and science first was assessed as part of the Six Subject Study in 1970-71. Mathematics and science were again the focus of major research efforts in 1980-82 and 1983-84, respectively. In 1990, the IEA General Assembly determined to assess science and mathematics together on a regular basis every four years. This decision marked the first of the large-scale international studies to measure trends in student performance, beginning with the original TIMSS (the Third International Mathematics and Science Study) conducted in 1995, TIMSS-Repeat in 1999, and now TIMSS 2003 (renamed the Trends in International Mathematics and Science Study), also known as TIMSS Trends.

## Frameworks for TIMSS 2003

A particular challenge for TIMSS 2003 was developing this set of frameworks articulating important content for students to have learned in mathematics and science, as well as describing important home and school contexts influencing achievement in these subjects. It is important that these frameworks capture important issues for mathematics and science education today, while providing the vision necessary to take the TIMSS cycle of studies beyond the 2003 assessment. The frameworks, produced at the beginning of the new millennium, are designed to shape future IEA assessments in mathematics and science so that they can evolve with the times, while recognizing the axiom – *If you want to measure change, do not change the measure.*

The TIMSS International Study Center at Boston College prepared this second edition of the frameworks to provide examples of the types of assessment questions contained in the TIMSS 2003 assessment. The example items for mathematics are presented in Appendix B and for science in Appendix C. The second edition also contains some minor revisions, in particular to the section on the assessment design.



## Acknowledgments

The IEA was founded in 1959 for the purpose of conducting comparative research studies on educational policies, practices, and outcomes. Since then, IEA studies have contributed a deeper understanding of the educational process both within and among the nearly 60 member countries. The IEA has a permanent Secretariat in Amsterdam, the Netherlands, and a Data Processing Center in Hamburg, Germany. TIMSS is directed by IEA's International Study Center at Boston College. The strength, quality, and success of IEA's studies, however, derive from the expertise among its members in curriculum, measurement, and education and their collaboration in conducting the research.

Also, extremely crucial to success is securing the funding necessary to carry out the extensive development and review work required by international projects of this magnitude. Without such support a project like TIMSS is not possible. The IEA is deeply grateful to the U.S. National Science Foundation, the U.S. National Center for Education Statistics, and for the fees paid by participating countries for helping to fund the development of the TIMSS frameworks presented herein.

The TIMSS frameworks are the result of considerable collaboration among individuals from around the world, most notably the specialists comprising the TIMSS Expert Panel in Mathematics and Science, the National Research Coordinators from the participating countries, staff from IEA's International Study Center at Boston College, and staff from IEA's Secretariat and Data Processing Center. I am extremely grateful for the contribution of each person who devoted his or her energy and time to this important and comprehensive effort. In particular, I would like to acknowledge the work of the TIMSS Mathematics Coordinator Robert Garden and the Science Coordinator Teresa Smith. Kelvin Gregory, the TIMSS Coordinator at the time the frameworks were developed, had special responsibility for the contextual framework. The Director of Operations and Analysis of the International Study Center and TIMSS, Eugene Gonzalez, oversaw development of the assessment design.

Without a dedicated, continuing center from which to coordinate projects like TIMSS and the experienced staff from the consortium of organizations that implements the studies, success would be limited. I would like to express my thanks to the staff at the International Study Center at Boston College, the IEA Secretariat, the IEA Data Processing Center, Statistics Canada, and Educational Testing Service. Finally, I would like to especially thank the Co-Directors of the International Study Center and TIMSS, Ina V.S. Mullis and Michael O. Martin, for their leadership and dedication to this project.

**Hans Wagemaker**  
**IEA Executive Director**

## The International Study Center at Boston College

The International Study Center (ISC) at Boston College is dedicated to conducting comparative studies in educational achievement. Principally, it serves as the International Study Center for IEA's studies in mathematics, science, and reading – the Trends in International Mathematics and Science Study (TIMSS), and the Progress in International Reading Literacy Study (PIRLS). The staff at the ISC is responsible for the design and implementation of these studies. In developing and producing the TIMSS frameworks, ISC staff conducted a collaborative effort involving a series of reviews by an Expert Panel and the National Research Coordinators. The following individuals were instrumental in this process.

Ina V.S. Mullis  
Co-Director, TIMSS

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## **International Association for the Evaluation of Educational Achievement (IEA)**

In developing the TIMSS Assessment Frameworks and Specifications, the IEA has provided overall support in coordinating TIMSS with IEA's member countries and reviewing all elements of the design. The following persons are closely involved with TIMSS.

Hans Wagemaker  
Executive Director

Barbara Malak  
Manager, Membership Relations

Dirk Hastedt  
IEA Data Processing Center

Oliver Neuschmidt  
IEA Data Processing Center

## **Statistics Canada**

Statistics Canada is responsible for collecting and evaluating the sample in TIMSS, and helping participants to adapt the TIMSS sampling design to local conditions. Senior methodologists Pierre Foy and Marc Joncas reviewed the frameworks from a sampling perspective, and made many helpful suggestions.

## **Educational Testing Service**

Educational Testing Service conducts the scaling of the TIMSS achievement data. Researchers Matthias Von Davier, Edward Kulick, and Kentaro Yamamoto reviewed the frameworks from a design perspective.

## **National Research Coordinators**

The TIMSS National Research Coordinators (NRCs) work with international project staff to ensure that the study is responsive to their concerns, both policy-oriented and practical, and are responsible for implementing the study in their countries. NRCs reviewed successive drafts of the frameworks, and made numerous suggestions that greatly benefited the final document. A list of the NRCs appears in Appendix A.

## International Expert Panel in Mathematics and Science

The Expert Panel worked with staff from the International Study Center in developing all aspects of the frameworks and particularly the mathematics and science frameworks. They made recommendations for the content areas, cognitive domains, problem-solving and inquiry tasks, and focus areas for policy-orientated research.

### Mathematics

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*United States*

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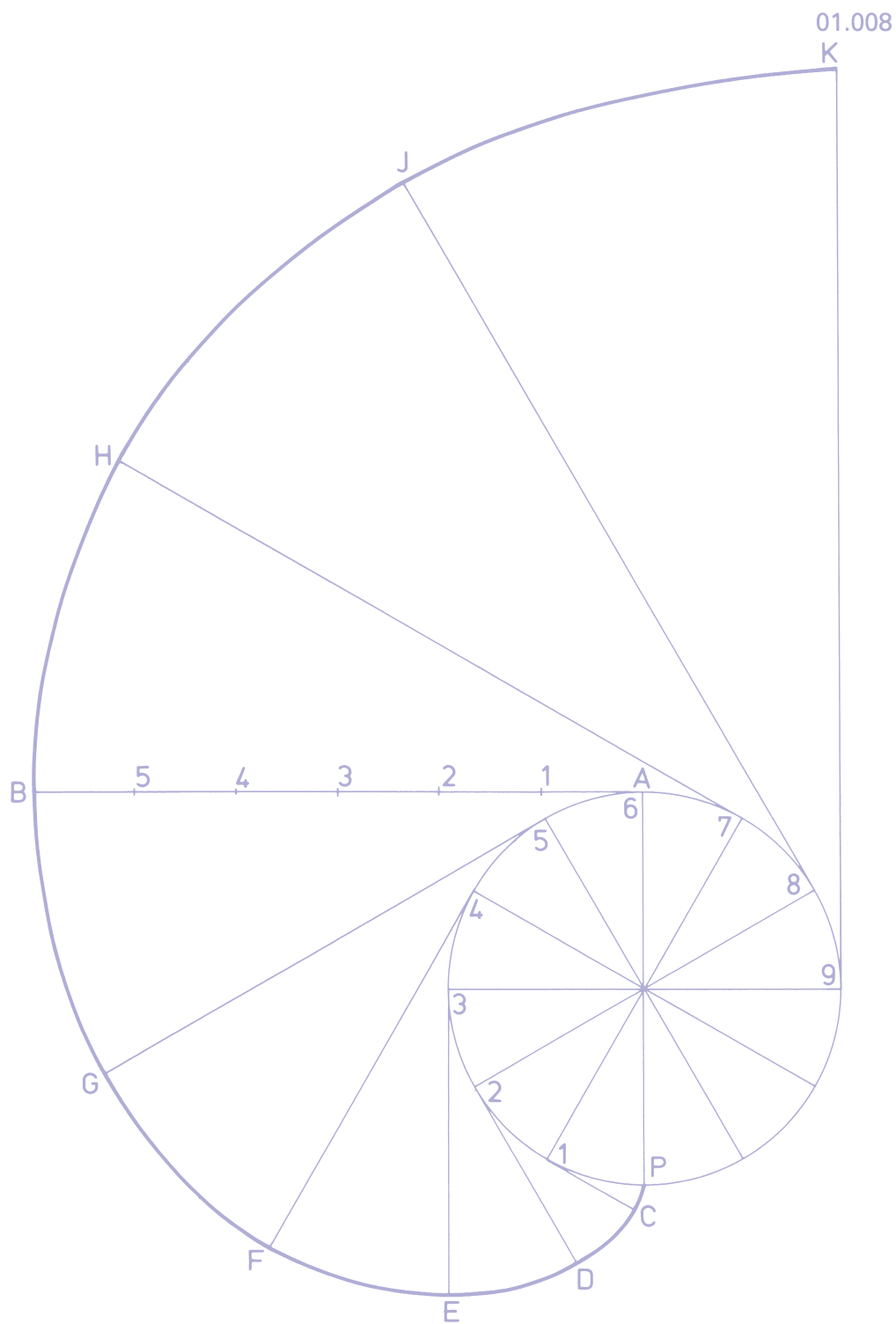
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*Morocco*

## Funding

Funding for the development of the TIMSS Assessment Frameworks and Specifications was provided by the U.S. National Science Foundation, the U.S. National Center for Education Statistics, and participating countries. In particular, much of the work was made possible by a grant from the U.S. National Science Foundation. Janice Earle, Finbarr Sloane, Elizabeth Vander Putten, and Larry Suter each played crucial roles in making the frameworks possible.

The background features a complex geometric design. It includes several concentric and intersecting circles in shades of blue and purple. Numbers 1 through 9 are placed at various points along the arcs of these circles. Some numbers are in white, while others are in a darker shade. The overall aesthetic is mathematical and architectural.

# Introduction



# Introduction

## Overview

The Trends in International Mathematics and Science Study (TIMSS<sup>1</sup>) is a project of the International Association for the Evaluation of Educational Achievement (IEA). The IEA is an independent international cooperative of national research institutions and government agencies that has been conducting studies of cross-national achievement since 1959.

TIMSS 2003 is the most recent in the series of IEA studies to measure trends in students' mathematics and science achievement. Offered first in 1995 and then in 1999, the regular cycle of TIMSS studies provides countries with an unprecedented opportunity to measure progress in educational achievement in mathematics and science.

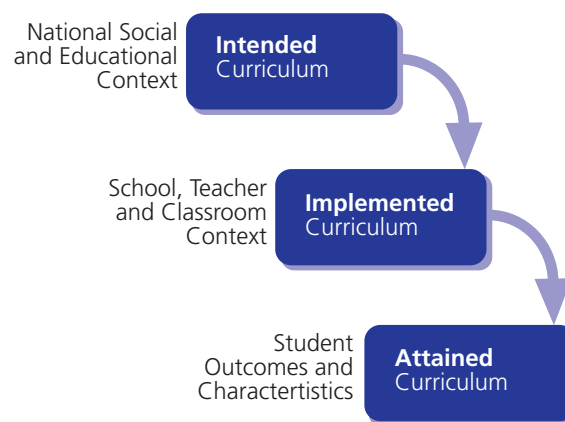
Additionally, to provide each participating country with a rich resource for interpreting the achievement results and to track changes in instructional practices, TIMSS asks students, their teachers, and their school principals to complete questionnaires about the contexts for learning mathematics and science. Trend data from these questionnaires provide a dynamic picture of changes in the implementation of educational policies and practices and help to raise new issues relevant to improvement efforts. TIMSS data have had an enduring impact on reform and development efforts in mathematics and science education around the world, leading on one hand to continuing demand for trend data to monitor developments and on the other to a need for more and better policy-relevant information to guide and evaluate new initiatives.<sup>2</sup>

This publication, the *TIMSS Assessment Frameworks and Specifications*, serves as the basis of TIMSS 2003 and beyond. It describes in some detail the mathematics and science content to be assessed in future assessments in mathematics and science. Topic areas are elaborated with objectives specific to grades 4 and 8. The TIMSS frameworks document also describes the contextual factors associated with students' learning in mathematics and science that will be investigated. Finally, it provides an overview of the assessment design and the guidelines for item development.

## The TIMSS Curriculum Model

Building on earlier IEA studies of mathematics and science achievement, TIMSS uses the curriculum, broadly defined, as the major organizing concept in considering how educational opportunities are provided to students, and the factors that influence how students use these opportunities. The TIMSS curriculum model has three aspects: the intended curriculum, the implemented curriculum, and the achieved curriculum (see Exhibit 1). These represent, respectively, the mathematics and science that society intends for students to learn and how the education system should be organized to facilitate this

**Exhibit 1:** TIMSS Curriculum Model



1 Originally named the Third International Mathematics and Science Study.

2 Robitaille, D. F., Beaton, A. E., and Plomp, T., eds. (2000), *The Impact of TIMSS on the Teaching and Learning of Mathematics and Science*, Vancouver, BC: Pacific Educational Press.



learning; what is actually taught in classrooms, who teaches it, and how it is taught; and, finally, what it is that students have learned, and what they think about these subjects.

Working from this model, TIMSS uses mathematics and science achievement tests to describe student learning in the participating countries, together with questionnaires to provide a wealth of information. The questionnaires ask about the structure and content of the intended curriculum in mathematics and science, the preparation, experience, and attitudes of teachers, the mathematics and science content actually taught, the instructional approaches used, the organization and resources of schools and classrooms, and the experiences and attitudes of the students in the schools.

## The Development Process for the TIMSS Assessment Frameworks and Specifications

Developing this document began by updating the *Curriculum Frameworks for Mathematics and Science*<sup>3</sup> used as the basis for the 1995 and 1999 assessments. This process involved widespread participation and reviews by educators around the world. To permit the content assessed by TIMSS to evolve, the frameworks were revised to reflect changes during the last decade in curricula and the way mathematics and science are taught. In particular, the frameworks were expanded to provide specific objectives for assessing students at grades 4 and 8, resulting in the specifications for the assessments in mathematics and science contained in this document.

To provide the basis for valid international tests, assessment frameworks require extensive international input. They must be appropriate for the levels of mathematics and science learning of the populations studied in the many TIMSS countries, and hence representatives from national centers were asked to play an important role in contributing critiques and advice as the frameworks were developed.

An international panel of mathematics and science education and testing experts provided guidance for the general form the assessment frameworks should take. The U.S. National Science Foundation provided support for the meetings and the work of the expert panel. Using an iterative process, successive drafts were presented for comment and review by National Research Coordinators (NRCs), national committees, and expert panel members. A detailed questionnaire to participating countries about

3 Robitaille, D.F., et al (1993), *TIMSS Monograph No. 1: Curriculum Frameworks for Mathematics and Science*, Vancouver, BC: Pacific Educational Press.

topics included in their curricula provided valuable feedback on the suitability of assessing individual mathematics and science topics at the fourth and eighth grades.

The frameworks do not consist solely of content and behaviors included in the curricula of all participating countries. The aim of the extensive consultation on curriculum was to ensure that goals of mathematics and science education regarded as important in a significant number of countries are included. The ability of policy makers to make sound judgments about relative strengths and weaknesses of mathematics and science education in their systems depends on achievement measures being based, as closely as possible, on what students in their systems have actually been taught. This is also a prerequisite for valid use of the measures in many potential secondary analyses.

The following factors were considered in finalizing the content domains and the topics and objectives of the assessment frameworks:

- Inclusion of the content in the curricula of a significant number of participating countries
- Alignment of the content domains with the reporting categories of TIMSS 1995 and TIMSS 1999
- The likely importance of the content to future developments in mathematics and science education
- Appropriateness for the populations of students being assessed
- Suitability for being assessed in a large-scale international study
- Contribution to overall test balance and coverage of content and cognitive domains.

## The TIMSS Tests

The overriding principle in constructing tests for the upcoming cycles of the study is to produce assessment instruments that will generate achievement data that are valid for the purposes they are to be used for, and are reliable. Based on the frameworks, the TIMSS tests are developed through an international consensus-building process involving input from experts in education, mathematics, science, and measurement. The tests contain questions requiring students to select appropriate responses or to solve problems and answer questions in an open-ended format. With each cycle, TIMSS releases test questions to the public and then replaces these with newly developed questions. As in earlier phases of TIMSS, most test items, while focusing on a particular content element, will also assume knowledge or skills from one or more other content areas. Additionally, some topics have been stated more broadly, and it is expected that a number of the newly developed items will require students to synthesize knowledge and skills from more than one topic. From 2003 on, TIMSS will gradually place more emphasis on questions and tasks that offer better insight into students' analytical, problem-solving, and inquiry skills and capabilities. To facilitate innovations in assessment instrumentation, the plan calls for incorporating investigative- or production-based tasks into the tests to the extent possible.

TIMSS test results can be used for a variety of purposes. Policy makers and researchers can look forward to achievement data in mathematics and science overall and in major content areas that:

- Extend and strengthen measurement of trends in mathematics and science begun in TIMSS 1995 and continued in TIMSS 1999
- Allow informed between-country comparisons of achievement and, in conjunction with other TIMSS data, suggest reasons for differences
- Enhance evaluation of the efficacy of mathematics and science teaching and learning within each country
- Highlight aspects of growth in mathematical and scientific knowledge and skills from grade 4 to grade 8
- Provide data for secondary analyses concerned with raising achievement levels through better-informed policy making in education systems and schools, and improved teaching practice.

## Student Populations Assessed

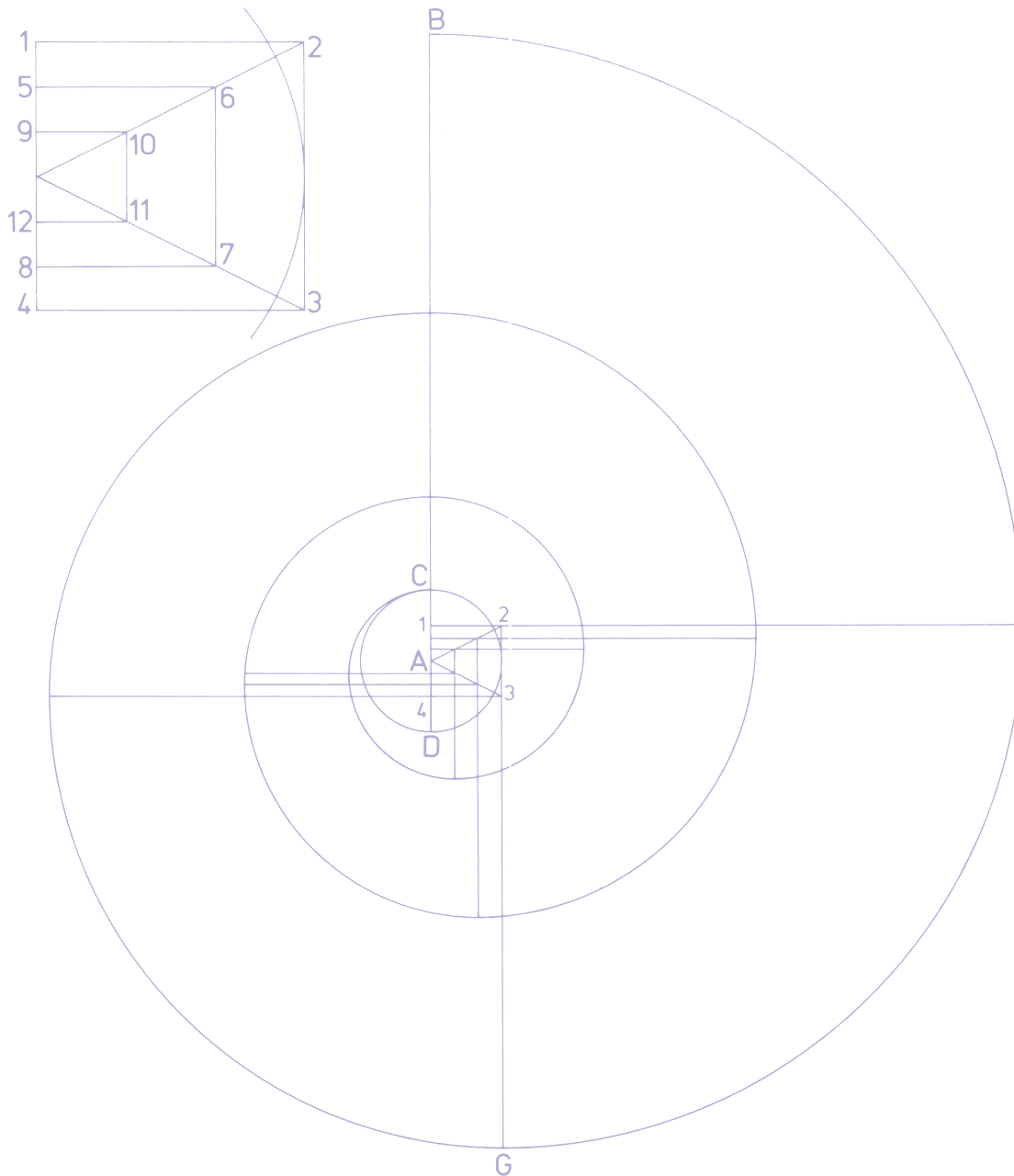
TIMSS 2003 will assess the mathematics and science achievement of children in two target populations. One target population, sometimes referred to as Population 1, includes children ages 9 and 10. It is defined as “the upper of the two adjacent grades with the most 9-year-olds.” In most countries, this is the fourth grade. The other target population, sometimes referred to as Population 2, includes children ages 13 and 14, and is defined as “the upper of the two adjacent grades with the most 13-year-olds.” In most countries, this is the eighth grade. Thus, through the remainder of this document, the grades assessed will be described as the fourth and eighth grades.

By assessing these grades using the same target populations as in 1995 and 1999, TIMSS 2003 can provide trend data at three points over an eight-year period. In addition, TIMSS data will complement IEA’s Progress in International Reading Literacy Study (PIRLS) being conducted in 2001 at the fourth grade. By participating in PIRLS and TIMSS, countries will have information at regular intervals about how well their students read and what they know and can do in mathematics and science. TIMSS also complements another international study of student achievement, the OECD’s Programme for International Student Achievement (PISA), which assesses the mathematics and science literacy of 15-year-olds.



The background features a large, dark blue spiral that originates from a central point and expands outwards. Overlaid on this spiral are several faint, light blue geometric diagrams. These include circles, straight lines, and points labeled with letters (A, B, C, D) and numbers (1, 2, 3, 4). One diagram shows a circle with a vertical line passing through its center, and points A, B, C, and D marked along this line. Another diagram shows a circle with a horizontal line passing through its center, and points A, B, C, and D marked along this line. A third diagram shows a circle with a diagonal line passing through its center, and points A, B, C, and D marked along this line. The overall design is clean and modern, with a focus on geometric shapes and patterns.

# Mathematics Framework








# Mathematics Framework





## Overview

The mathematics assessment framework for TIMSS 2003 is framed by two organizing dimensions, a content dimension and a cognitive dimension, analogous to those used in the earlier TIMSS assessments.<sup>1</sup> As outlined below, each dimension has several domains:

### Mathematics Content Domains

-  Number
-  Algebra
-  Measurement
-  Geometry
-  Data

### Mathematics Cognitive Domains

-  Knowing Facts and Procedures
-  Using Concepts
-  Solving Routine Problems
-  Reasoning

The two dimensions and their domains are the foundation of the mathematics assessment. The content domains define the specific mathematics subject matter covered by the assessment, and the cognitive domains define the sets of behaviors expected of students as they engage with the mathematics content. Each content domain has several topic areas (i.e., number is further categorized by whole numbers, fractions and decimals, integers, and ratio, proportion, and percent). Each topic area is presented as a list of objectives covered in a majority of participating countries, at either grade 4 or grade 8.<sup>2</sup>

Exhibit 2 shows the target percentages of testing time devoted to each content and cognitive domain for both the fourth and eighth grade assessments. The content and cognitive domains for the mathematics assessment are discussed in detail in the following sections. Example mathematics items and tasks are presented in Appendix B.

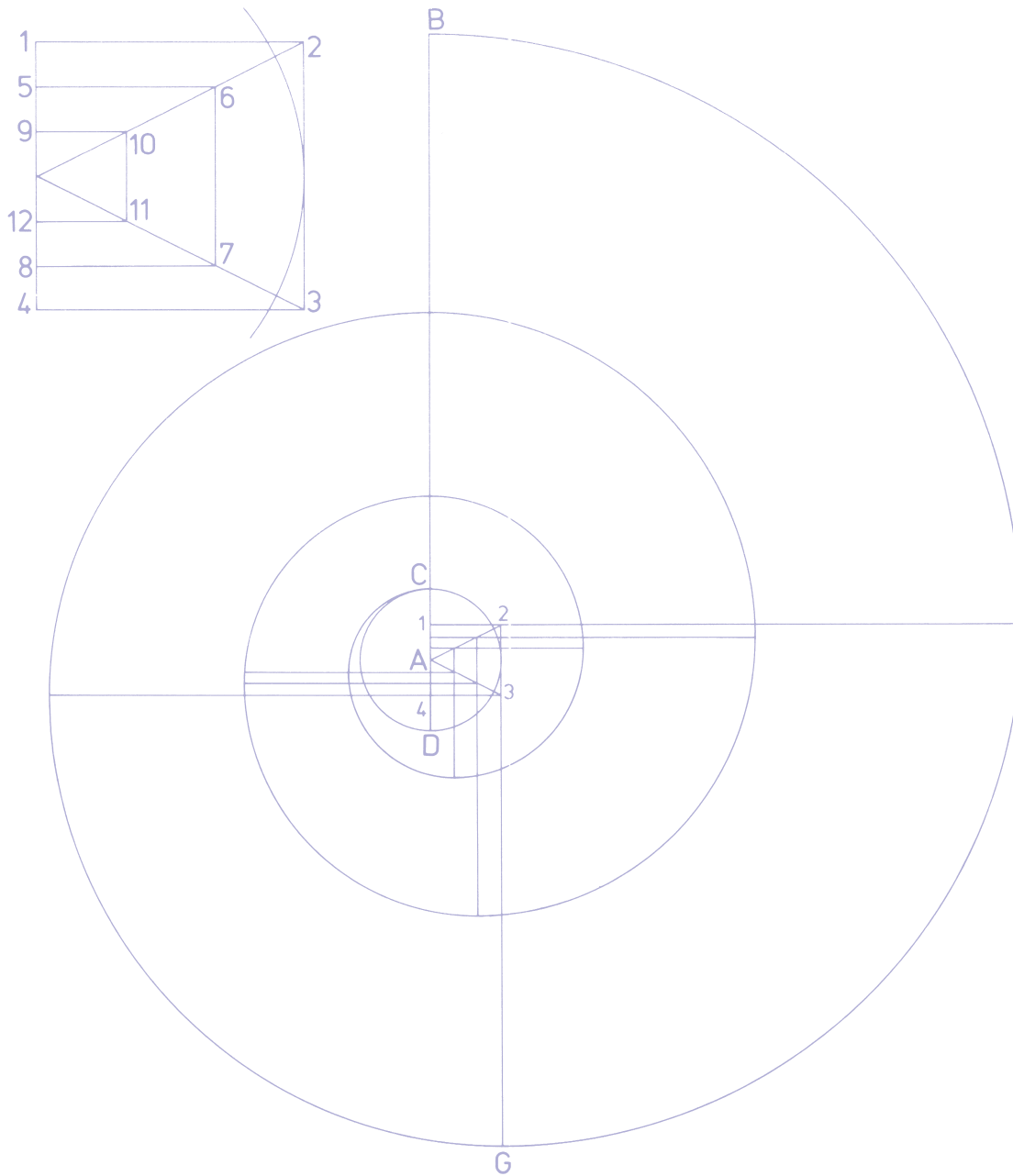
**Exhibit 2:** Target Percentages of TIMSS 2003 Mathematics Assessment Devoted to Content and Cognitive Domains by Grade Level

	Fourth Grade	Eighth Grade
<b>Mathematics Content Domains</b>		
Number	40%	30%
Algebra*	15%	25%
Measurement	20%	15%
Geometry	15%	15%
Data	10%	15%
<b>Mathematics Cognitive Domains</b>		
Knowing Facts and Procedures	20%	15%
Using Concepts	20%	20%
Solving Routine Problems	40%	40%
Reasoning	20%	25%

\*At fourth grade, the Algebra content domain is called Patterns, Equations, and Relationships.

<sup>1</sup> Similarly, the curriculum frameworks for TIMSS 1995 and 1999 assessments included content areas and performance expectations (Robitaille, D.F., et al, (1993), *TIMSS Monograph No. 1: Curriculum Frameworks for Mathematics and Science*, Vancouver, BC: Pacific Educational Press).

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



## Mathematics Content Domains

As mentioned earlier, the five content domains described in the mathematics framework, with assessment objectives defined that are appropriate for either the fourth or eighth grade, are:

- Number
- Algebra
- Measurement
- Geometry
- Data

The structure of the content dimension of the TIMSS framework reflects the importance of being able to continue comparisons of achievement with previous assessments in these content domains. The organization of topics across the content domains reflects some minor revision in the definition of the reporting categories used in the 1995 and 1999 assessments, particularly for the fourth grade.<sup>3</sup> The current structure, however, permits the direct mapping of trend items from 1995 and 1999 into the content domains defined for 2003. Thus, each mathematics content domain is considered as an analysis and reporting category.

The grade-specific assessment objectives indicated by topic areas within content domains define the assessment areas appropriate for each mathematics reporting category. These grade-specific objectives are written in terms of student understandings or abilities that items aligned with these objectives are designed to elicit. The range of behaviors assessed to measure student understandings and abilities is discussed in the section of the mathematics framework describing the cognitive domains. While the assessment of

abilities such as solving non-routine problems and reasoning with mathematics will be of special interest, the factual, procedural, and conceptual knowledge that form the initial base for the development and implementation of these skills will also be assessed.

Problem solving and communication are key outcomes of mathematics education that are associated with many of the topics in the content domains. They are regarded as valid behaviors to be elicited by test items in most topic areas.

The categorization by mathematics topic area within content domains at the fourth grade parallels that used at the eighth grade. Not all of the topic areas, however, are appropriate for the fourth grade. Also, the mathematical and cognitive levels of items developed according to the assessment objectives in the frameworks will be appropriate for the grade/age group. For example, at the fourth grade, there is a greater emphasis on number relative to the other major domains.

The following sections describe each of the mathematics content domains. They give an overview of the topic areas to be covered in the TIMSS assessment, focusing on the difference in student understandings expected at the fourth and eighth grades. Following the general description of each content domain is a table indicating a set of assessment outcomes for each main assessment topic area. 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.

<sup>3</sup> The five reporting categories used in the TIMSS 1999 international report for eighth grade were Fractions and Number Sense; Measurement; Data Representation, Analysis, and Probability; Geometry; and Algebra. The six reporting categories used in the TIMSS 1995 international report for fourth grade were Whole Numbers; Fractions and Proportionality; Measurement, Estimation, and Number Sense; Data Representation, Analysis, and Probability; Geometry; and Patterns, Relations, and Functions.



# Number

The number content domain includes understanding of counting and numbers, ways of representing numbers, relationships among numbers, and number systems. At the fourth and eighth grades, students should have developed number sense and computational fluency, understand the meanings of operations and how they relate to one another, and be able to use numbers and operations to solve problems.

The number content domain consists of understandings and skills related to:

- Whole numbers
- Fractions and decimals
- Integers
- Ratio, proportion, and percent

In this domain, there is more emphasis on computing with whole numbers at the fourth grade than at the eighth grade. Since whole numbers provide the easiest introduction to operations with numbers that are basic to the development of mathematics, working with whole numbers is the foundation of mathematics in the primary school. Most children learn to count at a young age and can solve simple addition, subtraction, multiplication, and division

problems during the first few years of school. Grade 4 students should be able to compute with whole numbers of reasonable size, estimate the sums, differences, products, and quotients, and use computation to solve problems.

In the area of common fractions and decimal fractions, the emphasis is on representation and translation between forms, understanding what quantities the symbols represent, and computation and problem solving. At the fourth grade, students should be able to compare familiar fractions and decimals. By the eighth grade, they should be able to move flexibly among equivalent fractions, decimals, and percents using a range of strategies.

Although the integer topic area is not appropriate for grade 4, students in the middle grades of schooling should extend their mathematical understanding from whole numbers to integers, including order and magnitude as well as operations with integers.

Assessing students' ability to work with proportions is an important component. Aspects of proportional reasoning can include numerical and qualitative comparison problems as well as the more traditional missing value problems (i.e., presenting three values and asking students to find the fourth or missing value).

## Number: Whole Numbers

### Grade 4

- Represent whole numbers using words, diagrams, or symbols, including recognizing and writing numbers in expanded form.
- Demonstrate knowledge of place value.
- Compare and order whole numbers.
- Identify sets of numbers according to common properties such as odd and even, multiples, or factors.
- Compute with whole numbers.
- Estimate computations by approximating the numbers involved.
- Solve routine and non-routine problems, including real-life problems.

### Grade 8

- Demonstrate knowledge of place value and of the four operations.
- Find and use factors or multiples of numbers, and identify prime numbers.
- Express in general terms and use the principles of commutativity, associativity, and distributivity.
- Evaluate powers of numbers, and square roots of perfect squares to 144.
- Solve problems by computing, estimating, or approximating.

## Number: Fractions and Decimals

### Grade 4

- Recognize fractions as parts of unit wholes, parts of a collection, locations on number lines, divisions of whole numbers.
- Identify equivalent fractions.
- Compare and order fractions.
- Show understanding of decimals.
- Represent fractions or decimals using words, numbers, or models.
- Add and subtract fractions with the same denominator.
- Add and subtract with decimals.

Notes: Grade 4 fractions items will involve denominators of 2, 3, 4, 5, 6, 8, 10, or 12.

Grade 4 decimals items will involve decimals to tenths and/or hundredths.

### Grade 8

- Compare and order fractions.
- Compare and order decimals.
- Demonstrate knowledge of place value for decimals.
- Represent decimals and fractions using words, numbers, or models (including number lines).
- Recognize and write equivalent fractions.
- Convert fractions to decimals and vice versa.
- Relate operations with fractions or decimals to situations and models.
- Compute with fractions and decimals, including use of commutativity, associativity, and distributivity.
- Approximate decimals to estimate computations.
- Solve problems involving fractions.
- Solve problems involving decimals.

## Number: Integers

### Grade 4

- Not assessed.

### Grade 8

- Represent integers using words, numbers, or models (including number lines).
- Compare and order integers.
- Show understanding of addition, subtraction, multiplication, and division with integers.
- Compute with integers.
- Solve problems using integers.

## Number: Ratio, Proportion, and Percent

### Grade 4

- Solve problems involving simple proportional reasoning.

### Grade 8

- Identify and find equivalent ratios.
- Divide a quantity in a given ratio.
- Convert percents to fractions or decimals, and vice versa.
- Solve problems involving percents.
- Solve problems involving proportions.

# Algebra

While functional relationships and their uses for modeling and problem solving are of prime interest, it is also important to assess how well the supporting knowledge and skills have been learned. The algebra content domain includes patterns and relationships among quantities, using algebraic symbols to represent mathematical situations, and developing fluency in producing equivalent expressions and solving linear equations.

Because algebra is generally not taught as a formal subject in primary school, this content domain will be identified as *Patterns, Equations, and Relationships* at the fourth grade. In contrast, at the eighth grade the algebra reporting category will reflect understandings across all of the topic areas below.

The major topic areas in algebra are:

- Patterns
- Algebraic expressions
- Equations and formulas
- Relationships

Students will be asked to recognize and extend patterns and relationships. They will also be asked to recognize and use symbols to represent situations algebraically. At the fourth grade, understandings related to patterns, simple equations, and the idea of functions as they apply to pairs of numbers are included. Algebraic concepts are more formalized at the eighth grade, and students should focus on understanding linear relationships and the concept of variable. Students at this level are expected to use and simplify algebraic formulas, solve linear equations and inequalities and pairs of simultaneous equations involving two variables, and use a range of linear and nonlinear functions. They should be able to solve real-world problems using algebraic models and to explain relationships involving algebraic concepts.

## Algebra: Patterns

### Grade 4

- Extend and find missing terms of numeric and geometric patterns.
- Match numeric and geometric patterns with descriptions.
- Describe relationships between adjacent terms in a sequence or between the number of the term and the term.

### Grade 8

- Extend numeric, algebraic, and geometric patterns or sequences using words, symbols, or diagrams; find missing terms.
- Generalize pattern relationships in a sequence, or between adjacent terms, or between the number of the term and the term, using words or symbols.

## Algebra: Algebraic Expressions

### Grade 4

- Not assessed.

### Grade 8

- Find sums, products, and powers of expressions containing variables.
- Evaluate expressions for given numeric values of the variable(s).
- Simplify or compare algebraic expressions to determine equivalence.
- Model situations using expressions.

## Algebra: Equations and Formulas

### Grade 4

- Show understanding of equality using equations, areas, volumes, masses/weights.
- Find the missing number in an equation (e.g., if  $17 + \underline{\quad} = 29$ , what number would go in the blank to make the equation true?).
- Model simple situations involving unknowns with an equation.
- Solve problems involving unknowns.

### Grade 8

- Evaluate formulas given values of the variables.
- Use formulas to answer questions about given situations.
- Indicate whether a value, or values, satisfies a given equation.
- Solve simple linear equations and inequalities, and simultaneous (two variables) equations.
- Write linear equations, inequalities, or simultaneous equations that model given situations.
- Solve problems using equations or formulas.

## Algebra: Relationships

### Grade 4

- Generate pairs of numbers following a given rule (e.g., multiply the first number by 3 and add 2 to get the second number).
- Write, or select, a rule for a relationship given some pairs of numbers satisfying the relationship.
- Graph pairs of numbers following a given rule.
- Show why a pair of numbers follows a given rule. (E.g., a rule for a relation between two numbers is "multiply the first number by 5 and subtract 4 to get the second number." Show that when the first number is 2 and the second number is 6 the rule is followed.)

### Grade 8

- Recognize equivalent representations of functions as ordered pairs, tables, graphs, words, or equations.
- Given a function in one representation, generate a different but equivalent representation.
- Recognize and interpret proportional, linear, and nonlinear relationships (travel graphs and simple piecewise functions included).
- Write or select a function to model a given situation.
- Given a graph of a function, identify attributes such as intercepts on axes, and intervals where the function increases, decreases, or is constant.



# Measurement

Measurement involves assigning a numerical value to an attribute of an object. The focus of this content domain is on understanding measurable attributes and demonstrating familiarity with the units and processes used in measuring various attributes. Measurement is important to many aspects of everyday life.

The measurement content domain is comprised of the following two main topic areas:

- Attributes and units
- Tools, techniques, and formulas

A measurable attribute is a characteristic of an object that can be quantified. For example, line segments have length, plane regions have area, and physical objects have mass. Learning about measurement begins with a realization of the need for comparison and the fact that different units are needed to measure

different attributes. The types of units that students use for measuring and the ways they use them should expand and shift as students move through the curriculum.

At both the fourth and eighth grades, age-appropriate performances expected of students include the use of instruments and tools to measure physical attributes, including length, area, volume, weight/mass, angle, temperature, and time, in standard or non-standard units and converting between systems of units. Students at the fourth grade are expected to use approximation and estimation, and simple formulas, to calculate areas and perimeters of squares and rectangles. At the eighth grade, the measurement domain is expanded to include the measurement of rate (such as speed or density) as well as the application of more complex formulas to measure compound areas and the surface areas of solids.

## Measurement: Attributes and Units

### Grade 4

- Use given non-standard units to measure length, area, volume, and time (e.g., paper clips for length, tiles for area, sugar cubes for volume).
- Select appropriate standard units to measure length, area, mass/weight,\* angle, and time (e.g., kilometers for car trips, centimeters for human height).
- Use conversion factors between standard units (e.g., hours to minutes, grams to kilograms).
- Recognize that total measures of length, area, volume, angle, and time do not change with position, decomposition into parts, or division.

\* More properly mass, but weight expressed in grams or kilograms is the common usage at these levels. Countries in which mass is the common usage for grades 4 and/or 8 will frame items accordingly.

### Grade 8

- Select and use appropriate standard units to find measures of length, area, volume, perimeter, circumference, time, speed, density, angle, mass/weight.\*
- Use relationships among units for conversions within systems of units, and for rates.

## Measurement: Tools, Techniques, and Formulas

### Grade 4

- Use instruments with linear or circular scales to measure length, weight, time, and temperature in problem situations (e.g., dimensions of a window, weight of a parcel).
- Estimate length, area, volume, weight, and time in problem situations (e.g., height of a building, volume of a block of material).
- Calculate areas and perimeters of squares and rectangles of given dimensions.
- Compute measurements in simple problem situations (e.g., elapsed time, change in temperature, difference in height or weight).

### Grade 8

- Use standard tools to measure length, weight, time, speed, angle, and temperature in problem situations and to draw line segments, angles, and circles of given size.
- Estimate length, circumference, area, volume, weight, time, angle, and speed in problem situations (e.g., circumference of a wheel, speed of a runner).
- Compute with measurements in problem situations (e.g., add measures, find average speed on a trip, find population density).
- Select and use appropriate measurement formulas for perimeter of a rectangle, circumference of a circle, areas of plane figures (including circles), surface area and volume of rectangular solids, and rates.
- Find measures of irregular or compound areas by covering with grids or dissecting and rearranging pieces.
- Give and interpret information about precision of measurements (e.g., upper and lower bounds of a length reported as 8 centimeters to the nearest centimeter).



# Geometry

Even at the fourth grade, the geometry content domain extends well beyond identification of geometric shapes. At both the fourth and eighth grades, students should be able to analyze the properties and characteristics of a variety of geometric figures, including lines, angles, and two- and three-dimensional shapes, and to provide explanations based on geometric relationships. The focus should be on geometric properties and their relationships. The geometry content area includes understanding coordinate representations and using spatial visualization skills to move between two- and three-dimensional shapes and their representations. Students should be able to use symmetry and apply transformation to analyze mathematical situations.

The major topic areas in geometry are:

- Lines and angles
- Two- and three-dimensional shapes
- Congruence and similarity
- Locations and spatial relationships
- Symmetry and transformations

Spatial sense is an integral component of the study and assessment of geometry. The cognitive range extends from making drawings and constructions to mathematical reasoning about

combinations of shapes and transformations. At both the fourth and eighth grades, students will be asked to describe, visualize, draw, and construct a variety of geometric figures, including angles, lines, triangles, quadrilaterals, and other polygons. Students should be able to combine, decompose, and analyze compound shapes. By the middle grades, they should be able to interpret or create top or side views of objects and use their understanding of similarity and congruence to solve problems. They should be able to make use of grids, find distances between points in the plane, and apply the Pythagorean theorem to solve real-world problems.

At both the fourth and eighth grades, students should be able to recognize line symmetry and draw symmetrical figures. They should be able to determine the effects of transformation. In the middle grades, students should understand and be able to describe rotations, translations, and reflections in mathematical terms (e.g., center, direction, and angle). As students progress through school, using proportional thinking in geometric contexts is important, as is making some initial links between geometry and algebra. Students should be able to solve problems using geometric models and explain relationships involving geometric concepts.

## Geometry: Lines and Angles

### Grade 4

- Classify angles as greater than, equal to, or less than a right angle (or  $90^\circ$ ).
- Identify and describe parallel and perpendicular lines.
- Compare given angles and place them in order of size.

### Grade 8

- Classify angles as acute, right, straight, obtuse, reflex, complementary, and supplementary.
- Recall the relationships for angles at a point, angles on a line, vertically opposite angles, angles associated with a transversal cutting parallel lines, and perpendicularity.
- Know and use the properties of angle bisectors and perpendicular bisectors of lines.



**Geometry: Two- and Three-dimensional Shapes****Grade 4**

- Know and use vocabulary associated with familiar two- and three-dimensional shapes.
- Identify common geometric shapes in the environment.
- Classify two- and three-dimensional shapes according to their properties.
- Know properties of geometric figures and use them to solve routine problems.
- Decompose shapes and rearrange the parts to form simpler shapes.

**Grade 8**

- Recall properties of geometric shapes: triangles (scalene, isosceles, equilateral, right-angled) and quadrilaterals (scalene, trapezoid, parallelogram, rectangle, rhombus, square).
- Use properties of familiar geometric shapes in a compound figure to make conjectures about properties of the compound figure.
- Recall properties of other polygons (regular pentagon, hexagon, octagon, decagon).
- Construct or draw triangles and rectangles of given dimensions.
- Apply geometric properties to solve routine and non-routine problems.
- Use Pythagorean theorem (not proof) to solve problems (e.g., find the length of a side of a right-angled triangle given the lengths of the other two sides; or, given the lengths of three sides of a triangle, determine whether the triangle is right-angled).

**Geometry: Congruence and Similarity****Grade 4**

- Identify triangles that have the same size and shape (congruent).
- Identify triangles that have the same shape but different sizes (similar).

**Grade 8**

- Identify congruent triangles and their corresponding measures.
- Identify congruent quadrilaterals and their corresponding measures.
- Consider the conditions of congruence to determine whether triangles with given corresponding measures (at least three) are congruent.
- Identify similar triangles and recall their properties.
- Use properties of congruence in mathematical and practical problem situations.
- Use properties of similarity in mathematical and practical problem situations.





### Geometry: Locations and Spatial Relationships

#### Grade 4

- Use informal coordinate systems to locate points in a plane.
- Relate a net to the shape it will make.
- Recognize relationships between two-dimensional and three-dimensional shapes when shown nets and different two-dimensional views of three-dimensional objects.

#### Grade 8

- Locate points using number lines, coordinate grids, maps.
- Use ordered pairs, equations, intercepts, intersections, and gradient to locate points and lines in the Cartesian plane.
- Recognize relationships between two-dimensional and three-dimensional shapes when shown nets and different two-dimensional views of three-dimensional objects.

### Geometry: Symmetry and Transformations

#### Grade 4

- Recognize line symmetry.
- Draw two-dimensional symmetrical figures.
- Recognize translation, reflection, and rotation.

#### Grade 8

- Recognize line and rotational symmetry for two-dimensional shapes.
- Draw two-dimensional symmetrical figures.
- Recognize, or demonstrate by sketching, translation, reflection, rotation, and enlargement.
- Use transformations to explain or establish geometric properties.

The data content domain includes understanding how to collect data, organize data that have been collected by oneself or others, and display data in graphs and charts that will be useful in answering questions that prompted the data collection. This content domain includes understanding issues related to misinterpretation of data (e.g., about recycling, conservation, or manufacturers' claims).

The data content domain consists of the following four major topic areas:

- Data collection and organization
- Data representation
- Data interpretation
- Uncertainty and probability

At the fourth and eighth grades, students can engage in simple data-gathering plans or work with data that have been gathered by others or generated by simulations. They should understand what various numbers, symbols, and points mean in data displays. For example, they should recognize that some numbers represent the values of the data and others represent the

frequency with which those values occur. Students should develop skill in representing their data, often using bar graphs, tables, or line graphs. They should be able to compare the relative merits of various types of displays.

Students at grades 4 and 8 should be able to describe and compare characteristics of data (shape, spread, and central tendency). They should be able to draw conclusions based on data displays. In the eighth grade, students should be able to identify trends in data, make predictions based on data, and evaluate the reasonableness of interpretations.

Probability will not be assessed at the fourth grade, and at the eighth grade the probability items will focus on assessing student understandings of the concept.<sup>4</sup> By the eighth grade students' appreciation of probability should have increased beyond being able to designate the occurrence of familiar events as certain; as having greater, equal, or less likelihood; or as impossible, and they should be able to compute probabilities for simple events, or estimate probabilities from experimental data.

### Data: Data Collection and Organization

#### Grade 4

- Match a set of data with appropriate characteristics of situations or contexts (e.g., outcomes from rolling a die).
- Organize a set of data by one characteristic (e.g., height, color, age, shape).

#### Grade 8

- Match a set of data, or a data display, with appropriate characteristics of situations or contexts (e.g., monthly sales of a product for a year).
- Organize a set of data by one or more characteristics using a tally chart, table, or graph.
- Recognize and describe possible sources of error in collecting and organizing data (e.g., bias, inappropriate grouping).
- Select the most appropriate data collection method (e.g., survey, experiment, questionnaire) to answer a given question, and justify the choice.

<sup>4</sup> The original data representation, analysis, and probability category defined in the 1995 and 1999 assessments included a small number of items related to uncertainty and probability, but these depended heavily on knowledge of whole numbers, fractions, and proportionality.

**Data: Data Representation****Grade 4**

- Read data directly from tables, pictographs, bar graphs, and pie charts.
- Display data using tables, pictographs, and bar graphs.
- Compare and match different representations of the same data.

**Grade 8**

- Read data from charts, tables, pictographs, bar graphs, pie charts, and line graphs.
- Display data using charts, tables, pictographs, bar graphs, pie charts, and line graphs.
- Compare and match different representations of the same data.

**Data: Data Interpretation****Grade 4**

- Compare characteristics of related data sets (e.g., given data or representations of data on student heights in two classes, identify the class with the shortest/tallest person).
- Draw conclusions from data displays.

**Grade 8**

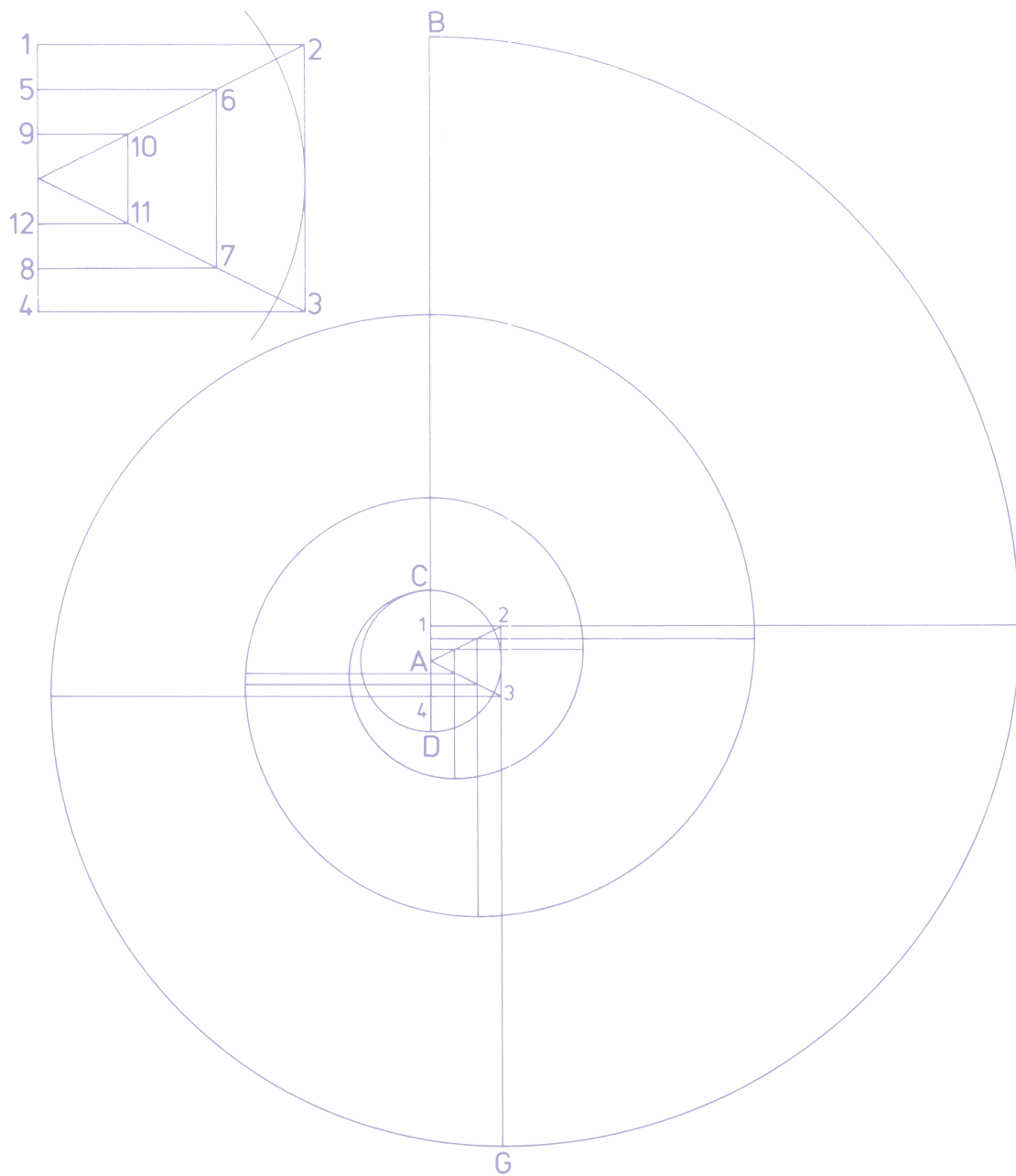
- Compare characteristics of data sets, using mean, median, range, and shape of distribution (in general terms).
- Interpret data sets (e.g., draw conclusions, make predictions, and estimate values between and beyond given data points).
- Evaluate interpretations of data with respect to correctness and completeness of interpretation.
- Use and interpret data sets to answer questions.

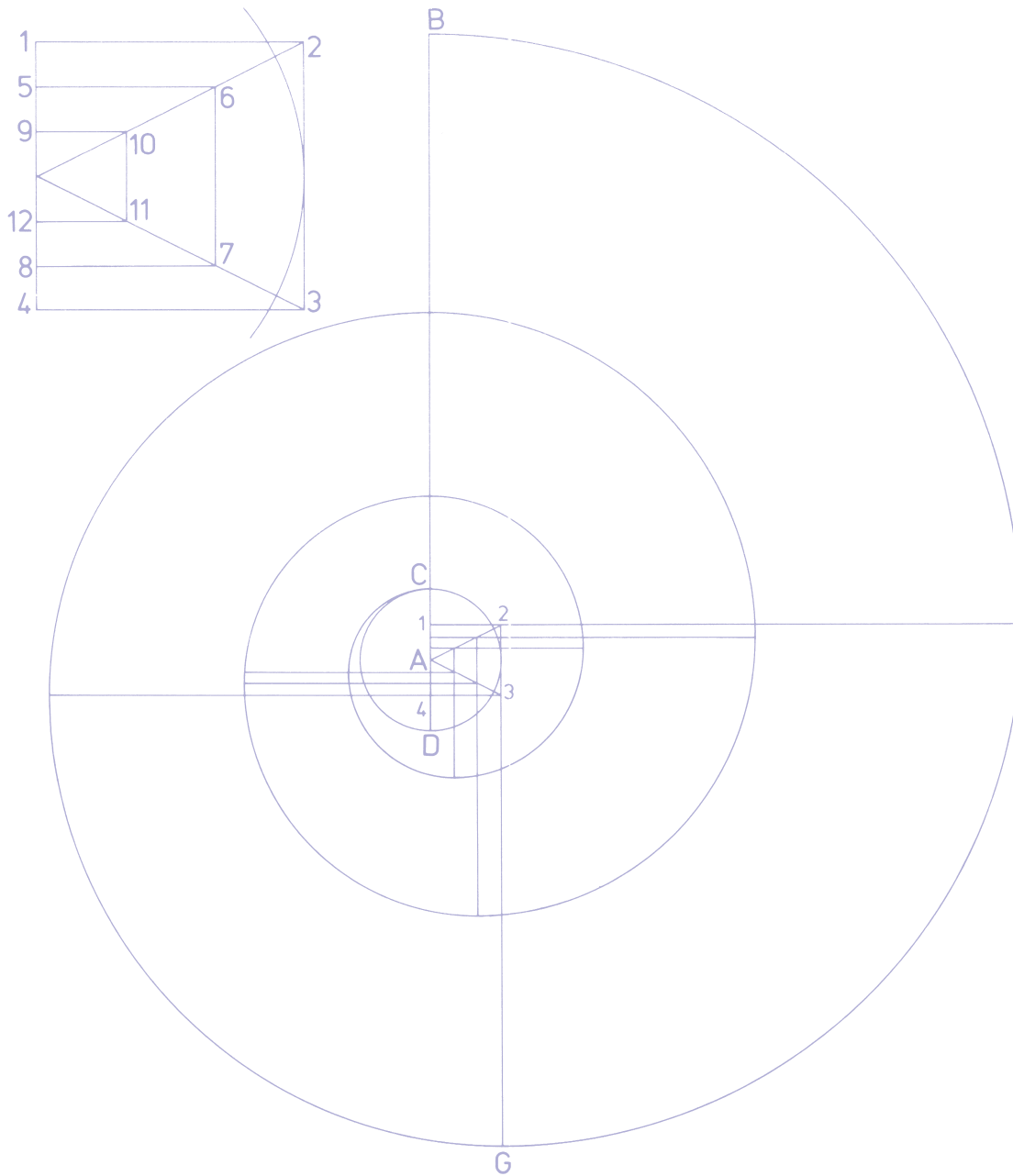
**Data: Uncertainty and Probability****Grade 4**

- Not assessed.

**Grade 8**

- Judge the likelihood of an event as certain, more likely, equally likely, less likely, or impossible.
- Use data from experiments to estimate probabilities for favorable outcomes.
- Use problem conditions to calculate theoretical probabilities for possible outcomes.





## Mathematics Cognitive Domains

To respond correctly to TIMSS test items, students will need to be familiar with the mathematics content of the items. Just as important, items will be designed to elicit the use of particular cognitive skills. Many of these skills and abilities are included with topics in the lists of assessable topics that comprise the content domains. However, as an aid in developing balanced tests in which appropriate weight is given to each cognitive domain across all topics, a full set of the learning outcomes mathematics educators would wish to see demonstrated is indispensable. Thus, descriptions of skills and abilities that make up the cognitive domains and will be assessed in conjunction with content are presented in the framework in some detail. These skills and abilities should play a central role in developing items and achieving a balance across the item sets at grades 4 and 8.

The student behaviors used to define the mathematics frameworks have been classified into the following four cognitive domains that are described in this section:

- Knowing Facts and Procedures
- Using Concepts
- Solving Routine Problems
- Reasoning

The specific student behaviors included in each cognitive domain comprise the outcomes sought by educational planners and practitioners around the world. Different groups within a society, and even among mathematics educators, have different views about the relative values of the cognitive skills, or at least about the relative emphases that should be accorded them in schools. For TIMSS they are all regarded as important, and a variety of test items will be used to measure each of them.

The skills and abilities included in each cognitive domain exemplify those that students could be expected to demonstrate in the TIMSS achievement tests. They are intended to apply to both grades 4 and 8, even though the accepted degree of sophistication in demonstrating behaviors will vary considerably between the two. The distribution of items over *knowing facts and procedures*, *using concepts*, *solving routine problems*, and *reasoning* also differs slightly between the two populations in accord with the mathematical experience of the target age/grade groups (see Exhibit 2).

As students' mathematical proficiency develops with the interaction of experience, instruction, and maturity, curricular emphasis moves from relatively straightforward problem situations to more complex tasks. In general, the cognitive complexity of tasks increases from one broad cognitive domain to the next. The intent is to allow for a progression from knowing a fact, procedure, or concept to using that knowledge to solve a problem, and from use of that knowledge in uncomplicated or familiar situations to the ability to engage in systematic reasoning.

Nevertheless, cognitive complexity should not be confused with item difficulty. For nearly all of the cognitive skills listed, it is possible to create relatively easy items as well as very challenging items. In developing items aligned with the skills, it is expected that a range of item difficulties will be obtained for each one, and that item difficulty should not affect the designation of the cognitive skill.

The following sections further describe the student behaviors, skills, and abilities used to define each cognitive domain with respect to the general capabilities expected of students. A table indicating specific behaviors to be elicited by items that are aligned with each skill in a domain follows the general descriptions, with examples of test items provided in some cases for illustration.





# Knowing Facts and Procedures

Facility in using mathematics, or reasoning about mathematical situations, depends primarily on mathematical knowledge. The more relevant knowledge a student is able to recall, the greater the potential for engaging a wide range of problem-solving situations. Without access to a knowledge base that enables easy recall of the language and basic facts and conventions of number, symbolic representation, and spatial relations, students would find purposeful mathematical thinking impossible. *Facts* encompass the factual knowledge that provides the basic language of mathematics, and the essential mathematical facts and properties that form the foundation for mathematical thought.

*Procedures* form a bridge between more basic knowledge and the use of mathematics for solving routine problems, especially those encountered by many people in their daily lives. In essence a fluent use of procedures entails recall of sets of actions and how to carry them out. Students need to be efficient and accurate in using a variety of computational procedures and tools. They need to see that particular procedures can be used to solve entire classes of problems, not just individual problems.

## Knowing Facts and Procedures

<b>Recall</b>	Recall definitions; vocabulary; units; number facts; number properties; properties of plane figures; mathematical conventions (e.g., algebraic notation such as $a \times b = ab$ , $a + a + a = 3a$ , $a \times a \times a = a^3$ , $a/b = a \div b$ ).
<b>Recognize/Identify</b>	Recognize/identify mathematical entities that are mathematically equivalent, i.e., areas of parts of figures to represent fractions, equivalent familiar fractions, decimals, and percents; simplified algebraic expressions; differently oriented simple geometric figures.
<b>Compute</b>	Know algorithmic procedures for $+$ , $-$ , $\times$ , $\div$ , or a combination of these; know procedures for approximating numbers, estimating measures, solving equations, evaluating expressions and formulas, dividing a quantity in a given ratio, increasing or decreasing a quantity by a given percent. Simplify, factor, expand algebraic and numerical expressions; collect like terms.
<b>Use Tools</b>	Use mathematics and measuring instruments; read scales; draw lines, angles, or shapes to given specifications. Use straightedge and compass to construct the perpendicular bisector of a line, angle bisector, triangles, and quadrilaterals, given necessary measures.







# Using Concepts

Familiarity with mathematical *concepts* is essential for the effective use of mathematics for problem solving, for reasoning, and thus for developing mathematical understanding.

Knowledge of concepts enables students to make connections between elements of knowledge that, at best, would otherwise be retained as isolated facts. It allows them to make exten-

sions beyond their existing knowledge, judge the validity of mathematical statements and methods, and create mathematical representations. Representation of ideas forms the core of mathematical thinking and communication, and the ability to create equivalent representations is fundamental to success in the subject.

## Using Concepts

### Know

Know that length, area, and volume are conserved under certain conditions; have an appreciation of concepts such as inclusion and exclusion, generality, equal likelihood, representation, proof, cardinality and ordinality, mathematical relationships, place value.

Grade 4 example: Decide whether area of paper is greater, the same, or less after a sheet of paper has been cut into strips (diagram shows complete sheet and separated strips).

Grade 8 example: Know that if five successive tosses of a fair coin come up "heads," the outcome of the next toss is as likely to be "tails" as "heads."

### Classify

Classify/group objects, shapes, numbers, expressions, and ideas according to common properties; make correct decisions about class membership; order numbers and objects by attributes.

Grade 4 example: Select the triangles from a set of geometric figures having various shapes and numbers of sides.

Grade 8 example: Group pairs of quantities (lengths, weights, costs, etc.) in which the first quantity is greater than the second quantity.

### Represent

Represent numbers using models; display mathematical information or data in diagrams, tables, charts, graphs; generate equivalent representations for a given mathematical entity or relationship.

Grade 4 example: Shade areas of figures to represent given fractions.

Grade 8 example: Given a function rule, generate ordered pairs that describe the function.

**Formulate**

Formulate problems or situations that could be modeled by given equations or expressions.

Grade 4 example: Jane has read 29 pages of her book. If the book has 87 pages, in the equation  $87 - \_ = 29$  the blank would contain the number of pages Jane still has to read. Make up another situation that this equation could be used for.

Grade 8 example: The equation  $4x + 3 = 51$  could be used to solve the following problem: Four boxes are filled with golf balls, and 3 golf balls are left over. If there are 51 balls altogether, how many does each box hold? Make up a problem that the equation  $25 - 3x = 1$  could be used to solve. (Do not solve the equation.)

**Distinguish**

Distinguish questions that can be addressed by given information, such as a data set, from those that cannot.

Grade 4 example: Given a bar graph, select from a set of questions those for which answers can be obtained from the graph.

Grade 8 example: The weights of boys in a class are <weights given>. Answers to which of the following questions can be found? What is the average weight of boys in the class? On average, do boys in the class weigh more than girls in the class? How many boys weigh more than 70 kg? What is the grade level of the class?



# Solving Routine Problems

Students should be educated to recognize mathematics as an immense achievement of humanity, and to appreciate its nature. Nevertheless, mathematical knowledge for its own sake is probably not the most compelling reason for universal inclusion of mathematics in school curricula. Prime reasons for inclusion of mathematics are the increasing awareness that effectiveness as a citizen and success in the workplace are greatly enhanced by knowing and, more important, being able to use mathematics. The number of vocations that demand a high level of proficiency in the use of mathematics, or mathematical modes of thinking, has burgeoned with the advance of technology, and with modern management methods.

Problem solving is a central aim, and often means, of teaching school mathematics, and hence this and supporting skills (e.g., manipulate expressions, select, model, verify/check) feature prominently in the *solving routine problems* domain. In items aligned with this domain, the problem settings are more routine than those aligned with the reasoning domain. The routine problems will have been standard in classroom exercises designed to provide practice in particular methods or techniques. Some of these problems

will have been in words that set the problem situation in a quasi-real context. Solution of other such “textbook” type problems will involve extended knowledge of mathematical properties (e.g., solving equations). Though they range in difficulty, each of these types of “textbook” problems is expected to be sufficiently familiar to students that they will essentially involve selecting and applying learned procedures.

Problem solving is a desired outcome of mathematics instruction linked with many mathematics topics in the TIMSS framework. Problems may be set in real-life situations, or may be concerned with purely mathematical questions involving, for example, numeric or algebraic expressions, functions, equations, geometric figures, or statistical data sets. Therefore, problem solving has been included not only in solving routine problems but also in reasoning, depending on whether students are asked to solve routine problems or more non-routine problems (see following).

## Solving Routine Problems

### Select

Select/use an efficient method or strategy for solving problems where there is a known algorithm or method of solution, i.e., an algorithm or method students at the target level could be expected to be familiar with. Select appropriate algorithms, formulas, or units.

Grade 4 example: A class is presenting a class concert and the 28 members of the class each have 7 tickets to sell. To find the total number of tickets you should: divide 28 by 7; multiply 28 by 7; add 7 to 28; etc.

Grade 8 example: Given a problem that can be modeled by a simple equation, select the appropriate equation.

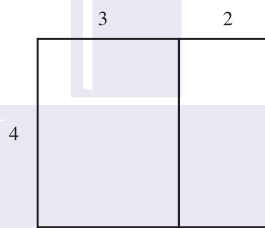


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<b>Model</b>	Generate an appropriate model, such as an equation or diagram, for solving a routine problem.
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<b>Interpret</b>	<p>Interpret given mathematical models (equations, diagrams, etc.); follow and execute a set of mathematical instructions.</p> <p>Grade 4 example: Given an unfamiliar (but not complex) figure or procedure, write the verbal instructions you would give to another student to have him/her reproduce the figure.</p> <p>Grade 8 example: Given a set of expressions including <math>4(3 + 2) = 4 \times 3 + 4 \times 2</math>, which one can the diagram be used to show?</p>
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<b>Apply</b>	Apply knowledge of facts, procedures, and concepts to solve routine mathematical (including real-life) problems, i.e., problems similar to those target students are likely to have encountered in class.
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<b>Verify/Check</b>	Verify/check the correctness of the solution to a problem; evaluate the reasonableness of the solution to a problem.
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Grade 4 example: Mario estimates the area of a room in his house in square meters. His estimate is 1300 square meters. Is this likely to be a good estimate? Explain.

Grade 8 example: Jack wants to find how far an airplane will travel in 3.5 hours at its top speed of 965 kph. He uses his calculator to multiply 3.5 by 965 and tells his friend Jenny that the answer is 33,775 km. Jenny says "that can't be right." How does she know?



# Reasoning

*Reasoning* mathematically involves the capacity for logical, systematic thinking. It includes intuitive and inductive reasoning based on patterns and regularities that can be used to arrive at solutions to non-routine problems. Non-routine problems are problems that are very likely to be unfamiliar to students. They make cognitive demands over and above those needed for solution of routine problems, even when the knowledge and skills required for their solution have been learned. Non-routine problems may be purely mathematical or may have real-life settings. Both types of items involve transfer of knowledge and skills to new situations, and interactions among reasoning skills are usually a feature.

Most of the other behaviors listed within the reasoning domain are those that may be drawn on in thinking about and solving such problems, but each by itself represents a valuable outcome of mathematics education, with the potential to influence learners' thinking more generally. For example, reasoning involves the ability to observe and make conjectures. It also involves making logical deductions based on specific assumptions and rules, and justifying results.

## Reasoning

<b>Hypothesize/Conjecture/ Predict</b>	<p>Make suitable conjectures while investigating patterns, discussing ideas, proposing models, examining data sets; specify an outcome (number, pattern, amount, transformation, etc.) that will result from some operation or experiment before it is performed.</p> <p>Grade 8 example: Twin primes are prime numbers with one other number between them. Thus, 5 and 7, 11 and 13, and 17 and 19 are pairs of twin primes. Make a conjecture about the numbers between twin primes.</p>
<b>Analyze</b>	<p>Determine and describe or use relationships between variables or objects in mathematical situations; analyze univariate statistical data; decompose geometric figures to simplify solving a problem; draw the net of a given unfamiliar solid; make valid inferences from given information.</p>
<b>Evaluate</b>	<p>Discuss and critically evaluate a mathematical idea, conjecture, problem solving strategy, method, proof, etc.</p> <p>Grade 4 example: Two painters use three tins of paint in painting a fence. They then have to use the same kind of paint to paint a similar fence that is twice as long and twice as high. One of the painters said that they would need about twice as much paint to paint the wall. Indicate whether the painter was right and support your answer with reasons.</p> <p>Grade 8 example: Comment on a survey with obvious flaws (too small a sample, non-representative sample, etc.).</p>

**Generalize**

Extend the domain to which the result of mathematical thinking and problem solving is applicable by restating results in more general and more widely applicable terms.

Grade 4 example: Given the pattern 1, 4, 7, 10, ..., describe the relationship between each term and the next, and give the next term after 61.

Grade 8 example: Given that the sum of the angles of a triangle is 2 right angles, and given diagrams of 4-, 5-, and 6-sided polygons divided into triangles, describe the relationship between the number of sides of any polygon and the sum of its angles in right angles.

**Connect**

Connect new knowledge to existing knowledge; make connections between different elements of knowledge and related representations; make linkages between related mathematical ideas or objects.

Grade 8 example: A triangle ABC has sides  $AB = 3\text{cm}$ ,  $BC = 4\text{cm}$ , and  $CA = 5\text{cm}$ . Which of these is the area of the triangle:  $6\text{ cm}^2$ ,  $7.5\text{ cm}^2$ ,  $10\text{ cm}^2$ , or  $12\text{ cm}^2$ ?

**Synthesize/Integrate**

Combine (disparate) mathematical procedures to establish results; combine results to produce a further result.

Grade 4 example: Solve a problem for which one of the key pieces of information must first be obtained from a table.

Grade 8 example: Combine results obtained from two distinct graphs to solve a problem.

**Solve Non-routine Problems**

Solve problems set in mathematical or real-life contexts where target students are very unlikely to have encountered closely similar items; apply mathematical procedures in unfamiliar contexts.

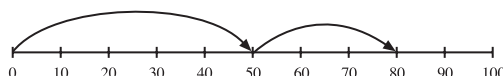
Grade 4 example: In a certain country the people write numbers as follows: 11 is written as  $\nabla\nabla\Phi$ , 42 is  $\square\square\Phi\Phi$ , and 26 is  $\square\nabla\Phi$ . How do people in this country write 37?

Grade 8 example: Given data and conditions in advertisements for competing products, select relevant data and find ways to make value comparisons valid in determining which product is most suitable in a particular context.

**Justify/Prove**

Provide evidence for the validity of an action or the truth of a statement by reference to mathematical results or properties; develop mathematical arguments to prove or disprove statements, given relevant information.

Grade 4 example:  $50 + 30 = 80$ . Use the number line below to show that this sentence is true. (Students to put in links or mark appropriately in some other way.)



Grade 8 example: Show that the sum of any two odd numbers is an even number.

## Communicating Mathematically

Communicating mathematical ideas and processes is another set of skills that is seen as important for many aspects of living and fundamental to the teaching and learning of the subject. Representing, modeling, and interpreting, for example, are aspects of communication. While communication is an important outcome of mathematics education, it is not included as a separate cognitive domain. Rather, it may be thought of as an overarching dimension across all mathematics content areas and processes. Communication is fundamental to each of the other categories of *knowing facts and procedures*, *using concepts*, *solving routine problems*, and *reasoning*, and students' communication in and about mathematics should be regarded as assessable in each of these areas.

Students in TIMSS may demonstrate communication skills through description and explanation, such as describing or discussing a mathematical object, concept, or model. Communication also occurs in using mathematical terminology and notation; demonstrating the procedure used in simplifying, evaluating, or solving an equation; or using particular representational modes to present mathematical ideas. Communication is involved in explaining why a particular procedure or model has been used, and the reason for an unexpected or anomalous result. While describing and explaining are not explicitly listed as behaviors in the framework document, items across a wide range of content and processes will require these communication skills. Students could be asked to describe or explain why they chose a particular method, why they made a particular response, and so on.

## Guidelines for Calculator Use

Although technology in the form of calculators and computers can help students learn mathematics, it should not be used to replace basic understanding and competencies. Like any teaching tool, calculators need to be used appropriately, and policies for their use differ across the TIMSS countries. Also, the availability of calculators varies widely. It would not be equitable to require calculator use when students in some countries may never have used them. Similarly, however, it is not equitable to deprive students of the use of a familiar tool. Thus, after considerable debate on this issue, beginning with TIMSS 2003 calculators are permitted but not required for newly developed grade 8 assessment materials.

The aim of the TIMSS guidelines for calculator use is to give students the best opportunity to operate in settings that mirror their classroom experience. Thus, if students are used to having calculators for their classroom activities, then the country should encourage students to use them during the assessment. On the other hand, if students are not used to having calculators or are not permitted to use them in their daily mathematics lessons, then the country need not permit their use. In developing the new assessment materials, every effort will be made to ensure that the test questions do not advantage or disadvantage students either way – with or without calculators.

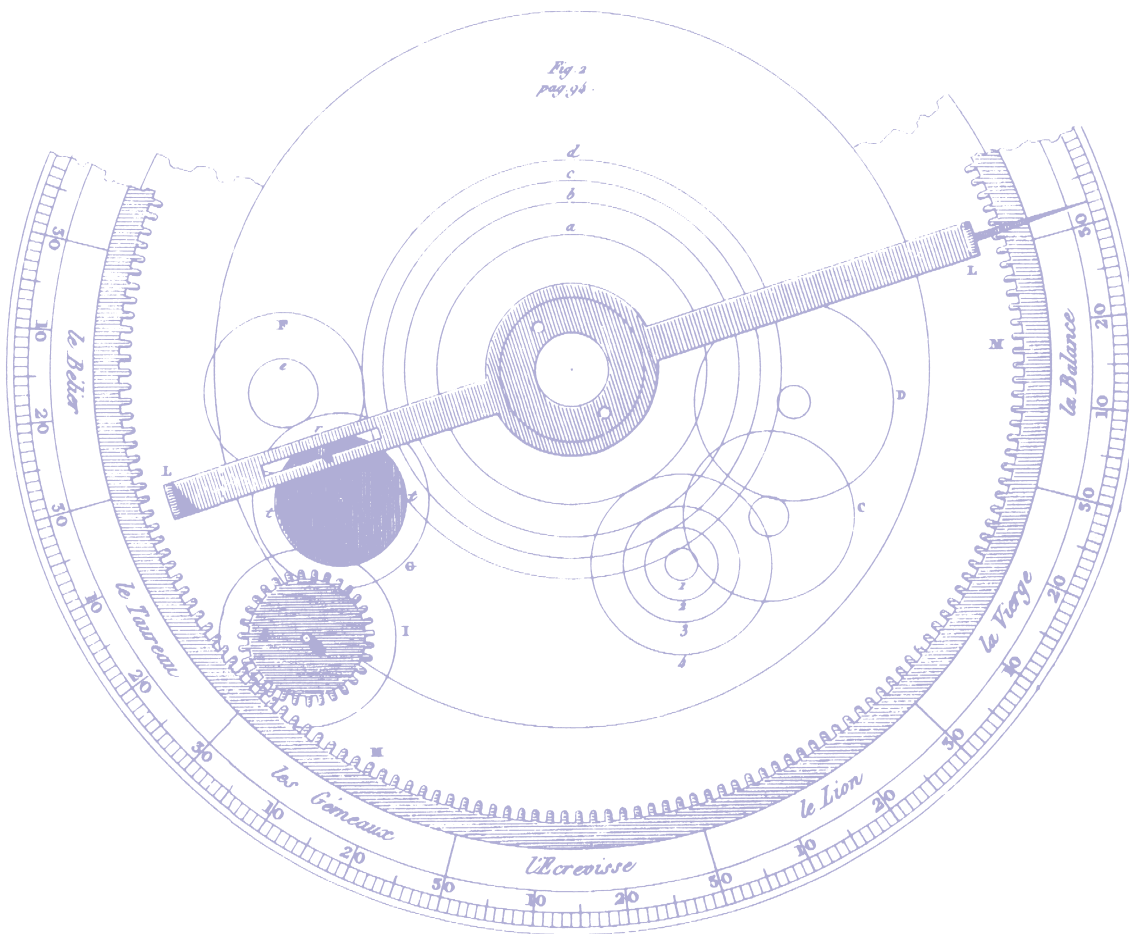
Students at grade 4 will not be permitted to use calculators. Since calculators were not permitted at grade 8 in the 1995 and 1999 assessments, test administration procedures will ensure that they are not available for items from those assessments used to measure trends.



# 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.<sup>1</sup> 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 assess-

ment 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.<sup>2</sup>

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
<b>Science Content Domains</b>		
Life Science	45%	30%
Physical Science	35%	*
Chemistry	*	15%
Physics	*	25%
Earth Science	20%	15%
Environmental Science	*	15%
<b>Science Cognitive Domains</b>		
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.

<sup>1</sup> 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.)

<sup>2</sup> 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.<sup>3</sup> 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.<sup>4</sup> Direct mapping of the trend items from 1995 and/or 1999 onto the science content domains defined in this framework 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<sup>5</sup>

### 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).

<sup>5</sup> 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.





## 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 physi-

cal 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<sup>6</sup>

#### 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.

<sup>6</sup> 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, reforestation).
- 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

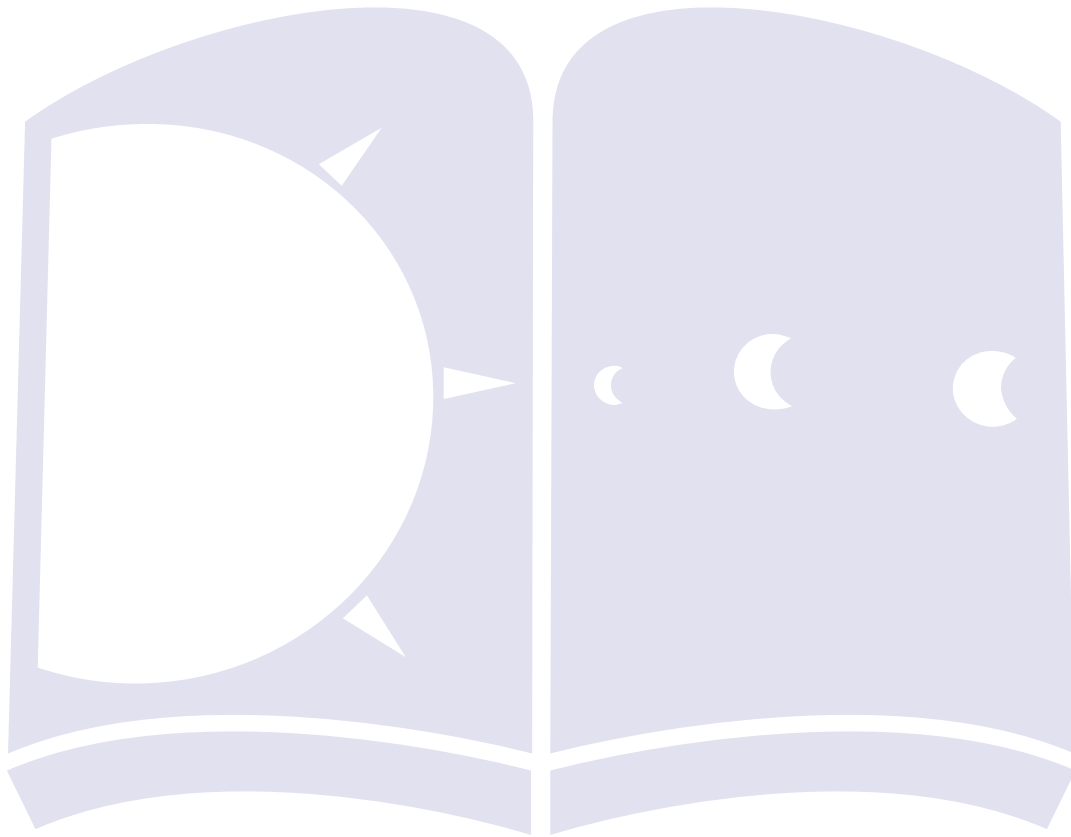
The TIMSS science framework is based on the idea of science as a process used to learn about the physical world that involves observation, description, investigation, and explanation of natural phenomena. As such, it includes both demonstration of content knowledge and the ability to apply and communicate 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 knowl-

edge 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

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

<b>Illustrate with Examples</b>	Support or clarify statements of facts/concepts with appropriate examples; identify or provide specific examples to illustrate knowledge of general concepts.
<b>Compare/Contrast/Classify</b>	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.
<b>Represent/Model</b>	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).
<b>Relate</b>	Relate knowledge of underlying biological and physical concepts to the observed or inferred properties/behaviors/uses of objects, organisms, and materials.
<b>Extract/Apply Information</b>	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.

**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:<sup>7</sup>

- 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

<sup>7</sup> 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.

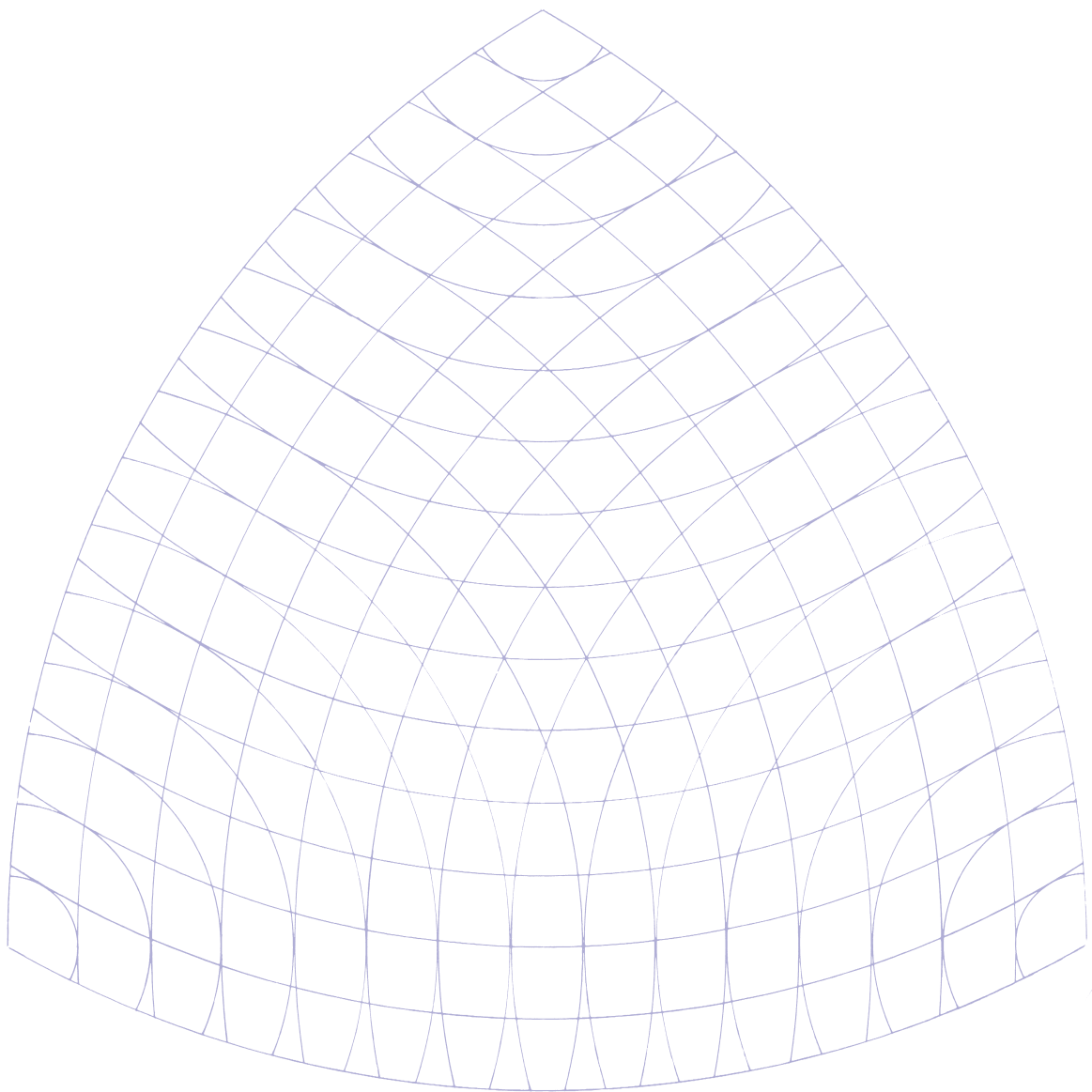
The assessment of both fourth- and eighth-grade students' ability to provide explanations based on evidence from scientific investigations provides another measure of their understanding and application of related science concepts. By the eighth grade, it is expected that students will be able to formulate 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.



# **Contextual Framework**



# Contextual Framework

## Overview

For a fuller appreciation of what the TIMSS achievement results mean and how they may be used to improve student learning in mathematics and science, it is important to understand the contexts in which students learn. In addition to testing students' achievement in mathematics and science, TIMSS collects a range of information about the contexts for learning these subjects. The Contextual Frameworks encompasses five broad areas:

- Curriculum
- Schools
- Teachers and Their Preparation
- Classroom Activities and Characteristics
- Students

In particular, TIMSS examines the curricular goals of the education system and how the system is organized to attain those goals; the educational resources and facilities provided; the teaching force and how it is educated, equipped, and supported; classroom activities and characteristics; home support and involvement; and the knowledge, attitudes, and predisposition that students and teachers themselves bring to the educational enterprise. Just as the mathematics and science frameworks describe what should be assessed in those areas, the contextual framework identifies the major characteristics of the educational and social contexts that will be studied with a view to improving student learning.

## The Curriculum

Building on IEA experience, the TIMSS contextual framework addresses five broad aspects of the intended curriculum in mathematics and science, from its formulation to its implementation.

Curriculum development involves consideration of the society which the education system serves, the needs and aspirations of the students, the nature and function of learning, and the formulation of statements on what learning is important. In understanding the intended curriculum, it is important to know who makes the curricular decisions, what types of decisions are made, and how decisions are communicated to the education community.

**Formulating the Curriculum.** When formulating a curriculum, developers take its situational context into account. Contextual considerations include the resources – national, regional, and local – available for education; the value society places on mathematics and science education; societal attitudes towards mathematics and science; and the degree to which educational attainment, broadly or narrowly defined, is linked to societal well-being and the nation's economic health.

**Scope and Content of the Curriculum.** Curricular documents define and communicate expectations for students in terms of the knowledge, skills, and attitudes to be acquired or developed through their formal education. The nature and extent of the mathematics and science goals to be attained in school are important to policy makers and curriculum specialists in all countries. Also important is how these goals are kept current in the face of scientific and technological advances, and how the demands and expectations of society and the workplace change.

Although mastery of the subject is a major focus of mathematics and science curricula in most countries, countries differ considerably in how the curriculum specifies that mastery should be achieved. For example, acquiring basic skills, applying mathematics to “real-life” situations, communicating mathematically, and problem solving in novel situations are approaches to teaching mathematics that have been advocated in recent years and are used to varying degrees in different countries.<sup>1</sup> In science, focus on the acquisition of basic scientific facts, the understanding and application of scientific concepts, emphasis on designing and conducting investigations, communicating scientific explanations, and the adoption of a thematic approach are teaching strategies that are recommended in some countries more so than in others.<sup>2</sup>

**Organization of the Curriculum.** The way the education system – national, regional, and local – is organized has a significant impact on students’ opportunities to learn mathematics and science. At the school level, the relative emphasis on and amount of time specified for mathematics, science, and other subjects up through various grade levels can greatly affect such opportunities. Practices such as tracking, streaming, or setting can expose students to different curricula. In science, teaching the major components of science as separate subjects can result in different experiences for students compared with the science-as-single-subject approach.

**Monitoring and Evaluating the Implemented Curriculum.** Many countries have systems in place for monitoring and evaluating the implementation of curriculum and for assessing the status of their education systems. Commonly used methods include standardized tests, school inspection, and audits. Policy makers may use influences external to the school, for example national or regional standardized tests, to prescribe the implementation of the curriculum. Policy makers may also work collaboratively with the school community (or selected subpopulations) to develop, implement, and evaluate the curriculum.

**Curricular Materials and Support.** Apart from the use of standardized tests, inspections, and audits, countries can employ a range of other strategies to facilitate the implementation of the intended curriculum. These include training teachers in the content and pedagogic approaches specified in the curriculum. Such training may be an integral part of the teacher education curriculum, or it may be included in professional development programs. The implementation of the curriculum can be further supported through the development and use of teaching materials, including textbooks, instructional guides, and ministerial notes, that are specifically tailored to the curriculum.

- 1 Mullis, I.V.S., et al (2000), *TIMSS 1999 International Mathematics Report: Findings from IEA's Repeat of the Third International Mathematics and Science Study at the Eighth Grade*, Chestnut Hill, MA: Boston College.
- 2 Martin, M.O., et al (2000), *TIMSS 1999 International Science Report: Findings from IEA's Repeat of the Third International Mathematics and Science Study at the Eighth Grade*, Chestnut Hill, MA: Boston College.



## The Schools

In the TIMSS contextual model, the school is the institution through which the goals of the curriculum are implemented. Accepting that a high-quality school is not simply a collection of discrete attributes but rather a well-managed integrated system where each action or policy directly affects all other parts, TIMSS focuses on a set of indicators of school quality that research has shown to characterize such schools.

**School Organization.** Whether as part of a larger national, regional, or local education system or because of decisions made at the school level, science and mathematics instruction is carried out within certain organizational constraints. For example, the time in terms of days per year and minutes per day allotted for schooling, and in particular for mathematics and science instruction, can influence achievement. It is also important to know about different types of schools, since some schools may specialize. For example, in countries with tracking, the school may be designated to emphasize either an academic or a vocational curriculum.

**School Goals.** Research on effective schools suggests that successful schools identify and communicate ambitious but reasonable goals and work towards implementing them. Commonly articulated school goals include literacy, academic excellence, personal growth, good work habits, and self-discipline.

**Roles of the School Principal.** The school principal typically fulfills multiple leadership roles. These include ensuring that the school, its operation, and its resources are managed optimally. The principal may guide the school in setting directions, seeking future opportunities, and building and sustaining a learning environment.

He or she can facilitate the development, articulation, implementation, stewardship, and evaluation of a model of learning that is shared and supported by the school community. The principal may actively advocate, nurture, and sustain a positive school culture and an education program conducive to student learning and teachers' professional growth. The primary roles that the principal fulfills provide a useful indication of the administrative and educational structure of the school.

**Resources to Support Mathematics and Science Learning.** Curriculum implementation can be facilitated by allocating the facilities, materials, and equipment necessary to achieve the specified learning goals. Results from TIMSS indicate that students in schools that are well-resourced generally have higher achievement than those in schools where shortages in resources affect capacity to implement the curriculum. Two types of resources affect implementation of the curriculum. General resources include teaching materials, budget for supplies, school buildings and supplies, heating/cooling and lighting systems, and classroom space. Subject-specific resources may include computers, computer software, calculators, laboratory equipment and materials, library materials, and audio-visual resources.



**Parental Involvement.** Research has shown that effective schools have a high degree of congruence between parental, student, and school expectations. Parental involvement in school activities can be an important source of support in working to achieve student and school goals, and in forming positive student attitudes. Data from TIMSS reveal that schools with a high degree of parental involvement, particularly in the areas of checking homework, volunteering for field trips, and fund raising, generally have higher academic performance than those that do not.

**Disciplined School Environment.** Although a safe and orderly school environment does not itself guarantee high levels of student achievement, student learning can be more difficult in schools where student discipline is a problem, where students are regularly absent or late to class, or where they fear injury or loss of personal property.

## Teachers and Their Preparation

Teachers are the primary agents of curriculum implementation. Regardless of how closely prescribed the curriculum, or how explicit the textbook, it is the actions of the teacher in the classroom that most affect student learning. What teachers know and are able to do is of critical importance. A recent review suggests that to ensure excellence, teachers should have high academic skills, teach in the field in which they received their training, have more than a few years of experience, and participate in high-quality induction and professional development programs.<sup>3</sup>

**Academic Preparation and Certification.** Aware of the key role played by the teacher in implementing the curriculum, many countries are focusing on improving education for aspiring teachers, particularly the mathematics and science prerequisites necessary for effective teaching in these subject areas.

The methods by which teachers are certified to practice vary widely across countries. They include the completing of specified courses, passing exams, and serving a probation period. In some countries there may be alternative methods of being certified, especially in subject areas with a shortage of teachers.

The relative emphasis on content knowledge and pedagogic approach of trainee teachers, and how teacher education programs keep abreast of the changes brought about by rapid advances in science and technology, are important features of teacher preparation programs. Methods used to enable teachers to become broadly educated, reflective, professional educators with a lifelong positive attitude toward

3 Mayer, D.P., Mullens, J.E., and Moore, M.T. (2000), *Monitoring School Quality: An Indicators Report*, NCES 2001-030, Washington, DC: National Center for Education Statistics.

learning may also be an important facet of teacher education. Collaboration between universities and schools and the use of teacher competency standards may also contribute to good academic preparation to teach. Innovative approaches to teacher education that capitalize on the opportunities provided by the Internet and modern information technology in general may also be important in preparing teachers.

**Teacher Recruitment.** The growth of technology in recent years has meant that education systems must compete with industry for the best mathematics and science candidates. The rapid advancement of mathematics and science necessitates that prospective teachers be capable of keeping pace with these fast-evolving fields. This calls for the attraction of top-level applicants who are capable of adjusting their teaching to the evolving demands of modern education. Employment contracts, incentives such as free college education, and other benefits are some methods used to recruit suitable candidates.

**Teacher Assignment.** TIMSS has shown that there is considerable variation across countries in the percentage of students taught mathematics or science by teachers with a major in the subject. While there can be both problems and benefits associated with teachers teaching “out of field,” of interest is how such teachers acquire the subject-specific knowledge they need in order to teach effectively.

**Teacher Induction.** The transition from university to a school teaching position can be difficult. Consequently, in many countries a large percentage of new teachers leave the profession after only a few years of teaching.<sup>4</sup> The extent to which schools take an active role in the acculturation and transition of the new teacher may

be important. Mentoring, the modeling of good teacher practice by peers, professional development activities, and induction programs designed by experienced teachers within the school may be important to aid the beginning teacher.

**Teacher Experience.** Studies have suggested that students learn more when taught by experienced teachers than they do when taught by teachers with just a few years’ experience. However, the relationship between experience and achievement may be affected by many factors. For example, assignment policies within schools may result in the more highly skilled teachers getting specific classes, or older teachers getting higher-tracked classes. The need for long-serving teachers to engage in professional development, and the extent to which they do so, can also impact their effectiveness.

**Teaching Styles.** Researchers have identified a number of teaching styles.<sup>5</sup> Information on how teachers allot their time to such activities as lecture-style presentation, teacher-guided student practice, re-teaching and clarifying content and procedures, small group work, and independent practice, for example, provides useful evidence about the predominant pedagogic approaches in the classroom. Student reports of how much time they spend being shown how to do mathematics and science, working from worksheets or textbooks, working on projects, or discussing homework are also important indicators of teaching style.

TIMSS international reports have shown that the use of the board was an extremely common presentation mode in both mathematics and science classes. Other presentation modes, including teacher use of an overhead projector, teacher use of a computer to demonstrate ideas, student use of the board, and student use of an overhead projector are less frequent.

4 Moskowitz, J. and Stephens, M., eds. (1997), *From Students of Teaching to Teachers of Students: Teacher Induction Around the Pacific Rim*, Washington, DC: U.S. Department of Education.

5 Grasha, A. (1996), *Teaching with Style*, Pittsburgh, PA: Alliance Publishers.

**Professional Development.** Although investment in pre-service education of prospective mathematics and science teachers will likely pay dividends in the long run, efforts to strengthen the knowledge and skills of existing teachers must rely on professional development opportunities. Unless teachers participate in ongoing professional development activities, they risk being uninformed about key developments in education and in their subject areas that have occurred since they received their initial training. There is special concern that without access to high-quality professional development, teachers will be unable to benefit from the advances made in information technology. Consequently, teachers need to learn how to use computers and the Internet in their classrooms to good advantage.

The professional development of teachers is of central importance to any attempts to change or reform an education system. Teacher development activities include expanding an individual's repertoire of well-defined and skillful classroom practices through training, observation of or by other teachers, immersion or internship activities, teacher task forces, teacher collaboratives, subject-matter associations, collaborations targeted at specific initiatives, and special institutes and centers.<sup>6</sup> The frequency and type of development activities, the level of intellectual, social, and emotional engagement, and the degree to which the program is grounded in the larger contexts of school practice and the educational needs of the students are important indicators of successful teacher development programs.<sup>7</sup>

## Classroom Activities and Characteristics

Although the school provides the general context for learning, it is in the classroom setting and through the guidance of the teacher that most teaching and learning take place. The classroom setting here is taken to include work assigned in the classroom but completed elsewhere, such as homework, library assignments, or field work. Aspects of the implemented curriculum that are most readily studied in the classroom include the curriculum topics that are actually addressed, the pedagogic approaches used, the materials and equipment available, and the conditions under which learning takes place, including the size and composition of the class and the amount of classroom time devoted to mathematics and science education.

**Curriculum Topics Taught.** A major focus of the implemented curriculum is the extent to which the mathematics and science topics in the TIMSS frameworks are covered in the classroom. TIMSS addresses this question by asking the mathematics and science teachers of the students assessed to indicate whether each of the topics tested had been covered in class, either in the current or previous years, and how many class periods were devoted to the topic. TIMSS characterizes the coverage and level of rigor of the mathematics and science courses taught in participating countries by describing the main focus of the work in the classes being tested.

6 Mullis, I.V.S., et al (2001), *Mathematics Benchmarking Report, TIMSS 1999 – Eighth Grade: Achievement for U.S. States and Districts in an International Context* (pp. 237-244), Chestnut Hill, MA: Boston College; Martin, M.O., et al (2001), *Science Benchmarking Report, TIMSS 1999 – Eighth Grade: Achievement for U.S. States and Districts in an International Context* (pp. 253-260), Chestnut Hill, MA: Boston College.

7 Little, J. W. (1993), "Teachers' Professional Development in a Climate of Educational Reform," *Educational Evaluation and Policy Analysis*, 15(2), 129-51, Washington, DC: American Educational Research Association.

**Time.** The amount of classroom instructional time devoted to mathematics and science is an important aspect of curricular implementation. TIMSS has shown that the efficient use of that time and the disruptive effects of outside interruptions are aspects related to effective teaching.

**Homework.** The reasons for assigning homework as well as the amount and types assigned are important pedagogic considerations. Homework serves to increase the time devoted to a subject. It can be used to reinforce and/or extend the concepts developed in a lesson.

**Assessment.** TIMSS results show that teachers devote a fair amount of time to student assessment, whether as a means of gauging what students have learned to guide future learning, or for providing feedback to students, teachers, and parents. The frequency of various types of assessment and the weight given to each are important indicators of teaching and school pedagogy. Types of assessment include external standardized tests, teacher-made tests requiring explanations, teacher made objective tests, homework assignments, projects or practical exercises, students' responses in class, and observations of students.

**Classroom Climate.** Classroom climate, or environment, characterizes the ambience, tone, atmosphere, and ethos of the classroom.<sup>8</sup> Student and teacher perceptions of the classroom environment influence learning behaviors and outcomes.<sup>9</sup> The extent to which students participate actively and attentively in class, the degree to which they like and interact positively with each other, the relationship between students and teacher, and the organizational clarity of the class are all important facets of classroom climate.

**Information Technology.** The computer is rapidly transforming education as students prepare to enter the technological workforce. Information technology saves time and, more important, gives students access to powerful new ways to explore concepts at a depth that has not been possible in the past. Computers can trigger a new enthusiasm and motivation for learning, enable students to learn at their own pace, and provide students with access to vast information sources via the Internet.

While computers are undoubtedly changing the educational landscape, schools operate with finite resources, and the allocation of money, time, and space for technology may divert scarce resources from other priorities, such as increasing teacher salaries, teachers' professional development, lowering student-teacher ratios, and the provision of teaching resources including laboratory equipment and space. Further, the sustainability of school computer systems and the continuity of support staffing may be as important as the acquisition of the computers.

The effective and efficient use of computers requires suitable training of teachers, students, and school staff. Factors limiting computer use include the lack of appropriate software and hardware, software not congruent with the curriculum, lack of teacher training and support, and lack of funding for computer repair and maintenance.

The rapid growth in access by students in schools and at home to the informational resources of the Internet has the potential to revolutionize mathematics and science learning like nothing before. There is evidence to show that multiple layers of access to the Internet, for example at schools, in libraries, and at home, is important. For countries in which students do have ready access to the Internet, it is important that they be taught how to use the information, and how to evaluate its truth or worth.

8 Fraser, B.J. and Walberg, H.J. (1991), *Educational Environments: Evaluation, Antecedents and Consequences*, New York, NY: Pergamon Press.

9 Lersbæk, A. W. and Jinks, J. L. (1999), "Self-Efficacy Theory and Learning Environment Research," *Learning Environments Research*, 2, 157-167, Boston, MA: Kluwer Academic Publishers.

Besides giving students access to the Internet, computers can serve a number of other educational purposes. While initially limited to learning drills and practice, they are now used in a variety of ways including tutorials, simulations, games, and applications. New software enables students to pose their own problems and explore and discover mathematics and scientific properties on their own. Computer software for modeling and visualization of ideas can open a whole new world to students and help them connect these ideas to their language and symbol systems.

**Calculator Use.** Calculator use varies widely among, and even within, countries, but generally is increasing steadily as cost becomes less of an impediment and mathematics curriculum evolves to take calculators into account. Many countries have policies regulating the access to and use of calculators, especially at the earlier grade levels. What those policies are and how they change over the grades can be important in understanding the curriculum.

Calculators can be used in exploring number recognition, counting, and the concepts of larger and smaller. They can allow students to solve numerical problems faster by eliminating tedious computation and thus become more involved in the learning process. Graphing calculators make it possible to switch from equations to graphs to data analysis, enabling problems to be approached either visually or numerically. How best to make use of calculators, and what role they should have, continue to be questions of importance to mathematics curriculum specialists and teachers.

**Emphasis on Investigations.** The emphasis on conducting projects and investigations varies widely across countries. An exploration of the frequency and the nature of a task can illuminate the learning at issue. In science, practical investigations are often an integral part of the learning process. The extent to which these activities are demonstrated by the teacher and conducted by the students also shows variation across countries.

**Class Size.** Class size can serve as an economic indicator, with smaller classes signifying greater wealth. However, smaller class sizes may be the result of government policies that cap class size. Further, class size may reflect selective resource allocation to, for example, special needs or practical classes. Whatever the reason for the class size, there is little doubt that it affects how teachers implement the curriculum.

## The Students

**Home Background.** Students come to school from different backgrounds and with different experiences. The number of books in the home, availability of a study desk, the presence of a computer, the educational level of the parents, and the extent to which students speak the language of instruction have been shown to be important home background variables, indicative of the family's socio-economic status, that are related to academic achievement. Also important are the attitudes of parents and their involvement in their child's education. The extent to which employment, sports and recreational pastimes, and other activities occupy the student's time may also affect learning.

**Prior Experiences.** Students engage with mathematics and science with a host of prior experiences that affect their preparedness to learn. These include past learning in the subject, positive or negative interactions with past teachers, and the difficulty or ease with which the subject matter was learned.

**Attitudes.** Creating a positive attitude in students toward mathematics and science is an important goal of the curriculum in many countries. Students' motivation to learn can be affected by whether they find the subject enjoyable, place value on the subject, and think it is important in the present and for future career aspirations. In addition, students' motivation can be affected by the degree to which they attribute success and failure in the subject to internal or external factors.

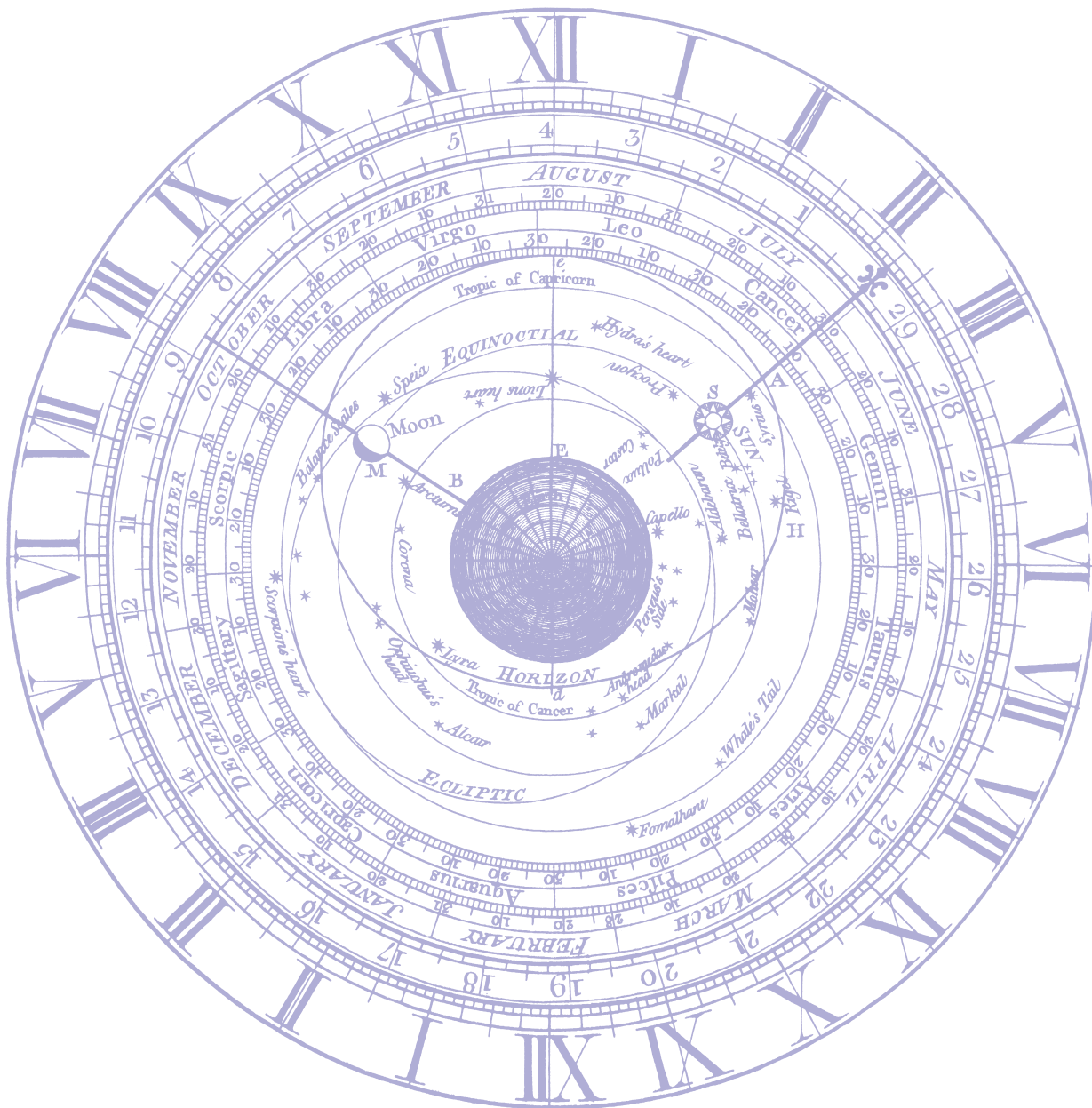






# Assessment Design





# Assessment Design

## Scope of the Assessment

To measure students' achievement in mathematics and science at the fourth and eighth grades and gather information about the contexts for achievement, the TIMSS 2003 assessment includes written tests of mathematics and science and a series of questionnaires focusing on contexts for student learning in those subjects. This chapter describes the design of the assessment and specifications for operationalizing the components of the study. A characteristic of TIMSS is that it includes both mathematics and science, with each student completing parts of the assessment in both subjects.

The TIMSS frameworks have broad coverage goals, and consequently the TIMSS Expert Panel found that a valid assessment of the mathematics and science described in the frameworks would require a substantial pool of assessment items and extensive testing time – at least seven hours at eighth grade (mathematics and science together) and more than five and one half hours at fourth grade. While the assessment material that can be presented in that time should provide good coverage of the mathematics and science students encounter at school and in their everyday lives, it is not reasonable to expect each student to answer the entire pool of test items.

## Dividing up the Item Pool

Since the testing time required by the entire assessment item pool greatly exceeds the time available for testing individual students, TIMSS divides the assessment material among students. The TIMSS approach, based on matrix sampling techniques, involves dividing the item pool among a set of student booklets, with each student completing just one booklet. Items are assigned to booklets in such a way

that a comprehensive picture of the achievement of the entire student population can be assembled from the combined responses of individual students to individual booklets.

Based on past experience with TIMSS, National Research Coordinators from participating countries agreed that the testing time for any one student should not be increased from previous assessments. Thus, as in the past, the assessment time for each student booklet needed to fit into approximately 90 minutes for eighth grade and approximately 65 minutes for fourth grade. An additional 15-30 minutes for a student questionnaire is also planned at each grade level.

To facilitate the creation of the student booklets, the items in the assessment pool are first grouped into clusters or blocks of items. These then become the building blocks from which the student booklets will be assembled. In TIMSS 2003, the total item pool at each grade level (seven hours of testing at eighth grade and more than five and one half hours at fourth grade) will be divided into 28 blocks, 14 in mathematics and 14 in science, as shown in Exhibit 6. Each block will contain mathematics items only or science items only. Eighth-grade

**Exhibit 6:** General Design of the TIMSS 2003 Matrix-Sampling Blocks

Source of Items	Mathematics Blocks	Science Blocks
Trend Items (TIMSS 1995 or 1999)	M1	S1
Trend Items (TIMSS 1995 or 1999)	M2	S2
Trend Items (TIMSS 1995 or 1999)	M3	S3
Trend Items (TIMSS 1999)	M4	S4
Trend Items (TIMSS 1999)	M5	S5
Trend Items (TIMSS 1999)	M6	S6
New Replacement Items	M7	S7
New Replacement Items	M8	S8
New Replacement Items	M9	S9
New Replacement Items	M10	S10
New Replacement Items	M11	S11
New Replacement Items	M12	S12
New Replacement Items	M13	S13
New Replacement Items	M14	S14

blocks will contain 15 minutes of assessment items and fourth-grade blocks 12 minutes; otherwise the general design is identical at both grade levels. The blocks containing mathematics items will be labeled M1 through M14 and the science items S1 through S14.

Since TIMSS in 2003 and in later cycles plans to provide an up-to-date assessment of student achievement in mathematics and science while also measuring trends in achievement since 1995 and 1999,<sup>1</sup> the TIMSS design for 2003 includes items from earlier assessments to measure trends as well as innovative new problem-solving and inquiry items and replacement items for those released into the public domain. Of the 14 item blocks in each subject, six (blocks 1 through 6) contain secure items from earlier TIMSS assessments to measure trends,<sup>2</sup> and eight (blocks 7 through 14) contain new replacement items.

Although calculators were not permitted in 1995 or 1999, calculators may be used in the eighth-grade assessment at the discretion of each participating country.<sup>3</sup> Calculators will not be permitted in the fourth-grade assessment.

## Block Design for Student Booklets

In choosing how to distribute assessment blocks across student booklets, the major goal was to maximize coverage of the framework while ensuring that every student responded to sufficient items to provide reliable measurement of trends in both mathematics and science. A further goal was to ensure that trends in the mathematics and science content areas could be measured reliably. To enable linking among booklets, at least some blocks had to be paired with others. Since the number of booklets can become very large if each block is to be paired with all other blocks, it was necessary to choose judiciously among possible block combinations to keep the number of student booklets to a minimum.

The decision to allow calculator use at the eighth grade for the first time in 2003 also had an impact on the booklet design. Since calculators were not allowed in 1995 or 1999 but will be permitted in the eighth-grade assessment in 2003, it was necessary in order to safeguard the measurement of trend to arrange the item blocks in the booklets so that calculators could be used for the new assessment items, but not for the trend items. Accordingly, the trend blocks were placed in the first part of each booklet, to be completed without calculators before the break. However, two mathematics trend blocks (M5 and M6) and two science trend blocks (S5 and S6) also were placed in the second part of one booklet each.

In the TIMSS 2003 design, the 28 assessment blocks will be distributed across 12 student booklets (see Exhibit 7). The same booklet design will be used at both fourth and eighth grade, although the eighth-grade blocks will contain 15 minutes of assessment items and the fourth grade blocks 12 minutes. Each student booklet will consist of six blocks of items. Half the booklets will contain four mathematics

1 TIMSS will measure trends at the eighth grade from 1995 and 1999, but at the fourth grade from 1995 only, since the TIMSS 1999 assessment was conducted at the eighth grade but not the fourth grade.

2 The six trend blocks for the TIMSS 2003 eighth-grade assessment will contain secure items from both the 1995 and 1999 TIMSS assessments, with all trend items from 1995 being placed in blocks 1 through 3. Because there are no fourth-grade items from 1999, trend blocks 4 through 6 for the fourth-grade assessment will consist of new items. In order to create balanced blocks, some new items are also included in blocks 1 through 6 at the eighth grade.

3 To avoid introducing bias into the measurement of trends, calculators will be used only with items new in 2003, and not with items measuring trends.

blocks and two science blocks, and the other half will contain four science blocks and two mathematics blocks. All student booklets will contain at least two blocks of mathematics items and two blocks of science items, so that all students will respond to enough items to provide reliable measurement of trends in both subjects. In addition, the students that are assigned booklets with four mathematics blocks (half of the student sample) will provide sufficient data to measure trends in the mathematics content areas, and the students assigned the booklets with four science blocks will provide data on trends in the science content areas.

As may be seen from Exhibit 7, students assigned Booklet 1 will complete four blocks of mathematics items, M1, M2, M5, and M7, and two blocks of science items, S6 and S7. The items in blocks M1, M2, M5, and S6 will be trend items from earlier TIMSS assessments, while those in M7 and S7 will be new items. Students assigned Booklet 2, 3, 4, 5, or 6 will also have four mathematics blocks and two science blocks, although the blocks will vary from booklet to booklet, as shown in Exhibit 7. Students assigned Booklets 7 through 12 each will complete four blocks of science and two blocks of mathematics items. To enable linking between booklets, all blocks will appear in at least two of the 12 booklets, with the trend blocks appearing in three or four of the booklets. Countries participating in TIMSS will aim for a sample of at least 4,500 students to ensure that there are enough respondents for each item. The 12 student booklets will be rotated among the students in each sampled class, so

**Exhibit 7:** TIMSS 2003 Booklet Design – Fourth and Eighth Grade

Student Booklet	Assessment Blocks					
Booklet 1	M1	M2	S6	S7	M5	M7
Booklet 2	M2	M3	S5	S8	M6	M8
Booklet 3	M3	M4	S4	S9	M13	M11
Booklet 4	M4	M5	S3	S10	M14	M12
Booklet 5	M5	M6	S2	S11	M9	M13
Booklet 6	M6	M1	S1	S12	M10	M14
Booklet 7	S1	S2	M6	M7	S5	S7
Booklet 8	S2	S3	M5	M8	S6	S8
Booklet 9	S3	S4	M4	M9	S13	S11
Booklet 10	S4	S5	M3	M10	S14	S12
Booklet 11	S5	S6	M2	M11	S9	S13
Booklet 12	S6	S1	M1	M12	S10	S14

that approximately equal proportions of students respond to each booklet.

As summarized in Exhibit 8, each student will complete just one of the 12 student booklets and a student questionnaire. The individual student response burden for the assessment is similar to TIMSS in 1995 and 1999, i.e., 72 minutes for the assessment and 30 minutes for the questionnaire at fourth grade (slightly more than the 65 minutes for the assessment in 1995), and 90 minutes and 30 minutes, respectively, at eighth grade. Students may not use calculators while working on Part 1 of the student booklet, as this

**Exhibit 8:** TIMSS 2003 Student Testing Time

Activity	Fourth Grade	Eighth Grade
Student Booklet – Part 1 (Calculators Not Permitted)	36 minutes	45 minutes
Break		
Student Booklet – Part 2 (Calculators Permitted – 8th grade only)	36 minutes	45 minutes
Break		
Student Questionnaire	30 minutes	30 minutes

contains the trend items. Calculators may be used for Part 2 of the student booklet, but only by eighth-grade students. Calculators are not permitted in the fourth-grade assessment.

## Question Types and Scoring Procedures

Students' knowledge and understanding of mathematics and science will be assessed through a range of questions in each subject. Two question formats will be used in the TIMSS assessment – multiple-choice and constructed-response. Each multiple-choice question will be worth one point. Constructed-response questions generally will be worth one, two, or three points, depending on the nature of the task and the skills required to complete it. Extended problem-solving and inquiry tasks may require students to work with materials and manipulatives and to provide one or more extended constructed responses. Up to two-thirds of the total number of points represented by all the questions will come from multiple-choice questions. In developing assessment questions, the choice of item format will depend on the mathematics or science being assessed, and the format that will best enable students to demonstrate their proficiency.

*Multiple-Choice Questions.* Multiple-choice questions provide students with four or five response options, of which only one is correct. These questions can be used to assess any of the behaviors in the cognitive domains. However, because they do not allow for students' explanations or supporting statements, multiple-choice questions may be less suitable for assessing students' ability to make more complex interpretations or evaluations.

In assessing fourth- and eighth-grade students, it is important that linguistic features of the questions be developmentally appropriate. Therefore, the questions are written clearly and

concisely. The response options are also written succinctly in order to minimize the reading load of the question. The options that are incorrect are written to be plausible, but not deceptive. For students who may be unfamiliar with this test question format, the instructions given at the beginning of the test include a sample multiple-choice item that illustrates how to select and mark an answer.

*Constructed-Response Questions.* For this type of test item students are required to construct a written response, rather than select a response from a set of options. Constructed-response questions are particularly well suited for assessing aspects of knowledge and skills that require students to explain phenomena or interpret data based on their background knowledge and experience.

In the TIMSS assessment, constructed-response questions will be worth one, two, or three points, depending on the nature of the task and the extent of the explanation the question requires. In these questions, it is important to provide enough information to help students understand clearly the nature of the response expected.

Scoring guides for each constructed-response question describe the essential features of appropriate and complete responses. The guides focus on evidence of the type of behavior the question assesses. They describe evidence of partially correct and completely correct responses. In addition, sample student responses at each level of understanding provide important guidance to those who will be rating the students' responses. In scoring students' responses to constructed-response questions, the focus is solely on students' achievement with respect to the topic being assessed, not on their ability to write well. However, students need to communicate in a manner that will be clear to those scoring their responses.



In addition, scoring guides are designed to enable, for each item, identification of the various successful, partially successful, and unsuccessful approaches. Diagnosis of common learning difficulties in mathematics and science as evidenced by misconceptions and errors is an important aim of the study.

Since constructed-response questions constitute an important part of the assessment and are an integral part of the measurement of trends, it is very important for scoring guides to be implemented consistently in all countries and in each data collection year. To ensure consistent application of the scoring guides for trend items in the 2003 assessment, IEA has archived samples of student responses from each country; these will be used to train scorers in 2003 and to monitor consistent application.

*Score Points.* In developing the assessment, the aim is to create blocks of items that each provide, on average, about 15 score points at eighth grade and about 12 score points at fourth grade. For example, at eighth grade blocks 1 through 14 in each subject could be made up of approximately 8 multiple-choice items (1 point each), 2 or 3 short constructed-response items (1 or 2 points each), and 1 extended constructed-response item (3 points). The exact number of score points and the exact distribution of question types per block will vary somewhat. Since the blocks for the fourth-grade assessment will be designed to yield 12 rather than 15 score points, there will be fewer items but the relative proportions of different item types will be approximately the same.

## Scales for Reporting Student Achievement

TIMSS will report trends in student achievement in both the general areas of mathematics and science and in the major subject matter content areas. As each student will respond to only part of the assessment, these parts must be combined for an overall picture of the assessment results for each country. Using item response theory (IRT) methods,<sup>4</sup> individual student responses to the items related to mathematics and science will be placed on common scales that link to TIMSS results from 1995 and 1999. At the eighth grade, there will be an overall mathematics scale that will allow countries that participated in TIMSS in 1995 or 1999 to track their progress in mathematics achievement since then, and a similar scale in science overall that will provide the same information for science. At the fourth grade, the overall mathematics and science scales will link to 1995 only, since the TIMSS 1999 assessment did not include fourth grade. All students will have overall mathematics and science scores.

All student responses will contribute to the measurement of achievement in each of the mathematics and science content areas. In addition, those students assigned booklets with four blocks of mathematics items (half of the student sample) will provide the data to report on trends in mathematics content areas, while those assigned booklets with four blocks of science items (the other half) will provide data on trends in science content areas.

4 For a description of the TIMSS scaling techniques as applied to the 1999 data, see Yamamoto, K. and Kulick, E. (2000), "Scaling Methods and Procedures for the TIMSS Mathematics and Science Scales" in M.O. Martin, K.D. Gregory, and S.E. Stemler (eds.), *TIMSS 1999 Technical Report*, Chestnut Hill, MA: Boston College.

In mathematics at the eighth grade there will be five content reporting categories in 2003:

- Number
- Algebra
- Measurement
- Geometry
- Data

At fourth grade there also will be five content reporting categories in mathematics:

- Number
- Patterns, Equations, and Relationships
- Measurement
- Geometry
- Data

Eighth-grade science will have five content reporting categories:

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

At fourth grade, science will have just three content reporting categories:

- Life Science
- Physical Science
- Earth Science

Results will be reported separately for each content area and grade level.

In addition to the IRT scales that will be used to summarize achievement in mathematics and science content areas and in these subjects overall, TIMSS will report on performance in

each of the cognitive domains in terms of the average percentage of students answering items correctly in each domain. This approach may also be used to report student performance in scientific inquiry.

## Releasing Assessment Material to the Public

The data collection in 2003 will be the third in the TIMSS series of regular four-year studies, and will provide data on trends in mathematics and science achievement since 1995 and 1999. TIMSS will be administered again in 2007, 2011, and so on into the future. The design provides for releasing many of the items into the public domain as the international reports are published, while safeguarding the trend data by keeping secure a substantial proportion of the items. As items are released, new items will be developed to take their place.

According to the TIMSS design, half of the 14 assessment blocks in each subject will be released when the assessment results for 2003 are published, and half will be kept secure for use in later assessments. The released blocks will include the three blocks containing trend items from 1995, one block of trend items from 1999, and three blocks of items used for the first time in 2003.<sup>5</sup> The released items will be replaced with new items before the next survey cycle, in 2007.

## Background Questionnaires

An important purpose of TIMSS is to study the educational context within which students learn mathematics and science. To that end, TIMSS will administer questionnaires to curriculum specialists, and to the students in participating schools, their mathematics and science teachers,

<sup>5</sup> Since there are no 1999 trend items at fourth grade, four blocks of 2003 items will be released at this grade level.

and their school principals. The questions are designed to measure key elements of the curriculum as it is intended, as it is implemented, and as it is learned.

**Curriculum Questionnaires.** The curriculum questionnaires, one for mathematics and one for science, are designed to collect basic information about the organization of the mathematics and science curriculum in each country, and about the content in these subjects intended to be covered up to and including the fourth grade and between fourth and eighth grades. The National Research Coordinator in each country will be responsible for completing the questionnaires, drawing upon the knowledge and expertise of curriculum specialists and educators as necessary.

**Student Questionnaire.** This questionnaire will be completed by each student who takes the TIMSS assessment. It asks about aspects of students' home and school lives, including classroom experiences, self-perception and attitudes about mathematics and science, homework and out-of-school activities, computer use, home educational supports, and basic demographic information. The questionnaire requires 15-30 minutes to complete.

**Teacher Questionnaires.** In each school participating at the eighth grade, a single eighth-grade mathematics class will be sampled to take part in the TIMSS testing. The mathematics teacher of that class will be asked to complete a mathematics teacher questionnaire, providing information on the teacher's background, beliefs, attitudes, educational preparation, and teaching load, as well as details of the pedagogic approach used in that class. The science teacher (or teachers) of the students in that class will be asked to complete a science teacher questionnaire, which in many respects will parallel the mathematics questionnaire. Both questionnaires ask about characteristics of the class tested in TIMSS;

instructional time, materials, and activities for teaching mathematics and science and promoting students' interest in the subjects; use of computers and the Internet; assessment practices; and home-school connections. They also ask teachers their views on their opportunities for collaboration with other teachers and professional development, and for information about themselves and their education and training.

At the fourth grade, there will be a single teacher questionnaire containing questions about mathematics and science instruction and about the teachers' background that will be completed by the classroom teacher of the sampled fourth-grade class. The teacher questionnaires require 30-45 minutes of the teacher's time.

**School Questionnaire.** The principal of each school in TIMSS will be asked to respond to this questionnaire. It asks about enrollment and staffing; resources available to support mathematics and science instruction, such as the availability of instructional materials and staff; school goals and the role of the principal; instructional time; home-school connections; and school climate. It is designed to take about 30 minutes.





# Endnotes

The following is a partial list of works that were consulted in the preparation of the mathematics, science, and contextual frameworks. Although not cited, additional curriculum materials provided by a number of TIMSS 1999 countries were also consulted.

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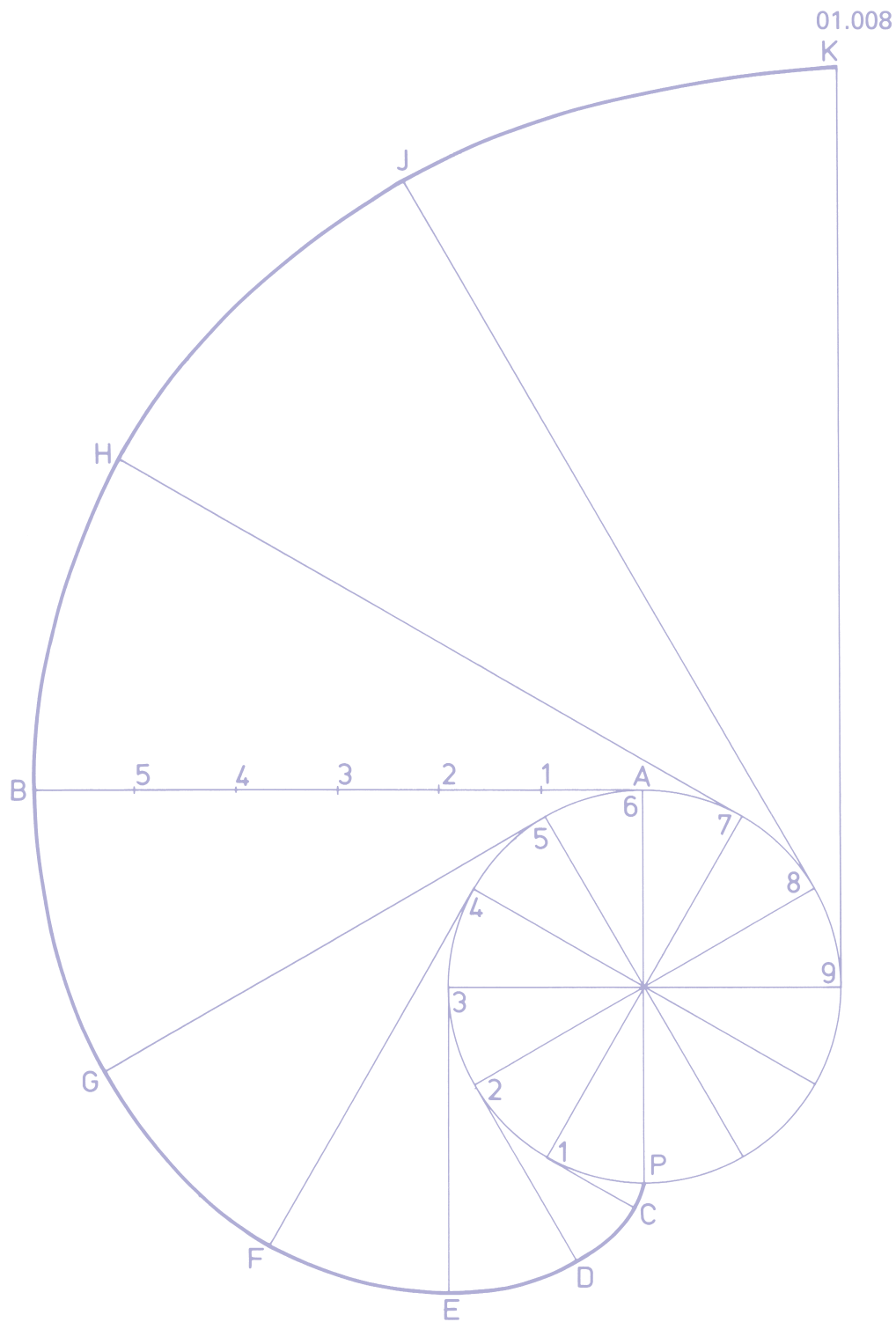
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# Appendix A

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# National Research Coordinators

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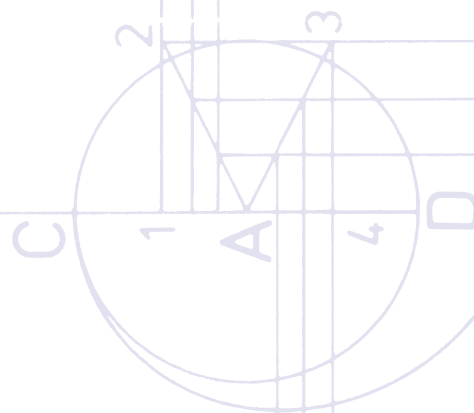
## **Yugoslavia**

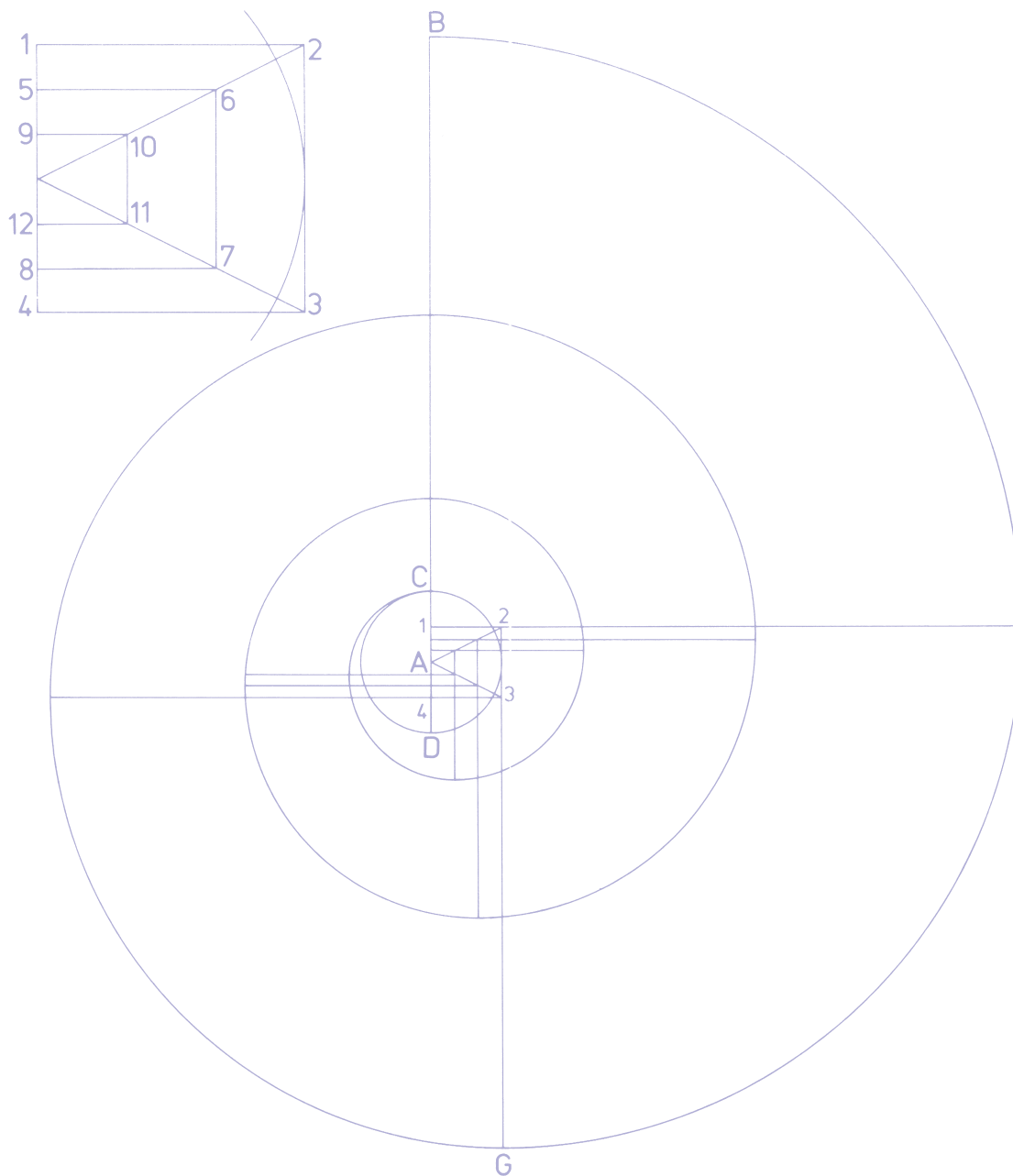
Djordje Kadijevich  
Slobodanka Milanovic-Naho  
*Institute for Educational Research*

# Appendix B

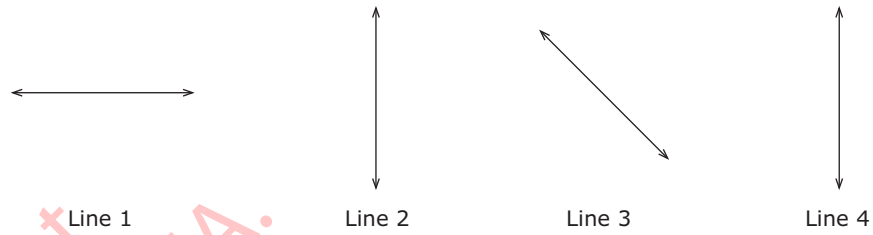
## Example Mathematics Items

Grade 4 and Grade 8





**Example Mathematics Items: Grade 4**

**1**

Which two of these lines are parallel?

- (A) 1 and 2
- (B) 1 and 3
- (C) 2 and 3
- \* (D) 2 and 4

**2**

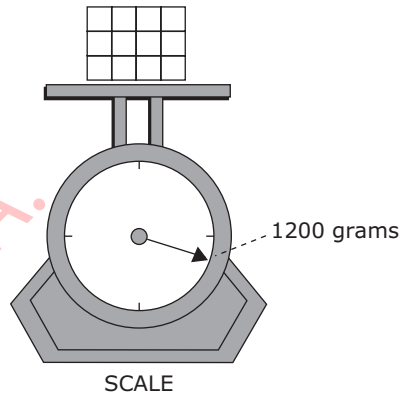
Brad thought of a number. He then multiplied it by 2 and added 4. The answer Brad obtained was 16. What was the number he first thought of?

Answer: 6

$$\begin{array}{r} 16 \\ - 4 \\ \hline 12 \end{array} \qquad \begin{array}{r} 6 \\ 2 \overline{) 12} \\ \underline{- 12} \\ 0 \end{array}$$

\*Correct Answer

3



Ana placed 12 identical blocks on the scale as shown in the figure.  
How many blocks should be removed to reduce the weight to 1000 grams?

- (A) 1
- \* (B) 2
- (C) 3
- (D) 4

4



On the number line, which of these numbers would be closest to 1?

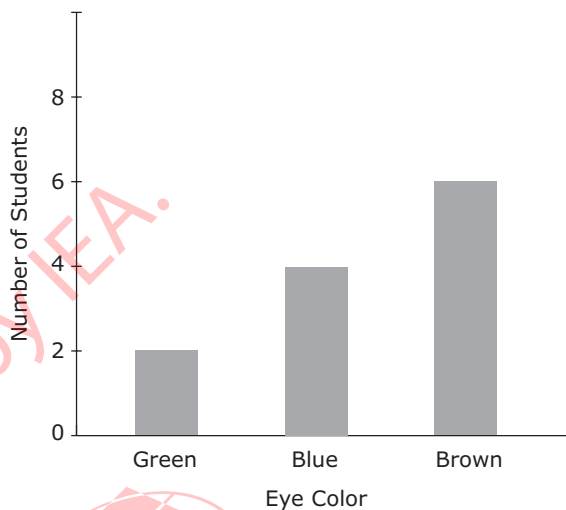
- (A) 0.1
- \* (B) 0.9
- (C) 1.2
- (D) 1.9

\*Correct Answer



5

Student's Eye Color



The chart above shows the eye color of all students in Ms. Hagan's choir.

A. How many students are in Ms. Hagan's choir?

Answer: 12  $2 + 4 + 6 = 12$

B. What fraction of Ms. Hagan's choir has blue eyes?

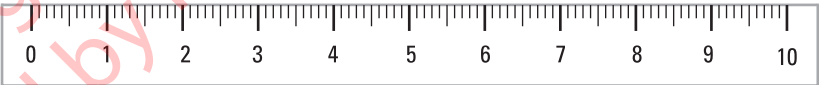
Answer:  $\frac{1}{3}$   $\frac{4}{12} = \frac{1}{3}$



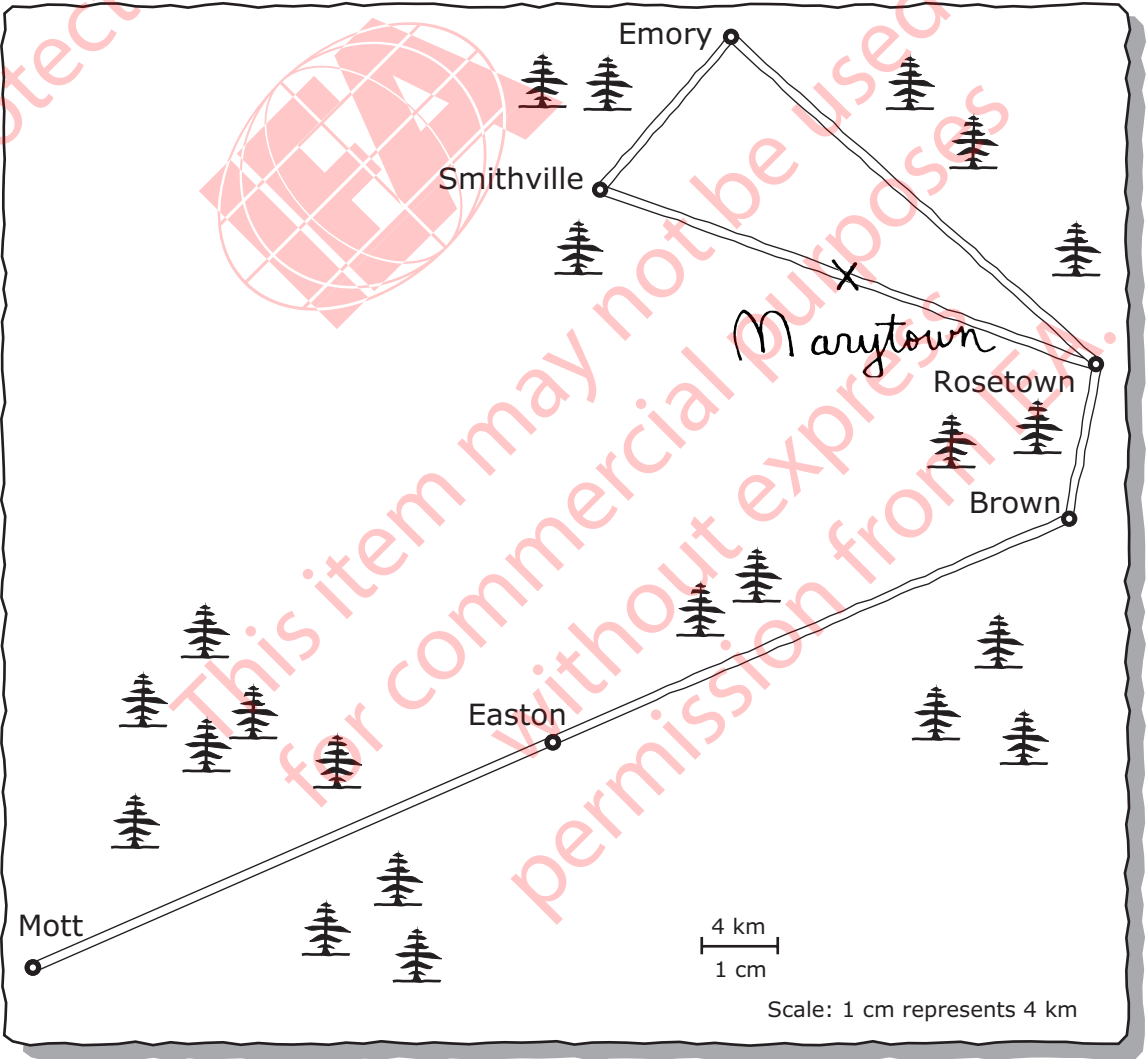
# Map

**Instructions:** Questions **6** and **7** are about using a map.

For these questions, you have been given a cardboard ruler.  
If you do not have the cardboard ruler raise your hand.



Use the map below and your ruler to answer this set of questions.



Questions for Map begin on the next page.



6

**Traveling Between Towns**

A. How many centimeters is it between Mott and Brown on the map?

Answer: 15 centimeters (cm)

B. How many kilometers is it between Mott and Brown on the road?

Answer: 60 kilometers (km)

C. It takes one hour to drive from Mott through Easton to Brown. At the same speed, how much time would it take to travel from Mott to Easton?

Answer: 30 minutes

7

**Distances From Rosetown**

A. Is Emory or Smithville closer to Rosetown?

Answer: Emory

B. How many centimeters closer is it on the map?

Answer: 0.5 centimeters (cm)

C. Another town called Marytown is the same distance from Rosetown as it is from Smithville. Show **on the map** where Marytown might be located. Mark it with an **X** and write Marytown below it.

End of Map section.

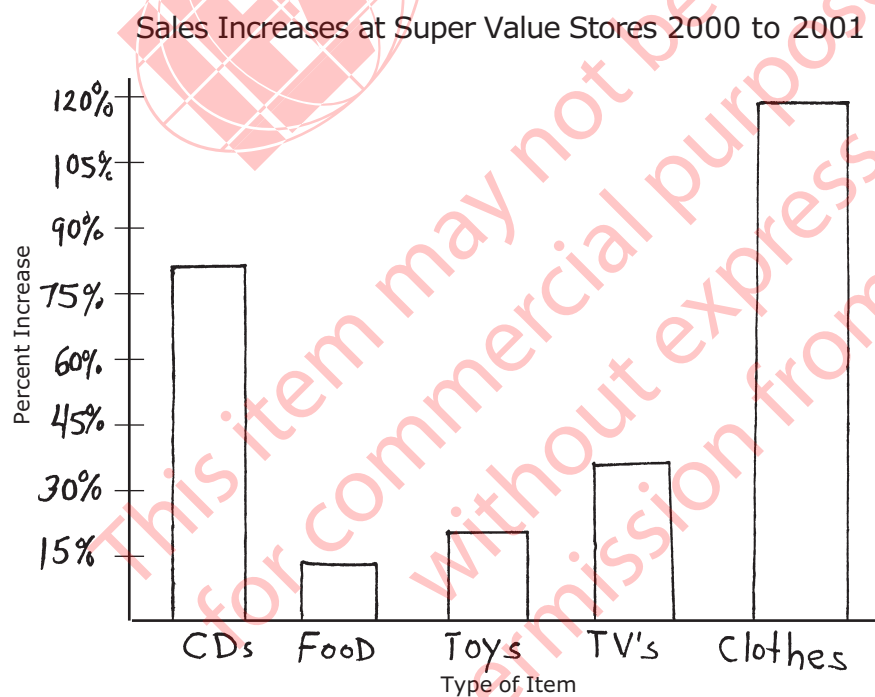


## Example Mathematics Items: Grade 8

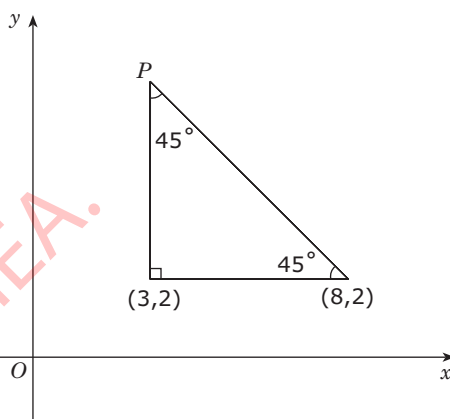
1

Sales Increases at Super Value Stores 2000 to 2001	
Type of Item	Percent Increase
CDs	80%
Food	15%
Toys	25%
TVs	40%
Clothes	120%

Use the data in the table above to construct a bar graph using the axis below. Indicate the scale for the percent increase and label each bar.



2



In the coordinate plane above, what are the coordinates of vertex  $P$ ?

- (A) (2,7)
- (B) (2,8)
- \* (C) (3,7)
- (D) (3,8)

\*Correct Answer

3

Row	Terms	Sum
Row 1	1	1
Row 2	1 + 3	4
Row 3	1 + 3 + 5	9
Row 4	1 + 3 + 5 + 7	16
⋮		
Row 7	1 + 3 + 5 + 7 + 9 + 11 + 13	49
⋮		

A. Enter the terms and sum for Row 7 in the table.

B. Without writing out all the terms, what is the sum for Row 20?

Answer: 400

C. What is the value of the sum for Row  $n$ ?

Answer:  $n \times n$



4

If  $\sqrt{81} < n < \sqrt{144}$ , then  $n$  could be which of the following numbers?

- (A) 9
- \* (B) 11
- (C) 12
- (D) 13

5

Write an equation to represent the following sentence.

“When half of  $x$  is added to 10, the result is 24.”

Answer:  $\frac{1}{2}x + 10 = 24$

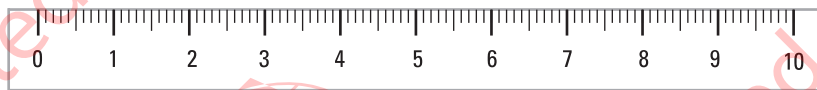
\*Correct Answer



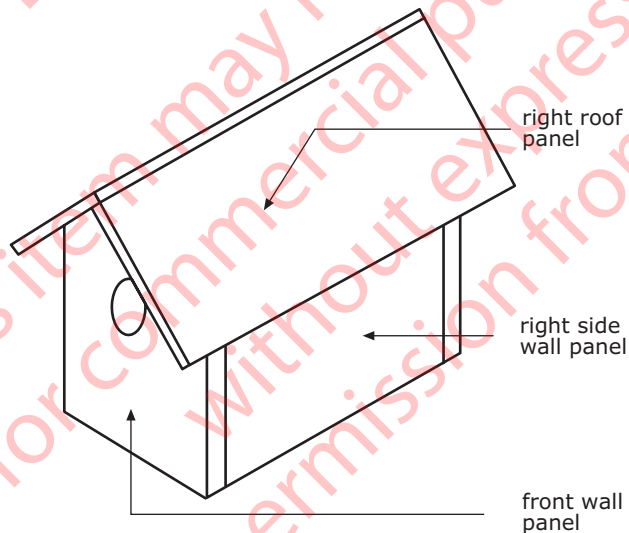
## Birdhouse

**Instructions:** Questions **6** and **7** are about building a bird house. To answer these questions you may refer to any information shown on the pages in the Birdhouse section.

For these questions you have been given a cardboard ruler.  
If you do not have the cardboard ruler raise your hand.



As a class project, students in Ms. Grant's eighth grade class are making small birdhouses out of wood. Chris receives a paper pattern to build a small birdhouse that looks like the one shown below.



picture not to scale

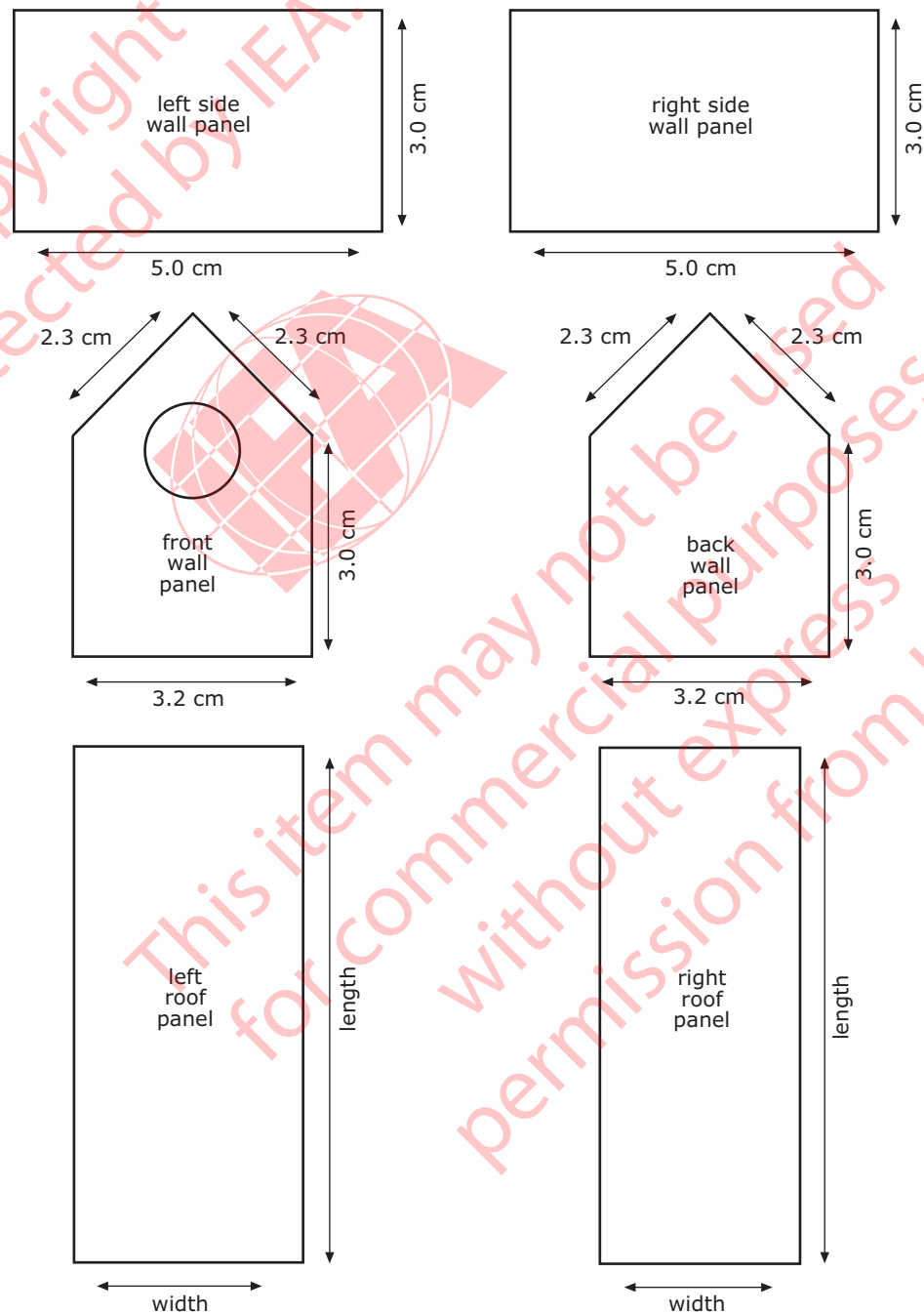
Questions for Birdhouse begin on the next page.



6

Chris has the pattern for 6 pieces: 4 wall pieces and 2 roof pieces. The sheet with the pattern for the floor is lost. Chris' pattern pieces are shown in Figure 1 below. The directions state that 1 centimeter in the pattern represents 3 centimeters for the actual birdhouse.

Figure 1



This Birdhouse question continues on the next page. ➡

- A. Figure 1 shows the dimensions of the pattern pieces for the four wall panels. Use your ruler to measure the dimensions of the pattern pieces for the two roof panels, to the closest millimeter.

What is the length and width of the pattern for the **left** roof panel?

The length of the left roof panel is 7.0 cm.

The width of the left roof panel is 3.1 cm.

What is the length and width of the pattern for the **right** roof panel?

The length of the right roof panel is 7.0 cm.

The width of the right roof panel is 2.7 cm.

- B. What needs to be done to the measurements in the pattern to find the measurements in centimeters for the actual birdhouse?

Answer: times all the measurements by 3

- C. What will be the actual measurements of the left side wall panel of the birdhouse?

Answer: 15 cm x 9 cm

- D. Since some of the pattern pieces in Figure 1 are exactly the same in size and shape, Chris does not need to find the actual measurements for every piece.

What is the **least** number of the 6 pattern pieces Chris needs to find the actual measurements for the birdhouse?

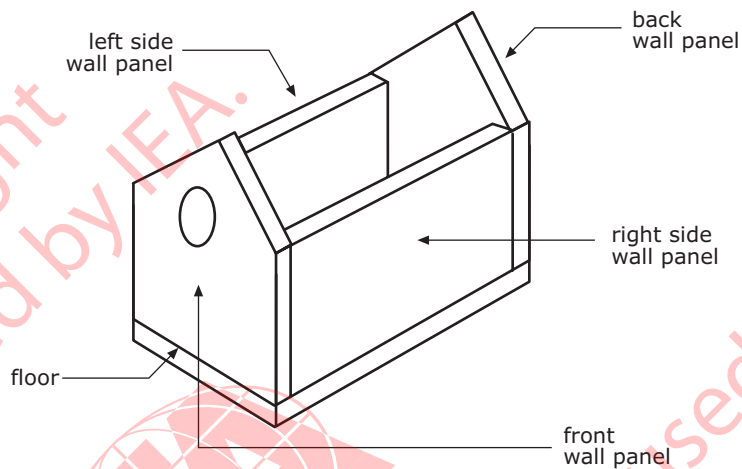
Answer: 4

Questions for Birdhouse continue. ➡

7

Figure 2 below shows how the birdhouse should look when the front panel, back panel, side panels, and floor are assembled using glue and nails.

Figure 2



Since the pattern for the floor piece is lost, Chris must use this figure to determine the measurements for the floor. To do this, Chris needs to know the thickness of the wood used to build the birdhouse.

The thickness of the wood is 1.2 cm.

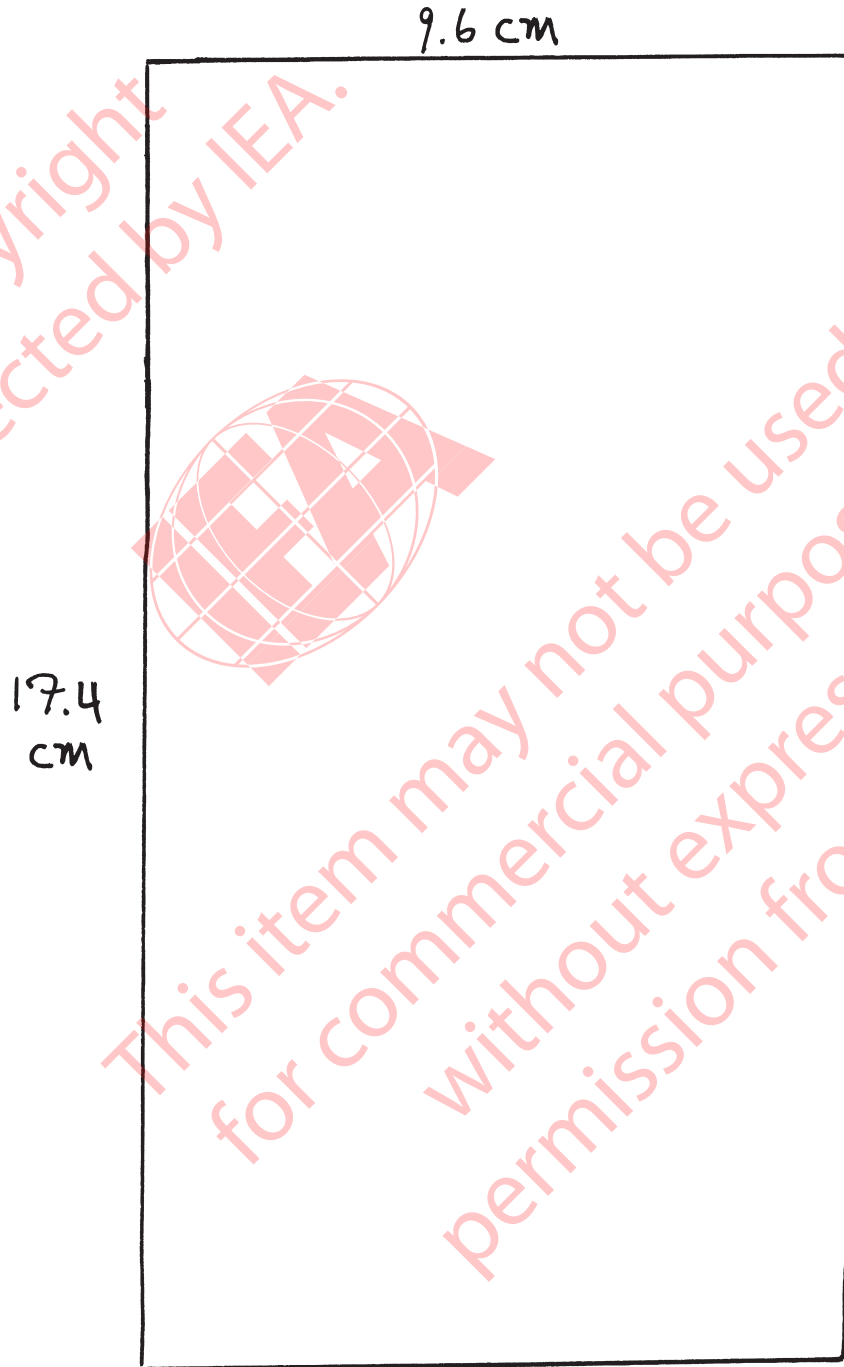
- A. What is the length (longer side) and width (shorter side) of the piece of wood Chris would need for the birdhouse floor?

Length: 17.4 cm

Width: 9.6 cm

This Birdhouse question continues on the next page. ➡

- B. In the space below make a drawing of the actual size of the floor of the birdhouse using your ruler. Indicate the length, in centimeters, of the longer and shorter sides.



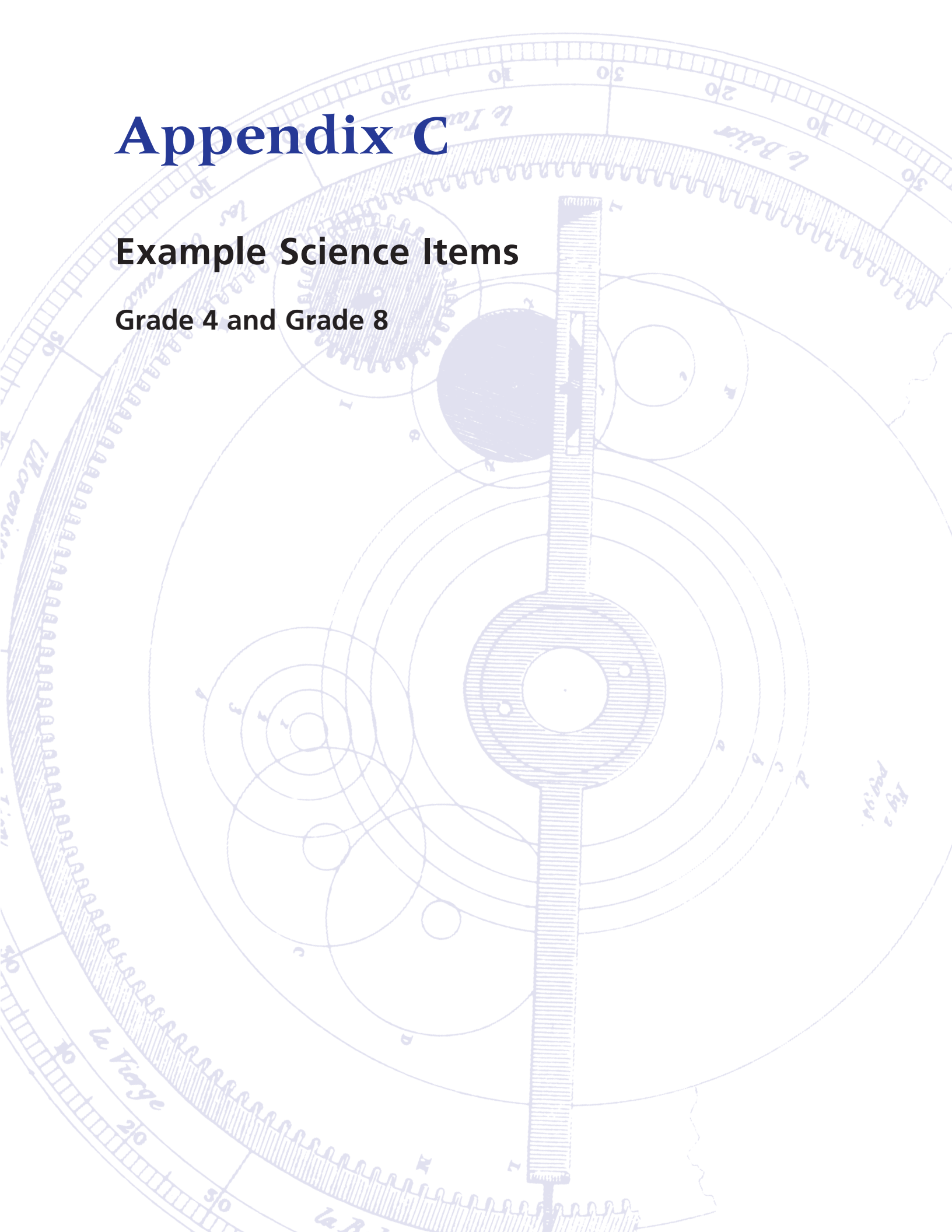
End of Birdhouse section.



# Appendix C

## Example Science Items

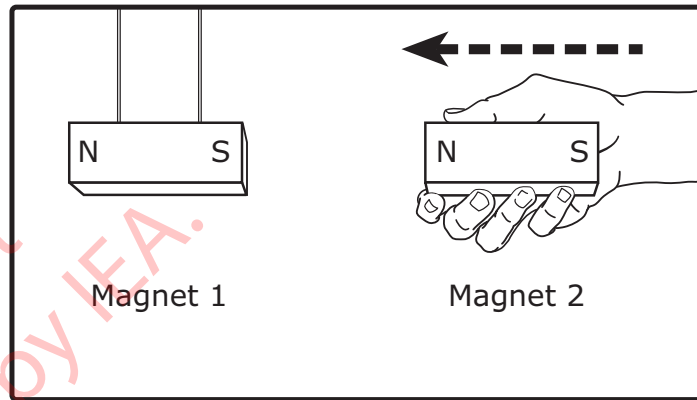
Grade 4 and Grade 8







1



Magnet 1 is hanging by two strings. Magnet 2 is moved towards Magnet 1 as shown in the picture. What will happen to Magnet 1?

- (A) Magnet 1 will swing away from Magnet 2.
- \* (B) Magnet 1 will swing towards Magnet 2.
- (C) Magnet 1 will swing back and forth.
- (D) Magnet 1 will not move.

2

Describe two ways people can help to reduce air pollution in a city.

1. We can ride busses, bikes or share cars with other people.
2. Grow more plants.

\*Correct Answer

3

You are given a mixture of sawdust, pebbles, and iron filings.  
You must separate the mixture into its parts.

A. What things would you need to separate this mixture?


A: Magnet



A: Container



B. Write down the steps you would take to separate the mixture.

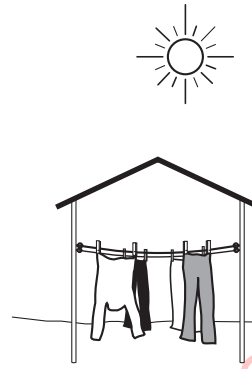
1. First you use the magnet to get the iron filings,
2. Then you bring a  and put the sawdust and the pebbles into it and the sawdust falls through it and pebbles stay on it because the hole is too small and there is a container underneath it and sawdust falls into it and all is done,

4

The picture below shows clothes drying outside on two different days in the same month. On Day 1 it is raining. On Day 2 the sun is shining. The clothes are protected from the rain by the hut.



Day 1



Day 2

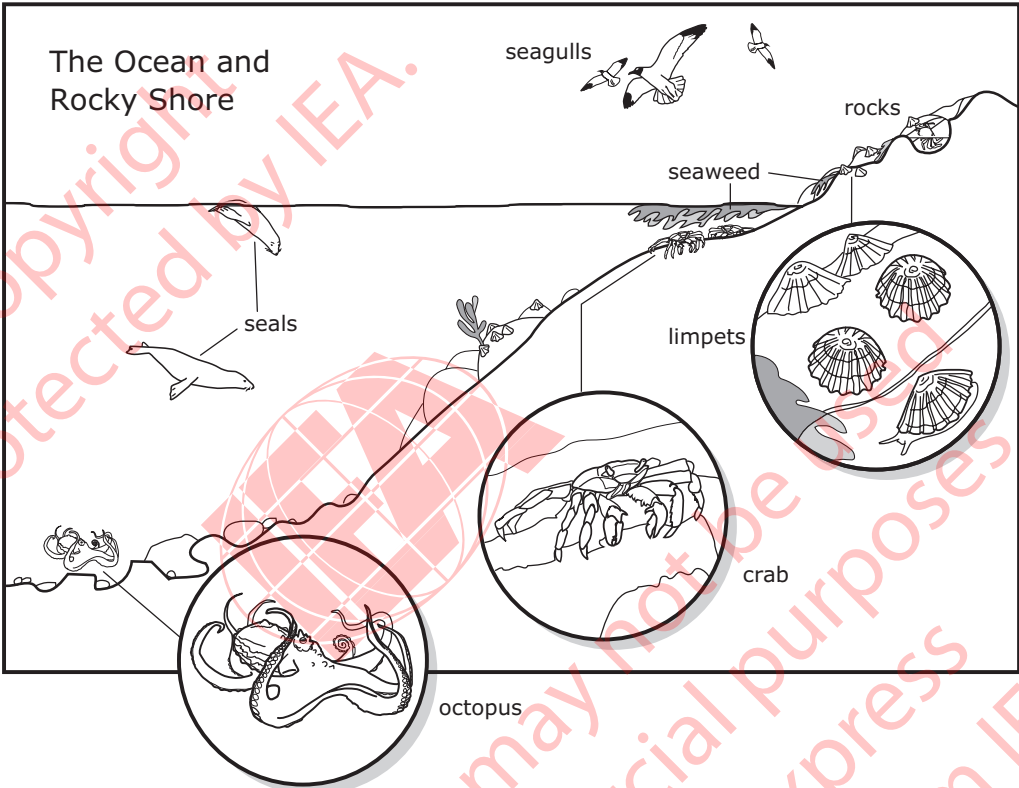
On Day 1 the clothes dry in 24 hours. On Day 2 they dry in 8 hours. Explain why it takes longer to dry clothes on Day 1 than on Day 2.

because on day one it's raining and it would be damp under the hut and on day two it would be warm so they would dry easier.

5

Ocean Food Chain

The picture below shows part of an ocean and some of the organisms (plants and animals) that live in and around the ocean.

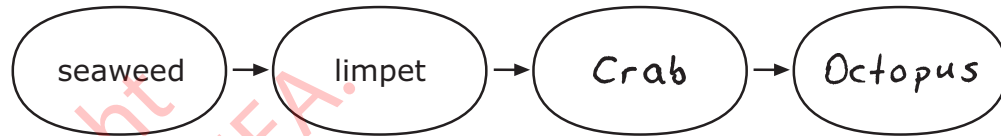


Look at the list of living organisms (plants and animals) below. The table gives information about what each organism in the picture of the ocean needs for food.

Name of Organism	What the Organism Needs for Food
Seaweed	Sunlight to make its own food
Limpet	Seaweed
Crab	Limpets
Octopus	Limpets, crabs, and fish
Seagull	Crabs and fish
Seal	Crabs, octopus and fish

Questions for Ocean Food Chain begin on the next page. ➡

The diagram below shows part of a food chain. The arrows go from one organism to another organism that eats it. In this food chain, the limpets eat seaweed.



- A. Complete the food chain **above** by writing the names of two other organisms from the table in the blank spaces. Use the information in the table about what each organism needs for food.  
(There is more than one correct food chain. You need to show just one.)

- B. One year a disease causes many limpets to die. What would happen to the **seaweed** in your food chain when the limpets die?

The amount of seaweed will grow because there isn't lots of limpets to eat it.

- C. Choose another organism in your food chain (not seaweed or limpet).

Name of organism: Crab

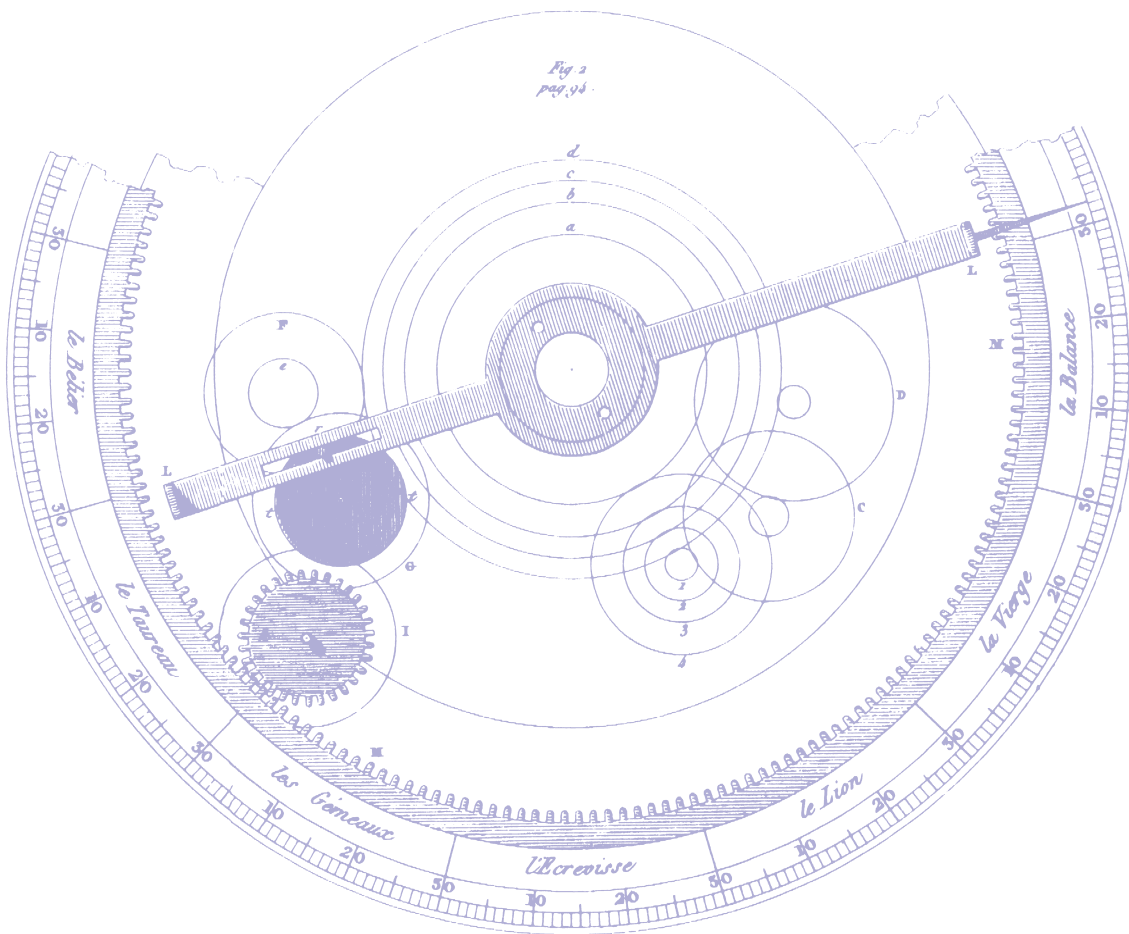
What would happen to this organism when the limpets die?

Some crabs will die because there isn't a lot of limpets to eat.

- D. What would happen to the other organisms in your food chain if the seaweed does not grow well?

The limpets will starve, so some crabs will die, so some octopuses will die. If one tiny thing happens to an animal or plant, it can affect the whole food chain.

End of Ocean Food Chain questions.



Example Science Items: Grade 8

**1**

Your skin and your hair are both made up of cells. When you cut your skin, it hurts. When you cut your hair, it does not hurt.

Explain why.

This is because in our body skin, there are nerves. As our skin is cut, the nerves will then send signal messages to the brain to let us feel pain. Unlike the skin, hair does not have nerves, therefore unable to send signal messages to the brain to feel pain.

**2**

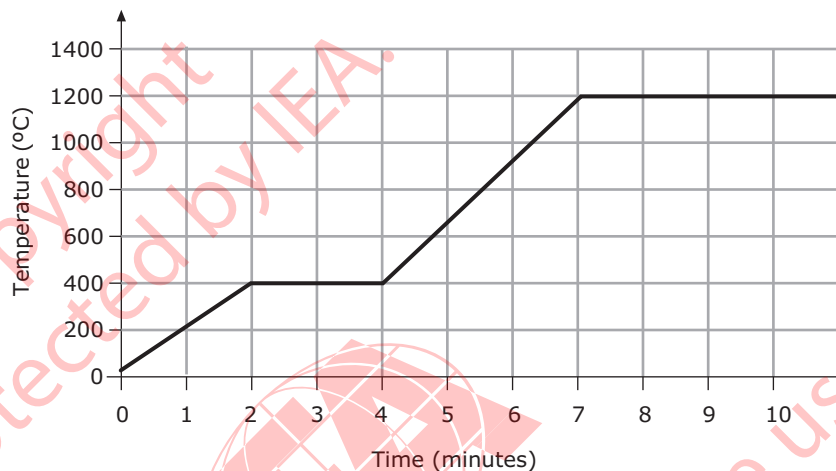
The human population of the world has grown rapidly over the past 200 years. Describe one way the increased world population has affected the environment.

With more people, more roads, schools, buildings and facilities have to be built in order for them to live more comfortably. This means that air pollution (from vehicles, factories) and noise pollution (construction work) are increasing too.



3

A metal was heated for several minutes at a constant rate. It melted and then boiled. The graph below shows how the temperature changed as heat was added over time.



From the graph, what is the melting point of the metal?

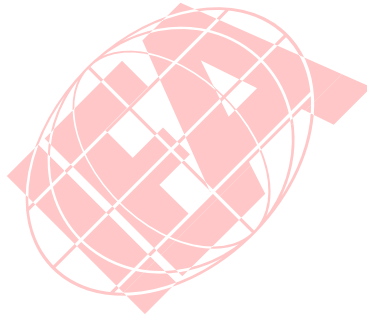
- (A) 200°C
- \* (B) 400°C
- (C) 800°C
- (D) 1200°C

\*Correct Answer

4

A ship is built mostly of metal. Metal usually sinks when put into water, but a ship does not sink. Explain why.

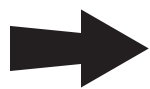
Because the ship is filled with air and because of its surface, also the density of water is more dense than the density of ship.



5

How was the oil formed that is found in the rock layers beneath the ocean floor?

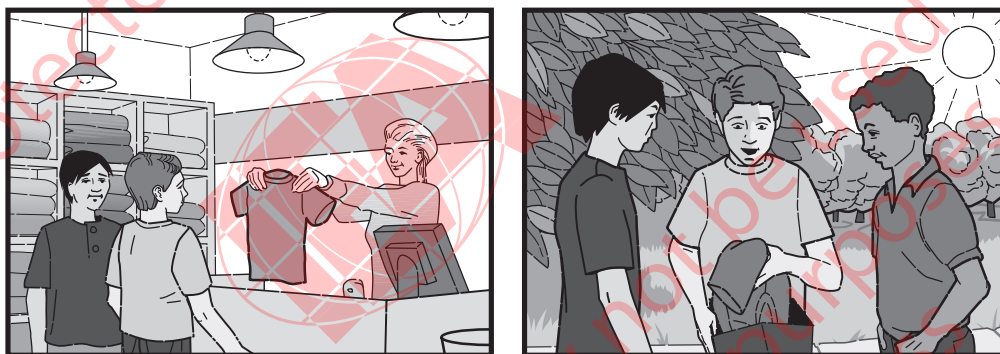
It was formed by dead organisms that over pressure and time decomposed to form oil.



## Light Filters

**Instructions:** Questions **6**, **7**, **8**, **9**, and **10** are about light filters. To answer these questions you may refer to any information shown on the pages in the Light Filters section.

Emile and Andre went to a clothing store. They bought an orange shirt. On the way home, they opened up the bag to show a friend the new orange shirt. They noticed, however, that the shirt looked red instead of orange.



Emile thought that they were given the wrong shirt. Andre thought that they had the right shirt. He said that the color of a material can change under different light conditions. They decided to conduct an investigation to test Andre's ideas about light and color.

Questions for Light Filters begin on the next page.



6

Emile and Andre got a flashlight, some transparent sheets of colored plastic to use as light filters, and some colored paper. They used these materials for their investigation. First they looked at the different pieces of paper in sunlight. They recorded what they saw.

	Paper 1	Paper 2	Paper 3	Paper 4
Appearance in sunlight	White	Red	Green	Black

- A. Andre said that sunlight is made up of a mixture of different colors. He also said that the papers looked the way they did because they reflect only part of the sunlight to the eye and absorb the rest. What colors that make up sunlight are reflected to the eye by papers 1, 2, 3, and 4?

Paper 1: all the colours

Paper 2: red

Paper 3: green

Paper 4: none of the colours

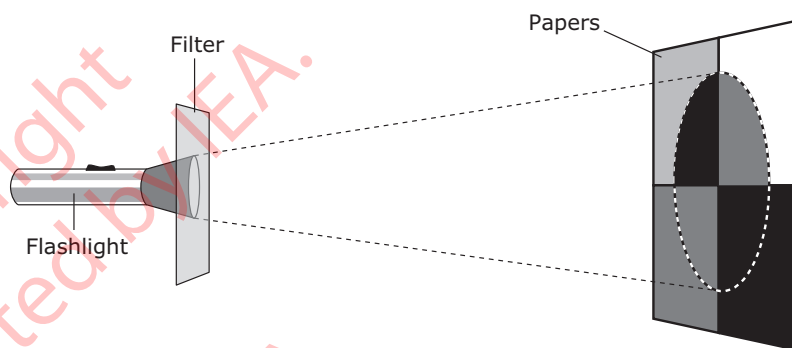
- B. Andre said that sunlight can be separated into its different colors. Give an example of how this can be demonstrated.

This can be demonstrated by passing light through a glass triangular prism.

Questions for Light Filters continue.



Emile and Andre took the colored papers, the colored sheets of plastic, and the flashlight into a dark room. First they shined the flashlight onto each piece of paper. Then they put each sheet of colored plastic (light filter) over the flashlight and shined the flashlight onto the papers.



They recorded all of their results in a table.

Light Condition	Appearance of Paper			
	Paper 1	Paper 2	Paper 3	Paper 4
<b>Sunlight</b>	White	Red	Green	Black
<b>Flashlight</b> (without a filter)	White	Red	Green	Black
<b>Red light</b> (red filter placed over flashlight)	Red	Red	Black	Black
<b>Green light</b> (green filter placed over flashlight)	Green	Black	Green	Black

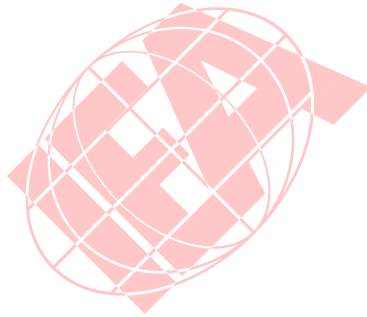
Questions for Light Filters continue.



7

Look at the results shown in the table. How does the light coming from the flashlight compare to the light coming from the sun? Explain your answer based on the results of Emile's and Andre's investigation.

it is the same. Both are made up of different coloured lights to form white light. The experiment's results are the same for both the sunlight and the flashlight.



8

Light filters transmit (pass through) only part of the light and absorb the rest. Which of the following statements is true about how the red filter affects the color of light from the flashlight?

- (A) The red filter absorbs the red part of light and transmits the green part of light.
- \* (B) The red filter transmits the red part of light and absorbs the green part of light.
- (C) The red filter absorbs both the red and green part of light
- (D) The red filter transmits both the red and green part of light.

Questions for Light Filters continue. ➡

\*Correct Answer

9

Green paper appears black when viewed in red light. Red paper appears black when viewed in green light. Explain why this happens in terms of the light that is transmitted by the filters and the light that is reflected by the papers.

as the light passes through the green filter every colour is absorbed but green, then as the green light hits the red paper the green light is absorbed and there is no red light to reflect so there appears to be an absence of light.

Questions for Light Filters continue.



10

Light filters have a number of uses. For example, color photographs can fade over time if they are exposed to bright sunlight.



BEFORE fading



AFTER fading

Light filters can be placed over color photographs to reduce the amount of fading that occurs in sunlight.

Plan an investigation using light filters that could be used to test how different colors of light affect the fading of color photographs. Describe the materials you would use and the procedures you would follow. Include in your plan a description of the variable that you would change and the variable(s) that you would keep constant.

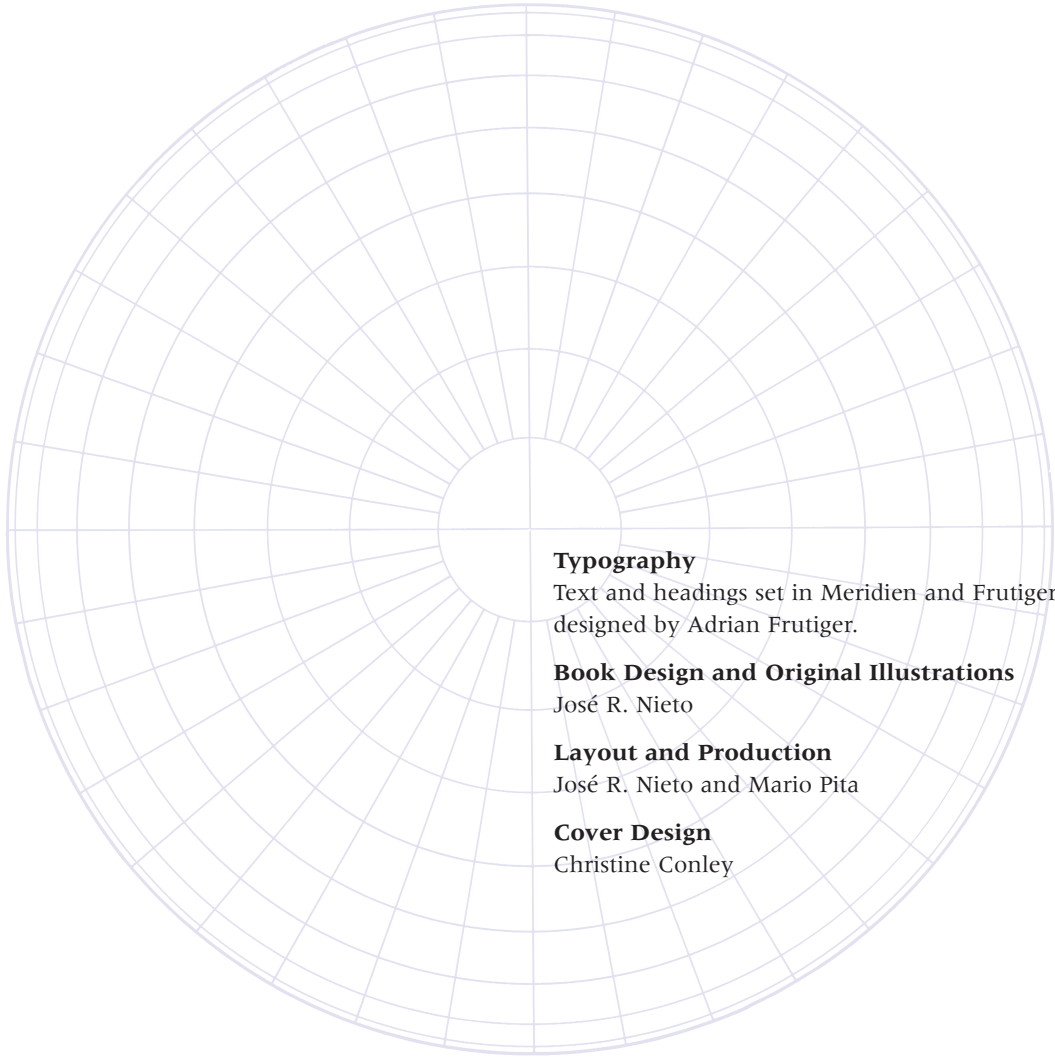


5 prints of the same photo would be placed under different filters and left in the sun. 1 of the photos would be a control and would not have a filter. I would record the time taken for each photo to fade.

End of Light Filters section.







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