TRENDS IN INTERNATIONAL MATHEMATICS AND SCIENCE STUDY

TIMSS

TIMSS Advanced 2015 Assessment Frameworks

Ina V.S. Mullis
Michael O. Martin, Editors

TIMSS & PIRLS
International Study Center
Lynch School of Education, Boston College

TRENDS IN INTERNATIONAL MATHEMATICS AND SCIENCE STUDY

TIMSS

TIMSS Advanced 2015
Assessment Frameworks

Ina V.S. Mullis
Michael O. Martin, Editors

TIMSS & PIRLS
International Study Center
Lynch School of Education, Boston College

TIMSS Advanced 2015 Assessment Frameworks
Ina V.S. Mullis and Michael O. Martin, Editors

Publishers: TIMSS & PIRLS International Study Center,
Lynch School of Education, Boston College
and
International Association for the Evaluation of Educational Achievement (IEA)

Library of Congress Catalog Card Number: 2013947583
ISBN: 978-1-889938-20-2

For more information about TIMSS Advanced contact:
TIMSS & PIRLS International Study Center
Lynch School of Education
Boston College
Chestnut Hill, MA 02467
United States

tel: +1-617-552-1600
fax: +1-617-552-1203
e-mail: timss@bc.edu
timss.bc.edu

Printed and bound in the United States.

Introduction

Ina V.S. Mullis

Overview of TIMSS Advanced 2015

The study of mathematics and science in primary school and secondary school prepares students to become knowledgeable, productive individuals and contributing members of society. TIMSS is an international assessment of the mathematics and science achievement of students at the fourth and eighth grades in more than sixty countries. Now entering its twentieth year of data collection, TIMSS provides countries with a measure of how well they are preparing their students with the mathematics and science knowledge they need to become effective citizens.

However, it also is critical for countries to ensure that capable secondary school students receive further preparation in advanced mathematics and science, so that they are ready to enter challenging university-level studies that prepare them for careers in science, technology, engineering, and mathematics (STEM) fields. This group of students will become the next generation of scientists and engineers who will drive innovation and technological development in all sectors of the economy; thus, it is important for countries to understand the mathematics and science achievement of these students as they begin their university-level education. First conducted in 1995, and then again in 2008, TIMSS Advanced is the only international assessment that targets this specific group of students and provides essential information about their advanced mathematics and physics achievement. TIMSS Advanced assesses these students in their final year of secondary school or, as an option offered in 2015 for the first time, at the start of their STEM coursework in universities.

Each country that participates in TIMSS Advanced 2015 gains valuable information on the following:

- The numbers of students and the proportion of the overall student population who are participating in advanced mathematics and physics study at the end of secondary school;

- The achievement of these students based on international benchmarks (advanced, high, and intermediate); and
- A rich set of contextual data on curricula, teaching and learning strategies, teacher preparation, school resources, and student preparation and attitudes that can be used to guide education reform and policy planning in STEM fields.

Thus, countries that participate in TIMSS Advanced 2015 can obtain data to help them understand how successful they are at preparing the future generation of scientists and engineers, and what policies can be implemented to support and expand the pipeline of students who enter STEM careers.

TIMSS Advanced 2015 continues the series of international assessments in mathematics and science conducted by 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. IEA pioneered international comparative assessments of educational achievement in the 1960s to gain a deeper understanding of effects of policies and practices across countries' different systems of education. As a program of the IEA, TIMSS Advanced has the benefit of drawing on the cooperative expertise provided by representatives from countries all around the world. TIMSS Advanced is directed by the TIMSS & PIRLS International Study Center at Boston College.

Monitoring Trends and Progress across Grades

TIMSS Advanced 2015 provides countries that participated in the prior assessments in 1995 and 2008 the opportunity to continue the trend line that shows achievement in advanced mathematics and physics over time. Also, for the first time since 1995, both TIMSS and TIMSS Advanced will be conducted together in the same year. TIMSS has regularly assessed mathematics and science at the fourth and eighth grades since 1995, but reuniting TIMSS and TIMSS Advanced and assessing them together in 2015 provides countries an opportunity to obtain a complete view of mathematics and science education from primary and middle school through upper secondary school.

Policy Relevant Contexts for Learning Advanced Mathematics and Physics

In conjunction with the collection of advanced mathematics and physics achievement data, TIMSS Advanced 2015 also will collect an array of contextual data from curriculum specialists, school principals, mathematics and physics teachers, and the students themselves in each participating country. These data include the following:

- Organization of the advanced mathematics and physics curriculum;
- Topics actually taught;
- Teacher qualifications and experience;
- Classroom instructional strategies, including technology use;
- School resources;
- Amount of instructional time;
- School environment and climate for learning;
- Students' homework and out-of-school activities;
- Home educational supports, including information and communications technology (ICT); and
- Students' attitudes and aspirations toward STEM-related careers.

This extensive set of TIMSS Advanced 2015 contextual data can be used to evaluate current educational policies and instructional strategies, and shape them to improve enrollment and achievement in the advanced secondary school courses required to prepare students for university study in STEM fields.

The student achievement data and the contextual data for TIMSS Advanced 2008 was reported in a comprehensive publication, the *TIMSS Advanced 2008 International Report* (Mullis, Martin, Robitaille, & Foy, 2009). This report summarized students' overall achievement in advanced mathematics and physics and at the TIMSS Advanced International Benchmarks. The report also presented the rich array of contextual data (listed above) in relation to student achievement.

The TIMSS Advanced 2015 Assessment Frameworks

Chapter 1 of this publication contains the framework for the advanced mathematics assessment and Chapter 2 contains the framework for the physics assessment. Each chapter describes the major content domains (e.g., algebra, calculus, etc. in mathematics; and mechanics, thermodynamics, etc. in physics), the topic areas within each content domain, and the topics to be assessed. Across the assessment, each topic receives approximately equal weight in terms of time allocated to assessing the topic.

The items in each TIMSS Advanced assessment also cover a range of thinking processes as described within three cognitive domains: knowing, applying, and reasoning. These cognitive domains also are described in Chapters 1 and 2. In general terms, items assess students' abilities to demonstrate their knowledge, apply what they have learned, solve problems, and reason through analysis and logical thinking. The knowing, applying, and reasoning cognitive domains describe the thinking students should be doing as they engage with the mathematics and science content, and are parallel for mathematics and science and across grades, but with different levels of emphasis depending on the subject and grade.

Also, new for TIMSS Advanced 2015, Chapter 2 contains a section describing science practices to be addressed in the physics assessment. These practices include skills that students use in a systematic way to conduct scientific inquiry.

Chapter 3 contains the TIMSS Advanced Contextual Framework describing the types of learning situations and factors associated with students' achievement in advanced mathematics and physics that will be investigated via the questionnaire data. Finally, Chapter 4 provides an overview of the TIMSS Advanced 2015 Assessment Design, including general guidelines for item development.

Updating the TIMSS Advanced Frameworks for the 2015 Assessment

The TIMSS Advanced assessment frameworks for 2015 were updated from those used in the *TIMSS Advanced 2008 Assessment Frameworks* (Garden et al., 2006). Updating the frameworks provides participating countries opportunities to provide fresh ideas and information about how curricula and instruction in mathematics and physics have evolved since the development of the frameworks for TIMSS Advanced 2008. These updates keep the frameworks educationally relevant, create coherence from assessment to assessment, and permit the frameworks, the instruments, and the procedures to evolve gradually into the future.

For TIMSS Advanced 2015, the advanced mathematics and physics frameworks were updated to better reflect the curricula, standards, and frameworks of the participating countries. Consideration also was given to current international research and initiatives in mathematics and science education. These updates were discussed by the TIMSS Advanced National Research Coordinators (NRCs) from the participating countries at their first meeting. Each participating country identifies an NRC to work with the international project staff to ensure that the TIMSS Advanced assessments are responsive to the country's concerns. Following the discussion at the first NRC meeting, the NRCs consulted with their national experts and responded to a topic-by-topic survey about how best to update the content and cognitive domains for TIMSS Advanced 2015.

Next, the TIMSS 2015 expert group, the Science and Mathematics Item Review Committee (SMIRC), conducted its own in-depth review of the frameworks and worked with the international project staff to use the countries' survey results to further refine and update the *TIMSS Advanced 2015 Assessment Frameworks*. Using an iterative process, the frameworks as revised by the SMIRC were once again reviewed by the NRCs and updated for a final time prior to publication.

CHAPTER 1

TIMSS Advanced 2015 Mathematics Framework

Liv Sissel Grønmo, Mary Lindquist, and Alka Arora

The assessment framework for TIMSS Advanced—Mathematics is organized around two dimensions: a content dimension specifying the domains of subject matter to be assessed within mathematics (i.e., algebra, calculus, and geometry) and a cognitive dimension specifying the domains of thinking processes to be assessed (i.e., knowing, applying, and reasoning). The cognitive domains describe the sets of behaviors expected of students as they engage with the mathematics content.

In general, these frameworks are similar to those used in TIMSS Advanced 2008. However, there have been minor updates to particular topics to better reflect the curricula, standards, and frameworks of the participating TIMSS Advanced countries. Also, attention was paid to current research and initiatives concerning mathematics and mathematics education, such as the *Common Core State Standards for Mathematics* (National Governors Association, 2010) developed in the United States, the *Mathematics Higher 2 Syllabus* (Singapore Examinations and Assessment Board, 2013) used in Singapore, the *Mathematics Curriculum (Secondary 4–6)* (Education Bureau, Hong Kong SAR, 2007) used in Hong Kong, and the *AP Calculus Course Description* (College Board, 2012).

Exhibit 1 shows the target percentages of testing time devoted to each content and cognitive domain for the advanced mathematics assessment.

Exhibit 1: Target Percentages of the TIMSS Advanced 2015 Mathematics Assessment Devoted to Content and Cognitive Domains

Content Domains	Percentages
Algebra	35%
Calculus	35%
Geometry	30%

Cognitive Domains	Percentages
Knowing	35%
Applying	35%
Reasoning	30%

TIMSS Advanced—Mathematics Content Domains

The TIMSS Advanced—Mathematics Framework consists of three content domains: algebra, calculus, and geometry. These content domains are the same content domains as were in the TIMSS Advanced 2008 Framework. Each of these content domains consists of topic areas, and each topic area in turn includes several topics. Across the advanced mathematics assessment, each topic receives approximately equal weight in terms of time allocated to assessing the topic.

Algebra

Algebra provides a foundation for further studies in mathematics as well as in many other disciplines. Building on the knowledge and skills developed in lower grades, the algebra domain encompasses three topic areas:

- Expressions and operations;
- Equations and inequalities; and
- Functions.

The first area includes operating with and evaluating a variety of algebraic expressions as well as working with arithmetic and geometric series. The second area includes using equations and inequalities, and systems of equations and inequalities to solve problems. The third area focuses on various representations and properties of functions.

Algebra: Expressions and Operations

1. Operate with exponential, logarithmic, polynomial, rational, and radical expressions; and perform operations with complex numbers.
2. Evaluate algebraic expressions (e.g., exponential, logarithmic, polynomial, rational, and radical).
3. Determine the n^{th} term of arithmetic and geometric series and the sums of finite and infinite series.

Algebra: Equations and Inequalities

1. Solve linear and quadratic equations and inequalities as well as systems of linear equations and inequalities.
2. Solve exponential, logarithmic, polynomial, rational, and radical equations.
3. Use equations and inequalities to solve contextual problems.

Algebra: Functions

1. Interpret, relate, and generate equivalent representations of functions, including composite functions, as ordered pairs, tables, graphs, formulas, or words.
2. Identify and contrast distinguishing properties of exponential, logarithmic, polynomial, rational, and radical functions.

Calculus

Calculus is an essential tool for understanding the principles governing the physical world and is the principal point of entry to most mathematically-based scientific careers. The calculus content for TIMSS Advanced—Mathematics concentrates on the following:

- Limits;
- Derivatives; and
- Integrals.

The focus is on understanding limits and finding the limit of a function, differentiation, and integration of a range of functions, and using these skills in solving problems.

Calculus: Limits

1. Determine limits of functions, including rational functions.
2. Recognize and describe the conditions for continuity and differentiability of functions.

Calculus: Derivatives

1. Differentiate polynomial, exponential, logarithmic, trigonometric, rational, radical, and composite functions; and differentiate products and quotients of functions.
2. Use derivatives to solve problems in optimization and rates of change.
3. Use first and second derivatives to determine slope, extrema, and points of inflection of polynomial and rational functions.
4. Use first and second derivatives to sketch and interpret graphs of functions.

Calculus: Integrals

1. Integrate polynomial, exponential, trigonometric, and simple rational functions.
2. Evaluate definite integrals, and apply integration to compute areas and volumes.

Geometry

Applications of geometry are tied directly to the solution of many real-world problems and are used extensively in the sciences. Because trigonometry has its origins in the study of triangle measurement, the geometry content domain also includes elements of trigonometry. The TIMSS Advanced 2015 geometry domain focuses on two topic areas common to most participating countries' curricula:

- Non-coordinate and coordinate geometry; and
- Trigonometry.

The focus of non-coordinate and coordinate geometry is on using the properties of geometric figures to solve problems in two and three dimensions, solving problems with coordinate geometry in two dimensions, and vectors. The other topic area concentrates on triangle trigonometry and trigonometric functions.

Geometry: Non-coordinate and Coordinate Geometry

1. Use non-coordinate geometry to solve problems in two and three dimensions.
2. Use coordinate geometry to solve problems in two dimensions.
3. Apply the properties of vectors and their sums and differences to solve problems.

Geometry: Trigonometry

1. Use trigonometry to solve problems involving triangles.
2. Recognize, interpret, and draw graphs of sine, cosine, and tangent functions.
3. Solve problems involving trigonometric functions.

TIMSS Advanced—Mathematics Cognitive Domains

The mathematics cognitive dimension consists of three domains based on what thinking processes students are expected to use when confronting the mathematics items developed for the TIMSS Advanced 2015 assessment. The first domain, knowing, addresses the students' ability to recall and recognize facts, procedures, and concepts necessary for a solid foundation in mathematics. The second domain, applying, focuses on using this knowledge to model and implement strategies to solve problems. The third domain, reasoning, includes analyzing, synthesizing, generalizing, and justifying through mathematical arguments or proofs. The situations requiring reasoning often are unfamiliar or complex.

While there is some hierarchy across the three cognitive domains (from knowing to applying to reasoning), each domain contains items representing a full range of difficulty. The following sections further describe the thinking skills and behaviors defining the cognitive domains. The general descriptions are followed by lists of specific behaviors to be elicited by items that are aligned with each domain.

Each content domain includes items developed to address each of the three cognitive domains. Accordingly, the algebra, calculus, and geometry domains include knowing, applying, and reasoning items.

Knowing

Knowing refers to students' knowledge of mathematical facts, concepts, and procedures. Mathematical facts and procedures form the foundation for mathematical thought.

Recall	Recall definitions, terminology, notation, mathematical conventions, number properties, and geometric properties.
Recognize	Recognize entities that are mathematically equivalent (e.g., different representations of the same function).
Compute	Carry out algorithmic procedures (e.g., determining derivatives of polynomial functions, and solving a simple equation).
Retrieve	Retrieve information from graphs, tables, texts, or other sources.

Applying

The applying domain involves the application of mathematics in a range of contexts. In this domain, students need to apply mathematical knowledge of facts, skills, and procedures or understanding of mathematical concepts to create representations and solve problems. The problems in this domain typically reflect standard types of problems expected to be familiar to students. Problems may be set in real-life situations, or may be purely mathematical in nature involving, for example, numeric or algebraic expressions, functions, equations, or geometric figures.

Determine	Determine efficient and appropriate methods, strategies, or tools for solving problems for which there are commonly used methods of solution.
Represent/Model	Generate an equation or diagram that models problem situations and generate equivalent representations for a given mathematical entity, or set of information.
Implement	Implement strategies and operations to solve problems in familiar mathematical concepts and procedures.

Reasoning

Reasoning mathematically involves logical, systematic thinking. Problems requiring reasoning may do so in different ways, because of the novelty of the context or the complexity of the situation, the number of decisions and steps, and may draw on knowledge and understanding from different areas of mathematics. Reasoning involves formulating conjectures, making logical deductions based on specific assumptions and rules, and justifying results.

Analyze	Identify the elements of a problem and determine the information, procedures, and strategies necessary to solve the problem.
Integrate/Synthesize	Link different elements of knowledge, related representations, and procedures to solve problems.
Evaluate	Determine the appropriateness of alternative strategies and solutions.
Draw Conclusions	Make valid inferences on the basis of information and evidence.
Generalize	Make statements that represent relationships in more general and more widely applicable terms.
Justify	Provide mathematical arguments, or proofs to support a strategy, solution, or statement.

CHAPTER 2

TIMSS Advanced 2015 Physics Framework

Lee R. Jones, Gerald Wheeler, and Victoria A.S. Centurino

Similar to the TIMSS Advanced—Mathematics Framework, the assessment framework for TIMSS Advanced—Physics is organized around two dimensions: a content dimension specifying the domains or subject matter to be assessed within physics (i.e., mechanics and thermodynamics, electricity and magnetism, and wave phenomena and atomic/nuclear physics), and a cognitive dimension specifying the domains or thinking processes to be assessed (i.e., knowing, applying, and reasoning). The cognitive domains describe the thinking processes expected of students as they engage with the physics content.

In general, this framework is similar to that used in TIMSS Advanced 2008. However, there have been updates to particular topics to better reflect the content coverage of current high school physics curricula, standards, and frameworks of participating TIMSS Advanced countries. Consideration also was given to current research and initiatives in science and science education, such as the *Framework for K–12 Science Education* (National Research Council, 2012) developed in the United States, the *Physics Higher 2 Syllabus* (Singapore Examinations and Assessment Board, 2013) used in Singapore, the *Physics Curriculum (Secondary 4–6)* (Education Bureau, Hong Kong, SAR, 2007) used in Hong Kong, and the *AP Physics Course Description* (College Board, 2012).

Exhibit 2 shows the target percentages of testing time devoted to each content and cognitive domain for the physics assessment.

Exhibit 2: Target Percentages of the TIMSS Advanced 2015 Physics Assessment Devoted to Content and Cognitive Domains

Content Domains	Percentages
Mechanics and Thermodynamics	40%
Electricity and Magnetism	25%
Wave Phenomena and Atomic/Nuclear Physics	35%

Cognitive Domains	Percentages
Knowing	30%
Applying	40%
Reasoning	30%

TIMSS Advanced—Physics Content Domains

The TIMSS Advanced—Physics Framework includes three content domains: mechanics and thermodynamics, electricity and magnetism, and wave phenomena and atomic/nuclear physics. The content covered in these three domains is very similar to the content coverage in the TIMSS Advanced 2008 Framework, except that the content was organized into four domains in 2008. Organizing the content in three domains will support the reporting of reliable student scores at the physics domain level for TIMSS Advanced 2015. This organization also follows the structure of many current high school physics curricula. In the TIMSS Advanced 2015 Framework, topics that were included in the heat and temperature domain in 2008 are now included in the mechanics and thermodynamics domain, and some topics regarding sound and light, which were included in the mechanics domain and the electricity and magnetism domains, respectively, in 2008, are now included in the domain that includes wave phenomena.

Each of the three content domains in the TIMSS Advanced—Physics Framework is divided into topic areas, and each topic in turn includes several topics. Across the TIMSS Advanced—Physics assessment, each topic receives approximately equal weight in terms of time allocated to assessing the topic.

Mechanics and Thermodynamics

An understanding of forces and motion is fundamental to understanding the other areas of physics. This TIMSS Advanced 2015 domain focuses on three topic areas common to most participating countries' curricula:

- Forces and motion;
- The laws of conservation; and
- Heat and temperature.

Kinematics, dynamics (Newton's three laws of motion), and the law of gravitation are important components of this area. The conservation of certain physical quantities, such as energy or momentum, is a fundamental concept in physics that is expressed by the laws of conservation (energy and momentum) and the first law of thermodynamics. The area of thermodynamics includes mechanisms of heat transfer and how properties of matter change with temperature.

Mechanics and Thermodynamics: Forces and Motion

1. Predict and determine the position, displacement, and velocity of bodies given initial conditions; and use Newton's laws of motion to explain the dynamics of different types of motion and to calculate displacement, velocity, acceleration, distance traveled, or time elapsed.
2. Identify forces, including frictional force, acting on a body at rest, moving with constant velocity, or moving with constant acceleration and explain how their combined action influences the body's motion; and find solutions to problems involving forces.
3. Determine the forces acting on a body moving in a circular path at constant velocity, the body's centripetal acceleration, its velocity, and the time for it to complete a full revolution.
4. Use the law of gravitation to determine the motion of celestial objects and the forces acting on them.

Mechanics and Thermodynamics: The Laws of Conservation

1. Apply the law of conservation of mechanical energy in practical contexts, including finding solutions to problems involving the transformation of potential to kinetic energy and vice versa.
2. Apply the law of conservation of linear momentum in elastic and inelastic collisions.
3. Solve problems using the first law of thermodynamics.

Mechanics and Thermodynamics: Heat and Temperature

1. Demonstrate understanding of mechanisms of heat transfer and the mechanical equivalent of heat (work); and use specific heats or heat capacities to predict equilibrium temperature when bodies of different temperature are brought together.
2. Determine the expansion of solids in relation to temperature change; and use the ideal gas law (in the form pV/T = constant) to solve problems and demonstrate an understanding of the limitations of this law.

Electricity and Magnetism

Electricity and magnetism are core areas of study in physics that have a wide range of practical applications. The TIMSS Advanced 2015 electricity and magnetism domain focuses on the following:

- Electricity and electric circuits; and
- Magnetism and electromagnetic induction.

Important concepts in electricity encompass the behavior of electrostatic charges and their motion in electric circuits, including the role of resistance and energy losses. Understanding the relationship between electricity and magnetism, including the interaction of charged particles with magnetic fields, the production of magnetic fields from current-carrying wires, and induction is central to this domain.

Electricity and Magnetism: Electricity and Electric Circuits

1. Calculate the magnitude and direction of the electrostatic attraction or repulsion between isolated charged particles by application of Coulomb's law.
2. Predict the force on and the path of a charged particle moving in a homogeneous electric field.
3. Solve problems relating current in electrical circuits (and components of circuits) to voltage, resistance, and energy transformation, including using Ohm's Law and Joule's Law.

Electricity and Magnetism: Magnetism and Electromagnetic Induction

1. Predict the force on and the path of a charged particle moving in a homogeneous magnetic field.

2. Demonstrate understanding of the relationship between magnetism and electricity in phenomena such as magnetic fields around electric conductors (Ampere's law), electromagnets, and electromagnetic induction.
3. Solve problems using Faraday's and Lenz' laws of induction.

Wave Phenomena and Atomic/Nuclear Physics

Wave phenomena and atomic/nuclear physics covers much of what is sometimes known as modern physics. This TIMSS Advanced 2015 domain focuses on two topic areas common to most participating countries' curricula:

- Wave phenomena; and
- Atomic and nuclear physics.

The study of wave phenomena provides a bridge between classical and modern physics, and includes mechanical wave phenomena, electromagnetic radiation, as well as refraction, interference, and diffraction. Atomic and nuclear physics form the core of modern physics and include the structure of atomic nuclei, the behavior of electrons, nuclear reactions, and radioactive decay.

Wave Phenomena and Atomic/Nuclear Physics: Wave Phenomena

1. Apply knowledge of mechanical wave phenomena and the relationship between speed, frequency, and wavelength to solve problems.
2. Demonstrate understanding of electromagnetic radiation in terms of waves caused by the interplay between variations in electric and magnetic fields; and identify various types of waves (radio, infrared, visible light, x-rays, gamma rays) by wavelength and frequency.
3. Demonstrate an understanding of thermal radiation in terms of temperature and wavelength of emitted electromagnetic radiation.
4. Demonstrate understanding of reflection, refraction, interference, and diffraction.

Wave Phenomena and Atomic/Nuclear Physics: Atomic and Nuclear Physics

1. Apply knowledge of the structure of atoms and isotopes, atomic number and atomic mass to solve problems; and relate light emission and absorption in the spectrum to the behavior of electrons.

2. Demonstrate understanding of wave-particle duality, including applying knowledge of the photoelectric effect to predict the consequence of changing the incoming intensity or wavelength of light and solving problems involving the wave nature of matter.
3. Demonstrate understanding of nuclear reactions and solve problems involving radioactive decay, such as finding the half-life of a radioactive isotope; and describe the role of nuclear reactions in nature (such as in stars), and explain their practical applications, such as in nuclear reactors.
4. Demonstrate understanding of mass-energy equivalence in nuclear reactions and particle transformations.

TIMSS Advanced—Physics Cognitive Domains

The physics cognitive dimension is divided into three domains based on the thinking processes students are expected to use when encountering the physics items developed for the TIMSS Advanced 2015 assessment. The first domain, knowing, addresses the students' ability to recall, recognize, and describe facts, concepts, and procedures that are necessary for a solid foundation in physics. The second domain, applying, focuses on using this knowledge to generate explanations and solve problems. The third domain, reasoning, includes using evidence and physics understanding to analyze, synthesize, and generalize, often in unfamiliar situations and complex contexts. While there is some hierarchy across the three domains (from knowing to applying to and reasoning), each domain contains items representing a full range of difficulty.

Each content domain includes items developed to address each of the three cognitive domains. Accordingly, the mechanics and thermodynamics domain includes knowing, applying, and reasoning items, as do the other content domains. The following sections further describe the thinking processes defining the cognitive domains. The general descriptions are followed by lists of specific behaviors to be elicited by items that are aligned with each domain.

Knowing

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

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

Applying

Items in this domain require students to engage in applying knowledge of facts, relationships, processes, concepts, equipment, and methods in contexts likely to be familiar in the teaching and learning of physics. This domain includes both quantitative problems requiring a numerical solution and qualitative problems requiring a written descriptive response.

Use Models	Use a diagram or other model to demonstrate knowledge of physics concepts and principles or to illustrate a structure, process, relationship, or system (e.g., electrical circuit, or atomic structure).
Interpret Information	Use knowledge of physics concepts and principles to interpret relevant textual, tabular, pictorial, or graphical information.
Find Solutions	Apply a physical relationship, equation, or formula to find a qualitative or quantitative solution.
Explain	Provide or identify an explanation for an observation or a natural phenomenon using a physics concept, principle, law, or theory.

Reasoning

Items in this domain require students to engage in scientific reasoning to analyze data, draw conclusions, solve problems, and extend their understandings to new situations. In contrast to the more direct applications of physics concepts exemplified in the applying domain, problem-solving situations in the reasoning domain involve unfamiliar or more complicated contexts. Solving such problems may involve a variety of approaches or strategies. Scientific reasoning also encompasses developing hypotheses and designing scientific investigations.

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

Science Practices in TIMSS Advanced—Physics

Physicists engage in scientific inquiry by following key science practices that enable them to explore physical phenomena and answer questions about those phenomena. Students of physics must become highly proficient at these practices to develop an understanding of how the scientific enterprise is conducted. These practices include skills from across mathematics and science coursework that students use in a systematic way to conduct scientific inquiry. Five science practices that are fundamental to scientific inquiry are represented in TIMSS Advanced 2015:

1. **Asking questions based on observations**—Scientific inquiry includes observations of physical phenomena with unfamiliar characteristics or properties, and studying existing data sets in detail. These observations, together with existing knowledge of physics concepts, lead to questions, which are used to formulate testable hypotheses to help answer those questions.
2. **Generating evidence**—Answering research questions and testing hypotheses requires designing and executing systematic investigations and controlled experiments (including identifying independent and dependent variables). Scientists must use their knowledge of physics concepts and physical phenomena to determine the appropriate approach to an investigation, including deciding on the evidence to be gathered, understanding what instrumentation and procedures are appropriate to use in data collection, and knowing the level of precision and accuracy needed in the data collection.
3. **Working with data**—Once the data are collected, scientists summarize the data in various types of visual displays. They describe and summarize trends in the data, recognize patterns in the data, interpolate and extrapolate from the data, explore relationships between variables, and determine which patterns and relationships may be worth exploring further. In addition, they evaluate the data for consistency with predictions, and consider when revisions to the initial hypothesis might be needed.
4. **Answering the research question**—Scientists use evidence from observations and investigations together with science knowledge to answer the questions they have posed and support or refute hypotheses.
5. **Making an argument from evidence**—Scientists use evidence and understanding of physics concepts to develop explanations and models of physical phenomena, identify gaps or weaknesses in scientific explanations or arguments, justify and support the reasonableness of their explanations, models, and conclusions, and extend these to new situations.

These science practices cannot be assessed in isolation, but must be assessed in the context of one of the TIMSS Advanced—Physics content domains, and drawing upon the range of thinking processes specified in the cognitive domains. Therefore, some items in TIMSS Advanced—Physics will assess one or more of these science practices as well as content specified in the content domains and thinking processes specified in the cognitive domains.

CHAPTER 3

TIMSS Advanced 2015 Context Questionnaire Framework

Martin Hooper, Ina V.S. Mullis, and Michael O. Martin

Because the global community's prosperity and welfare depend on technological development and scientific discovery, it is crucial that the world's educational systems provide students with advanced skills in science, technology, engineering, and mathematics (STEM). Future leaders in science and technology need to be fully prepared to produce innovative ideas that can spark economic and human development. Recognizing this, countries across the world invest tremendous resources in specialized programs to ensure that at least some students study STEM subjects at the high level through the final years of upper secondary school and have the skills to excel in STEM fields at the tertiary level. The degree of selectivity and intensity of these programs varies across countries, as does the advanced nature of the content.

Given the importance that countries place on these specialized programs, TIMSS Advanced collects detailed data on student achievement in advanced mathematics and physics, particularly in relation to system structure, school organization, curricula, teacher education, and classroom practices. These data can inform educational policy makers of key predictors of student learning and point them toward effective strategies for improving the educational system in scientific and technological areas.

The TIMSS Advanced 2015 Context Questionnaire Framework establishes the foundation for the background information that will be collected by TIMSS Advanced. The context questionnaires are administered to the students participating in TIMSS Advanced, as well as to their teachers and school principals, and provide a wide array of policy relevant information about the home and school contexts for teaching and learning advanced mathematics and physics. The student questionnaires also ask about attitudes toward learning advanced mathematics and physics. In addition, countries participating in TIMSS Advanced 2015 each contribute information about their provision for advanced mathematics and physics education in their country's chapter of the *TIMSS 2015 Encyclopedia*.

Contexts for student learning in the final year of secondary school typically include community, school, classroom, and home environments. Reflecting this situation, the TIMSS Advanced 2015 Context Questionnaire Framework encompasses four broad areas:

- National and community contexts;
- School contexts;
- Classroom contexts; and
- Student characteristics and attitudes toward learning.

National and Community Contexts

At the national and community level, key policy decisions about how to nurture students into STEM careers are made in the context of the cultural, social, political, and economic situation of the country. The success a country has in providing effective advanced mathematics and physics instruction often depends on a number of interrelated national characteristics and decisions:

- Economic resources;
- Organization and structure of the educational system;
- Admission or recruitment into specialized STEM programs;
- Intended advanced mathematics and physics curricula;
- Teachers and teacher education; and
- Administration of high-stakes summative examinations.

Economic Resources

Adequate economic resources are crucial for implementing a rigorous STEM curriculum and providing better educational facilities for teaching STEM subjects, technological resources to aid students in their learning, and well-trained mathematics and physics teachers. Financial resources also provide the opportunity to invest in programs that promote mathematics and physics education and incentivize students to enter these fields, such as special science schools with cutting edge technological equipment or partnerships with researchers in high-tech industries.

Organization and Structure of the Educational System

Some countries have highly centralized educational systems in which most policy-related decisions are made at the national or regional level. In these systems, there is typically a high-level of educational uniformity across the system, in terms of curriculum, textbooks, and general policies. National policy makers can ensure that the curriculum reflects what the national government deems to be essential for the formation of young scientists and mathematicians. In addition, a centralized system allows countries to structure the educational system so that the quantity of students in the STEM pipeline matches the expectations and projected needs of the national economy.

Other countries have more decentralized systems in which many important decisions are delegated to local governments and schools. A decentralized structure can result in greater variation in the curriculum, how schools operate, and how students are taught. Likewise, schools and school districts may have more autonomy to decide the number of students admitted to advanced mathematics and physics programs, or the students themselves may have more curricular choices.

TIMSS Advanced 2008 showed that differences exist across countries in the number of students in the STEM pipeline. In many countries, there is concern that not enough students are choosing to enter STEM programs (Ainley, Kos, & Nicholas, 2008; European Commission, 2004; National Research Council, 2011; Organisation for Economic Co-operation and Development (OECD), 2008), and there also is concern that women and minority groups are underrepresented in STEM fields (National Research Council, 2010; National Research Council, 2011; OECD, 2008). In this context, some countries have national strategies to promote educational opportunities in these fields. National initiatives include the installation of STEM centers to improve STEM teaching and develop STEM culture, and competitions and campaigns to make science more appealing across society (Kearney, 2011).

Admission or Recruitment into Specialized STEM Programs

TIMSS Advanced examines the educational achievement of the relatively small proportion of a student cohort that participates in specialized programs of study in advanced mathematics and physics. In this context, it is important to understand how students are selected to participate in these STEM programs. In some countries, the number of students studying advanced mathematics and physics is linked to system-level tracking that assigns students to academic or vocational pathways. In the context of TIMSS Advanced 2015, understanding the timing and extent of the selection process is important to interpreting the results. Some countries track students with aptitude in mathematics and physics into elite secondary institutions. In other countries, the top mathematics and physics students attend schools with other students who are on a more general track.

Intended Advanced Mathematics and Physics Curricula

At the senior secondary level, compared to earlier grades, there is considerable differentiation between countries regarding the curricular goals for advanced mathematics and physics, both in how subject mastery is defined and how the curricula specify that mastery should be achieved.

For advanced mathematics, countries vary in how much they emphasize advanced content, such as calculus, as well as high-level algebra, geometry, and trigonometry. There are differences between countries on how much weight is placed on expressing mathematics theories, results, and problems in numerical, analytical, and graphical form. There also is variation between countries in the relative emphasis that is placed on communicating and reasoning mathematically, developing mathematical models to describe real situations, and the degree to which various digital computing devices are used and relied on in the problem solving process.

For physics, countries emphasize to varying degrees the TIMSS Advanced content domains of mechanics and thermodynamics, electricity and magnetism, and wave phenomena and atomic/nuclear physics. Some countries stress the practice of physics more than other countries. The use of inquiry in physics teaching also varies across curricula. Other teaching strategies that are implemented to varying degrees include student involvement in planning and carrying out investigations, student involvement in developing and using mental models, and the extent to which students analyze and interpret data.

The relative emphasis on communicating scientific theory, constructing explanations, and engaging in arguments from evidence varies across countries, as does the use of technology to support student work.

Teachers and Teacher Education

Considering the complexity of the advanced mathematics and physics subject matter, many educational systems struggle to develop and retain a sufficient number of advanced mathematics and physics teachers to fill the needs of secondary schools (American Association for Employment in Education, 2010; National Committee for the Mathematical Sciences of the Australian Academy of Science, 2006; Schleicher, 2012). The pathway to becoming a STEM teacher differs between countries, but generally the pathway includes advanced coursework in mathematics and/or physics in lower and upper secondary school as well as a university qualification in mathematics and/or physics.

Administration of High-stakes Summative Examinations

Because TIMSS Advanced 2015 assesses students at the end of their secondary school careers, a country or educational systems' employment of summative assessments can be an important educational factor to take into account when interpreting TIMSS Advanced results. These high-stakes assessments, which can be used to determine student graduation and honors as well as placement in post-secondary institutions, may be the focal point for students at this stage in their academic career.

School Contexts

A school's environment and organization can influence the ease and effectiveness of fostering the education of students in STEM fields. Accepting that an effective 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 Advanced focuses on a set of well-researched school quality indicators:

- School composition by student socioeconomic background;
- Instruction affected by resource shortages;
- Teacher career satisfaction and teacher retention;
- Principal leadership; and
- School climate.

School Composition by Student Socioeconomic Background

The collective socioeconomic status of the students in the school can be a strong predictor of the achievement of individual students (Martin, Foy, Mullis, & O'Dwyer, 2013; Rumberger & Palardy, 2005; Sirin, 2005). Attending a school with many students from advantaged backgrounds can have a beneficial effect over and above the effects of a student's own home background. Furthermore, the relationship between advantaged schools and achievement may be influenced by other school factors. For example, in some countries, schools with many students of lower socioeconomic status have difficulties recruiting highly qualified teachers (Akiba, LeTendre, & Scribner, 2007; Clotfelter, Ladd, & Vigdor, 2010; Schleicher, 2012).

Instruction Affected by Resource Shortages

As a means of promoting STEM subjects and attracting students to enter and remain in the pipeline, many countries heavily invest to ensure that STEM schools and subjects are well-resourced. Research has shown that the extent and quality of school resources are critical for quality instruction (Greenwald, Hedges, & Laine, 1996; Lee & Barro, 2001; Lee & Zuze, 2011). These may include resources as basic as well-trained teachers, or adequate classroom space and school facilities (Schneider, 2002). Results from TIMSS 2011 at the fourth and eighth grades indicate that students in schools that are sufficiently resourced generally have higher achievement than those at schools where resource shortages affect the capacity to implement the curriculum. Subject-specific resources for advanced mathematics and physics may include availability of a variety of computing devises (e.g., tablets and graphing calculators), software for educational games and simulations, and laboratory equipment for physics experiments.

Teacher Career Satisfaction and Teacher Retention

TIMSS Advanced 2008 results revealed that, in some countries, a high percentage of teachers were nearing retirement age and that there were concerns about having enough teachers qualified in these advanced subject areas to replace them. From a school leadership perspective, it is important to encourage qualified teachers in advanced mathematics and physics to stay in the profession by providing good working conditions and fostering teacher career satisfaction.

The transition from university to a school teaching position can be difficult for teachers. Consequently, in many countries a large percentage of new teachers leave the profession after only a few years of teaching (Australian Primary Principals' Association, 2007; Guarino, Santibañez, & Daley, 2006; Hancock & Scherff, 2010). The extent to which schools take an active role in the acculturation and transition of new teachers may be important for maintaining a stable teaching force. Mentoring programs, modeling of good teacher practice by peers, and induction programs designed by experienced teachers within the school may be important aids to the beginning teacher (Moskowitz & Stephens, 1997; Tillmann, 2005). Nevertheless, because there may be only one physics teacher in a small or medium-sized school, the implementation of subject-specific physics mentoring programs, as well as other subject-specific collaboration programs, may not be possible in many schools (Tesfaye & White, 2012).

Providing good working conditions for STEM teachers also is essential to teacher retention. A manageable workload, adequate facilities, and the availability of instructional materials are important ingredients to fostering productive working conditions and promoting teacher satisfaction (Johnson, 2006; Johnson, Kraft, & Papay, 2012). Important social factors in a school that can affect teacher career satisfaction include a positive school culture, collaboration among teaching staff, and the leadership of the principal (Johnson et al., 2012). Teacher collaboration, in particular, has been found to be associated with increased student learning (Goddard, Goddard, & Tschannen-Moran, 2007; Wheelan & Kesselring, 2005).

Principal Leadership

A characteristic of a successful principal is being able to articulate the mission of the school (Witziers, Bosker, & Krüger, 2003). As such, a principal makes important decisions about the relative emphasis that is placed on STEM education within the school. Principals can foster a culture that emphasizes STEM education by hiring well-qualified teachers in advanced mathematics and physics, promoting their professional development, offering an advanced curricula in technological areas, and organizing activities such as contests and exchanges that promote student interest in studying STEM subjects.

In addition, successful principals often are involved in guiding the teaching process as instructional leaders and ensuring that teachers receive the necessary training and development to produce high achievement among the students

(Robinson, Lloyd, & Rowe, 2008). Within the constraints of the educational system, it is often the principal's responsibility to ensure that instructional time, and in particular the time devoted to advanced mathematics and physics, is sufficient for the purposes of curriculum implementation.

School Climate

One of the principal's central duties is maintaining a safe, orderly, and disciplined school. Results from TIMSS Advanced 2008 showed that there was not much concern about discipline or safety problems at schools for students in these specialized programs. Respect among individual students and teachers as well as constructive interactions among administrators, teachers, parents, and students, all contribute to this positive school climate and lead to higher student achievement (Cohen, McCabe, Michelli, & Pickeral, 2009; Konishi, Hymel, Zumbo, & Li, 2010). A socially welcoming school environment and friendships with classmates also can foster a sense of belonging (Goodenow & Grady, 1993; Hamm & Faircloth, 2005; Juvonen, 2007). Teachers can promote a sense of belonging for students by fostering supportive teacher-student relationships (Cornelius-White, 2007; Marzano, Marzano, & Pickering, 2003).

Classroom Contexts

Because most of the teaching and learning in school takes place in the classroom, STEM learning is influenced by the classroom environment and instructional activities. TIMSS Advanced 2015 focuses on the following factors that impact teaching and learning:

- Teacher preparation and experience;
- TIMSS Advanced 2015 mathematics and physics topics taught;
- Classroom instructional resources and technology;
- Instructional time; and
- Instructional engagement.

This section benefitted especially from John Hattie's (2009) book, *Visible Learning: A Synthesis of Over 800 Meta-analyses Relating to Achievement*.

Teacher Preparation and Experience

The preparation and competence of teachers is critical (Darling-Hammond, 2000; Hill, Rowan, & Ball, 2005), especially given the advanced content knowledge and pedagogical training required to teach advanced mathematics or physics. Prospective teachers need coursework to gain advanced content knowledge in these subjects, to understand about how students learn, and to develop and implement pedagogy for engaging students in the learning process. With appropriate coursework, teachers can gain the competence necessary to teach these subject areas confidently and spark student interest in them (OECD, 2006).

Content-focused professional development is especially important for fostering student achievement in advanced mathematics and physics. Professional development through seminars, workshops, conferences, and professional journals can help teachers increase their effectiveness and broaden their knowledge (Blank & de las Alas, 2009; Yoon, Duncan, Lee, Scarloss, & Shapley, 2007), as well as expose teachers to recent developments within the STEM fields (OECD, 2008).

In addition to preservice education and training, teaching experience is essential, and the first years of teaching experience are especially important for teacher professional development (Harris & Sass, 2011; Leigh, 2010). However, research also has found that teachers continue to develop after five years of experience, and that this development can positively affect student achievement (Harris & Sass, 2011).

With education, training, and experience, teachers should feel prepared and confident to teach advanced mathematics and physics topics. Research has shown teachers' confidence in their teaching skills to be associated with increased student motivation and student learning (Bandura, 1997; Caprara, Barbaranelli, Steca, & Malone, 2006; Henson, 2002; OECD, 2006).

TIMSS Advanced 2015 Mathematics and Physics Topics Taught

A major focus of the implemented curriculum is the extent to which the advanced mathematics and physics topics in the TIMSS Advanced 2015 frameworks are covered in the classroom. TIMSS Advanced addresses this question by asking advanced mathematics and physics teachers of the participating students to indicate whether each of the topics tested has been covered in class in current or previous years, as well as the percentage of time in class devoted to each of the TIMSS Advanced 2015 content domains.

Classroom Instructional Resources and Technology

Improvements in the functionality and availability of a wide range of computing devices (e.g. tablets, calculators, and smartphones) have increased the potential for incorporating technology within advanced mathematics and physics instruction. Teachers' decisions to use technology in the classroom can result from their beliefs, attitudes, and comfort levels, as well as access to training and materials (Mueller, Wood, Willoughby, Ross, & Specht, 2008; Russell, Bebell, O'Dwyer, & O'Connor, 2003).

How best to incorporate technology into the classroom and what role technology should have in advanced mathematics and physics instruction continue to be questions of importance to advanced mathematics and physics curricula specialists and teachers. For example, in TIMSS Advanced 2008, calculator use in advanced mathematics and physics instruction varied widely among, and even within, countries, as did the type of calculators that were used. Research on graphing calculators has concluded that these devices aid students in gaining conceptual understanding of the content, and the gains from using a graphing calculator are maximized when calculators are employed both in instruction and testing (Ellington, 2006). However, with the increasing functionality and accessibility of digital devices such as computers, tablets, and smart phones, the use of handheld graphing calculators may be decreasing as students increasingly use applications to perform the calculations once done only on a calculator.

Computers, including tablets such as iPads, and the Internet provide students tools to explore physics and advanced mathematics concepts in depth. Computers are used in a variety of ways, including tutorials, simulations, and educational games. Applications for modeling and visualization can aid students in grasping the abstract concepts of advanced mathematics and physics. Computer applications also can aid students in conducting simulations. For these various technologies to be integrated effectively into instruction, teachers must feel comfortable using them and receive adequate technical and pedagogical support. Nonetheless, research has confirmed the positive effects of computer technology use in the classroom on student learning (Li & Ma, 2010; Liao & Chen, 2007; Tamim, Bernard, Borokhovski, Abrami, & Schmid, 2011).

Instructional Time

At the school level, the relative emphasis and amount of time specified for advanced mathematics and physics can affect students' opportunities to learn. Results from TIMSS Advanced 2008 show that there is variation between countries in the intended instructional time prescribed by the curriculum and the actual time of implementation in the classroom. In some countries, the advanced mathematics or physics programs of study are highly specialized, and students receive almost exclusive instruction in these subjects and related fields. In other countries, students take advanced mathematics and/or physics in addition to a general course load that includes instruction in the arts, humanities (national language(s), foreign language(s)) and social sciences (government, social studies), among other subjects.

Instructional Engagement

In order to learn the complex concepts in subjects like advanced mathematics and physics, students need to actively engage with the content. According to McLaughlin et al. (2005), student content engagement focuses the student's "in-the-moment" cognitive interaction with the content. "Learning occurs through the cognitive engagement of the learner with the appropriate subject matter knowledge" (McLaughlin et al., 2005, p.5). Engagement can take place when students listen to the teacher, conduct lab experiments, or solve a mathematics problem. Engagement has been conceptualized as the idea that a student's "in-the-moment" mindset is torn between meaningful involvement with instruction and distractions that are unrelated to the topics in the class (Yair, 2000). The challenge for the teacher is to use effective methods of instruction to maintain student engagement in the content, activating the students cognitively (Klieme, Pauli, & Reusser, 2009; Lipowsky et al., 2009).

Although lectures can be an integral part of advanced mathematics and physics instruction, effective teachers also ensure that students are actively involved in their own learning process. Active involvement can occur when students are working individually or with their peers (Shernoff, Csikszentmihalyi, Schneider, & Shernoff, 2003; Yair, 2000). Peer-tutoring, small-group work, and peer mentoring are effective strategies that promote student engagement and are linked to achievement (Hattie, 2009; Springer, Stanne, & Donovan, 1999).

In order for advanced mathematics and physics students to grasp difficult content, it is important that teachers link the new material and concepts to the students' prior knowledge and understanding (Kleime et al., 2009; McLaughlin et al., 2005). Students also are more engaged when they are challenged and face greater cognitive demands (Shernoff et al., 2003; Yair, 2000). However, with the complexity of the content covered in these advanced subjects, it is important that the teacher conveys to the students that the challenges of the tasks are attainable. In this respect, effective teaching is setting challenging yet attainable goals for each student and supporting the students in reaching the goals (Hattie 2009; Klein, Wesson, Hollenbeck, & Alge, 1999). In setting goals, it is important that students understand the process of achievement, what outcome is expected, and why the goal is important for the learning process (Hattie, 2009; Martin, 2006).

STEM teachers have an important role, not only to foster student learning in the classroom, but also to act as ambassadors for these career paths (OECD, 2006, 2008). Many countries face the problem that students decide to leave STEM fields to study other subjects during their upper secondary or undergraduate education. An inspiring teacher who can model enthusiasm for STEM fields of study can convey the idea that STEM careers can offer interesting and fruitful career options.

Student Characteristics and Attitudes Toward Learning

In order to better understand the factors that support and motivate students studying advanced mathematics and physics, it is important to collect information about the students' background characteristics and their attitudes toward mathematics and physics. TIMSS Advanced focuses on the following indicators of student achievement:

- Educational and career intentions;
- Student motivation to learn advanced mathematics and physics;
- Expectations for educational attainment;
- Home resources for learning;
- Home use of language(s) of instruction;
- Student gender; and
- Tutoring.

Educational and Career Intentions

The TIMSS Advanced questionnaire data provide important information about whether students intend on continuing along the STEM path in their postsecondary education as well as whether students are interested in entering STEM careers upon completion of their postsecondary education. Policy makers can use these data to inform projections about the future workforce in these fields. Longitudinal research has confirmed that early student career plans are an important predictor of student likelihood to obtain a university degree in a STEM field (Maltese & Tai, 2011; Tai, Liu, Maltese, & Fan, 2006).

Student Motivation to Learn Advanced Mathematics and Physics

TIMSS Advanced 2008 results showed a positive relationship between student affect towards advanced mathematics and physics and student achievement in these subjects. Students participating in these specialized programs tend to have a high level of motivation to excel in school, although their intent to continue on toward careers in STEM fields varies considerably. The source of academic motivation and how it can be facilitated within the school, classroom, and home have been recurrent areas of research (Bandura, 1997; Csikszentmihalyi, 1990; Deci & Ryan, 1985). Intrinsic motivation is an "energizer of behavior" (Deci & Ryan, 1985, p.32), and as such tends to be strongly related to student achievement and career choice. Students who are intrinsically motivated to learn mathematics or physics find the subject to be interesting and enjoyable (Deci & Ryan, 1985).

Nevertheless, not all students have a penchant for studying advanced mathematics or physics. A common strategy to recruit students into these fields is to instill motivation into students by advising them of the career options available for engineers, scientists, and mathematicians. Extrinsic motivation refers to the drive that comes from external rewards like praise, career success, money, and other incentives. However, while extrinsic rewards can entice students to study and even excel in STEM fields, research shows that intrinsic motivation is more closely related to achievement than extrinsic motivation (Becker, McElvany, & Kortenbruck, 2010; Vansteenkiste, Timmermans, Lens, Soenens, & Van den Broeck, 2008).

Expectations for Educational Attainment

Students who excel in highly quantitative subjects, such as advanced mathematics and physics, generally have high expectations for their educational attainment, and these expectations drive them to persist through the rigors posed by challenging mathematical and scientific content. Research on educational expectations has found socioeconomic status to be highly related to a student's educational expectations, as is the selectivity and composition of the school that the student attends (Sikora & Saha, 2007). Research has found that students may reevaluate their educational expectations over time as they receive more information on their abilities and the opportunities that may be presented, although there is contention about the extent of this reevaluation process (Andrew & Hauser, 2011; Morgan, 2005).

Home Resources for Learning

In educational research, the most influential predictors of student achievement tend to be those that measure socioeconomic status of the parents or caregivers (Bradley & Corwyn, 2002; Dahl & Lochner, 2012; Davis-Kean, 2005; Martin, Foy, Mullis, & O'Dwyer, 2013; Sirin, 2005; Willms, 2006), often indicated through proxy variables such as parental level of education, income, occupational class, and, more generally, home resources such as access to technology, the Internet, and books. In addition to being predictors of student achievement, socioeconomic characteristics provide important insight into the factors influencing students entering the STEM pipeline, and to issues of access to STEM programs generally within countries. Because these students are in a specialized educational program, identifying their home background characteristics can facilitate countries in identifying underrepresented sub-populations in the STEM pipeline as well as achievement gaps among students taking these advanced courses.

Home Use of Language(s) of Instruction

Language fluency can be an obstacle to participation in STEM pipeline programs (Airey & Linder, 2006; Gasbarra & Johnson, 2008). TIMSS and other studies have shown that a learning gap can be associated with students not speaking the language of instruction in the home (Entorf & Minoui, 2005; Schnepf, 2007; Trong, 2009). If students are not fluent in the language of instruction, this can be an additional barrier to participation in the advanced coursework necessary for STEM programs.

Student Gender

The underrepresentation of women in advanced mathematics and physics careers is a concern in many countries (OECD, 2008). While TIMSS results have demonstrated increasing similarities in mathematics and science achievement between the genders at the fourth and eighth grades, TIMSS Advanced 2008 results showed that in most participating countries more male students were taking the advanced mathematics and physics courses than female students, and in many countries male students performed better than female students in advanced mathematics and physics. The pattern agrees with research on STEM career paths (OECD, 2006, 2008).

Tutoring

In some countries, students in advanced courses enroll in shadow education programs, private tutoring, or classes outside of formal schooling to supplement the academic instruction received at school. The reason advanced students enroll in this supplemental schooling varies. Some students enroll in these programs to keep pace with the class, and they find the support provided to be critical for understanding the complex material covered in these courses (Baker, Akiba, LeTendre, & Wiseman, 2001). Students also enroll in shadow education programs with the goal of mastering the curriculum in order to excel in school or to do well on a high-stakes examination (Bray, 2007; Buchman, Condron, & Roscigno, 2010), especially in circumstances where students compete for limited opportunities in select educational programs (Baker & LeTendre, 2005).

CHAPTER 4

TIMSS Advanced 2015 Assessment Design

Michael O. Martin, Ina V.S. Mullis, and Pierre Foy

Overview

The TIMSS Advanced 2015 assessment measures trends in student achievement in advanced mathematics and physics at the end of secondary schooling for students with advanced preparation in these subjects. The assessment comprises written tests in advanced mathematics and physics together with sets of questionnaires that gather information on the educational and social contexts for achievement at the end of secondary schooling. First administered in 1995 and again in 2008, TIMSS Advanced 2015 continues this trend line for those countries that participated in prior assessments, with each assessment linked to the next. Significantly in 2015, and for the first time since 1995, TIMSS Advanced will be administered in the same year as the fourth and eighth grade TIMSS assessments of mathematics and science; this will enable countries participating at all three levels (the fourth grade, the eighth grade, and at the end of secondary school) to collect data on student achievement in mathematics and science spanning the entire primary and secondary education system.

As described in the advanced mathematics and physics assessment frameworks (Chapters 1 and 2, respectively), the TIMSS Advanced assessments are wide ranging in their coverage of these subjects; the assessments are designed to provide valid and reliable information on the full range of student proficiency in each subject, as well as in the major content and cognitive domains.

A consequence of the TIMSS Advanced reporting goals is that the assessments require more assessment items than can reasonably be given to a student in the available testing time. Accordingly, TIMSS Advanced 2015 uses a matrix-sampling approach that assembles the pool of achievement items in advanced mathematics and physics into a set of 12 assessment booklets—6 advanced mathematics, and 6 physics booklets—with each student completing one booklet only. Each item appears in two booklets, providing a mechanism for linking the student responses from the various booklets. Booklets are distributed among sampled students so that the groups of students responding to each booklet are approximately equivalent in terms of student ability.

Student Populations Assessed

TIMSS Advanced assesses the advanced mathematics and physics achievement of students in the final year of secondary schooling. This is the twelfth year of formal schooling in most countries. The target populations for the TIMSS Advanced assessments are defined as follows:

> For advanced mathematics, all students in the final year of secondary schooling who are taking advanced mathematics courses.
>
> For physics, all students in the final year of secondary schooling who are taking physics courses.

Student eligibility is determined in terms of the courses the student has taken and, in countries with tracked educational systems, the track to which the student belongs. The decision as to which mathematics or physics courses should be included in defining the target population is determined by each participating country. In general, the courses included should be those taken by the most advanced students, typically those students planning further study in mathematics or physics at university or other institutes of higher education. Courses should cover most of the advanced mathematics and physics content topics specified in Chapters 1 and 2 of the *TIMSS Advanced 2015 Assessment Frameworks*. Depending on their course experience, students in the final year of secondary schooling may belong to the advanced mathematics target population, the physics target population, or both. Students who belong to both populations will be randomly assigned either an advanced mathematics booklet or a physics booklet.

Reporting Student Achievement

TIMSS Advanced 2015 will provide a detailed picture of the achievement of advanced mathematics and physics students in the final year of secondary school in each participating country. This will include achievement in each of the content and cognitive domains (as defined in Chapters 1 and 2) as well as overall advanced mathematics and physics achievement. Consistent with the goal of providing valid and reliable information on the full range of student proficiency in each subject, the complete TIMSS Advanced 2015 assessment consists of a large pool of advanced mathematics and physics questions, known as items. However, in order to keep the assessment burden on any one student to a minimum, each student is presented with only a sample of the items, as described in the next section. Following data collection, student responses are placed on common advanced mathematics and physics scales in order to provide an overall picture of the assessment results for each country.

One of the strengths of TIMSS Advanced is its measurement of trends over time in advanced mathematics and physics achievement. The TIMSS Advanced achievement scales provide a common metric on which countries can compare the progress of their student populations in advanced mathematics and physics from assessment to assessment. The TIMSS Advanced achievement scales were established in 1995, separately for advanced mathematics and physics, so that 100 points on the scale was equal to one standard deviation across all of the countries that participated in TIMSS 1995, and the scale midpoint of 500 was equal to the international average across those countries. Using items that were administered in both 1995 and 2008 assessments as a basis for linking the two sets of assessment results, the TIMSS Advanced 2008 data also were placed on the scale so that countries could gauge changes in students' advanced mathematics and physics achievement since 1995. Using similar procedures, the data from TIMSS Advanced 2015 will be placed on the TIMSS Advanced scales, enabling TIMSS Advanced 2015 countries that have participated in previous assessments to have comparable achievement data from 1995, 2008, and 2015, and to plot changes in performance over this 20-year period.

As previously mentioned, in addition to the achievement scales for advanced mathematics and physics overall, TIMSS Advanced 2015 includes scales for reporting relative student performance in each of the advanced mathematics and physics content and cognitive domains. Specifically, in advanced mathematics there are three content scales, corresponding to three content domains: algebra, calculus, and geometry. Similarly, in physics there are also three content scales, corresponding to three content domains: mechanics and thermodynamics, electricity and magnetism, and wave phenomena and atomic/nuclear physics. The *TIMSS Advanced 2015 Assessment Frameworks* specify three cognitive domains—knowing, applying, and reasoning—which span the content of both advanced mathematics and physics, and for which reporting scales are constructed.

TIMSS Advanced 2015 Student Booklet Design

A consequence of the ambitious reporting goals of TIMSS Advanced is that many more items are required for the assessment than can be answered by any one student in the available testing time. In order to address this challenge, TIMSS Advanced 2015 uses a matrix-sampling approach: the entire assessment pool of advanced mathematics and physics items are packaged into a set of 6 advanced mathematics booklets and 6 physics booklets, with each student completing just one booklet. Each item appears in two booklets, providing a mechanism for linking together the student responses from the various booklets. Booklets are distributed randomly among students in participating classrooms so that the groups of students completing each booklet are approximately equivalent in terms of ability. TIMSS Advanced uses item response theory scaling methods in order to assemble a comprehensive picture of the achievement of a country's student population by pooling individual students' responses to the booklets that they are assigned. This approach reduces to manageable proportions what otherwise would be an impossible student burden, albeit at the cost of greater complexity in booklet assembly, data collection, and data analysis.

In order to facilitate the process of creating the student achievement booklets, TIMSS Advanced groups the assessment items into a series of item blocks, with each item block consisting of approximately 10 items and requiring 30 minutes of assessment time. As far as possible, within each block the distribution of items across content and cognitive domains matches the distribution across the overall item pool. TIMSS Advanced 2015 consists of 18 item blocks in total: 9 blocks of advanced mathematics items, and 9 blocks of physics items. This represents an increase of 4 blocks over the 14 blocks that formed the basis of TIMSS Advanced 2008. The additional item blocks were added in order to provide more extensive coverage of the content and cognitive domains. Student booklets for advanced mathematics and physics are assembled from various combinations of these item blocks.

Following the 2008 assessment, three of the advanced mathematics item blocks and three of the physics blocks were retained and kept secure for use in measuring trends in 2015. The remaining 8 blocks (4 advanced mathematics, and 4 physics) were released into the public domain for use in publications, research, and teaching, to be replaced by newly-developed items for the TIMSS Advanced 2015 assessment. Accordingly, the 18 blocks in the TIMSS Advanced 2015 assessment comprise 6 blocks of trend items (3 advanced mathematics, and 3 physics) and 12 blocks of items newly developed for 2015. As presented in Exhibit 3, the TIMSS Advanced 2015 advanced mathematics blocks are labeled M1 through M9, and the physics blocks P1 through P9.

Exhibit 3: TIMSS Advanced 2015 Item Block Design

Advanced Mathematics Blocks		Physics Blocks	
M1	Block M2 from TIMSS Advanced 2008	P1	Block P2 from TIMSS Advanced 2008
M2	New items for TIMSS Advanced 2015	P2	New items for TIMSS Advanced 2015
M3	Block M4 from TIMSS Advanced 2008	P3	Block P4 from TIMSS Advanced 2008
M4	New items for TIMSS Advanced 2015	P4	New items for TIMSS Advanced 2015
M5	Block M5 from TIMSS Advanced 2008	P5	Block P5 from TIMSS Advanced 2008
M6	New items for TIMSS Advanced 2015	P6	New items for TIMSS Advanced 2015
M7	New items for TIMSS Advanced 2015	P7	New items for TIMSS Advanced 2015
M8	New items for TIMSS Advanced 2015	P8	New items for TIMSS Advanced 2015
M9	New items for TIMSS Advanced 2015	P9	New items for TIMSS Advanced 2015

Students are expected to spend, on average, 30 minutes on each item block. Consequently, the 9 blocks of advanced mathematics items are estimated to contain 4½ hours of testing time, and the physics blocks a further 4½ hours. From past experience with TIMSS Advanced, 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 (advanced mathematics or physics) must fit into 90 minutes. An additional 30 minutes for a student questionnaire also is required.

In choosing how to distribute item blocks across student achievement booklets, the major goal was to maximize coverage of the framework while ensuring that every student responded to sufficient items in order to provide reliable measurement of trends in both advanced mathematics and physics.

A further goal was to ensure that achievement in the advanced mathematics and physics content and cognitive domains could be measured reliably. In order to enable linking among booklets while keeping the number of booklets to a minimum, each item block appears in two booklets.

As presented in Exhibit 4, the 18 assessment item blocks are distributed across 12 student achievement booklets. Booklets 1 through 6 contain advanced mathematics items, and Booklets 7 through 12 contain physics items. Each student booklet consists of three item blocks.

Exhibit 4: TIMSS Advanced 2015 Student Achievement Booklet Design

	Assessment Blocks		
Student Achievement Booklet	Advanced Mathematics		
	Part 1	Part 2	Part 3
Booklet 1	M1	M2	M4
Booklet 2	M4	M3	M6
Booklet 3	M6	M7	M5
Booklet 4	M3	M8	M7
Booklet 5	M8	M5	M9
Booklet 6	M2	M9	M1
	Physics		
Booklet 7	P1	P2	P4
Booklet 8	P4	P3	P6
Booklet 9	P6	P7	P5
Booklet 10	P3	P8	P7
Booklet 11	P8	P5	P9
Booklet 12	P2	P9	P1

Countries participating in TIMSS Advanced aim for a sample of approximately 3,600 advanced mathematics students and the same number of physics students in order to ensure that there are enough respondents for each item. In classes where all students belong to both the advanced mathematics and physics populations, all 12 student booklets are distributed among the students according to a predetermined random order, so that approximately equal proportions of students respond to each booklet. In classes containing only students from the advanced mathematics population, only the six advanced mathematics booklets are distributed. Similarly, in classes with physics students, only the physics booklets are distributed.

Question Types and Scoring Procedures

Students' knowledge and understanding of mathematics and science are assessed through a range of questions in each subject. As described in the *TIMSS 2015 Item Writing Guidelines* (Mullis & Martin, 2013), two question (i.e., item) formats are used in the TIMSS Advanced assessments: multiple-choice and constructed-response. At least half of the total number of points represented by all of the items will come from multiple-choice items. Each multiple-choice item is worth one score point. Constructed-response items generally are worth one or two score points, depending on the nature of the task and the skills required to complete the item. In developing assessment items, the choice of item format depends on the mathematics or physics being assessed as well as the format that best enables students to demonstrate their proficiency.

Multiple-choice Items

In TIMSS, multiple-choice items provide students with four response options, of which only one is correct. These items can be used to assess any of the behaviors in the cognitive domains. Multiple-choice items allow valid, reliable, and economical measurement of a wide range of content in a relatively short testing time. However, because they do not allow for students' explanations or supporting statements, these items may be less suitable for assessing students' ability to make more complex interpretations or evaluations. In developing the multiple-choice items, it is important that the questions and response options are written clearly and concisely 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 Items

For this type of test item students are required to construct a written response, rather than select a response from a set of options. Because these items allow students to provide explanations, support an answer with reasons or numerical evidence, draw diagrams, or display data, constructed-response items 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.

The scoring guide for each constructed-response item describes the essential features of appropriate and complete responses. The guides focus on evidence of the type of behavior the item 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 items, 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 advanced mathematics and physics as evidenced by misconceptions and errors is an important aim of the study.

Because constructed-response items constitute an important component of the TIMSS Advanced 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. In order to ensure consistent application of the scoring guides for trend items in the 2015 assessment, IEA has archived samples of student responses to the TIMSS Advanced 2008 assessments from each country; these are used in order to train scorers in 2015 and to monitor consistent application for those items appearing in both assessments.

Score Points

In developing the assessment, the aim is to create item blocks that each provide, on average, about 15 score points. Item blocks contain a variety of item types, including multiple-choice items (1 point each) and constructed-response items (1, 2, or more points) that allow for partial as well as full credit. The exact number of score points and the exact distribution of question types per block varies somewhat.

Releasing Assessment Material to the Public

TIMSS Advanced 2015 is the third in the TIMSS Advanced series of studies, and provides data on trends in mathematics and science achievement over a 20-year period, from 1995 through 2008 to 2015. It is envisaged that, in the future, TIMSS Advanced will be administered on the same four-year schedule as TIMSS (i.e., in 2019, 2023, and so on into the future). With each assessment, as the international reports are published, a selection of items are released in order to provide the public with as much information as possible about the nature and contents of the assessment. At the same time, the measurement of trends is safeguarded 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 Advanced 2015 design, 4 of the 9 assessment blocks in each subject will be released when the assessment results for 2015 are published; the remaining 5 will be kept secure for use in later assessments. The released blocks will include one block containing trend items from 1995, one block of trend items from 2008, and two blocks of items used for the first time in 2015. The released items will be replaced with new items before the next survey cycle, in 2019.

Background Questionnaires

An important purpose of TIMSS Advanced is to identify the procedures and practices that are effective in improving students' learning in advanced mathematics and physics. In order to better understand the contextual factors detailed in Chapter 3 that affect students' learning, TIMSS Advanced administers background questionnaires to students, their teachers, and their school principals. TIMSS Advanced also administers curriculum questionnaires to specialists in order to collect information about educational policies and the national contexts that shape the content and implementation of the advanced mathematics and physics curricula across countries. Finally, the *TIMSS Encyclopedia* provides a more qualitative description of mathematics and science education in the participating countries.

Student Questionnaire

A student questionnaire is completed by each student who takes the TIMSS Advanced assessment. This questionnaire asks about aspects of students' home and school lives, including basic demographic information, their home environment, school climate for learning, and self-perception and attitudes toward advanced mathematics and/or physics. The student questionnaire requires about 30 minutes to complete.

Teacher Questionnaires

A teacher questionnaire is completed by the teachers of the advanced mathematics and/or physics classes sampled to take part in the TIMSS Advanced testing. This questionnaire is designed to gather information on teacher characteristics, the classroom contexts for teaching and learning advanced mathematics and physics, and the topics taught in these subjects.

In particular, the teacher questionnaire asks about teachers' backgrounds, their views on opportunities for collaboration with other teachers, their job satisfaction, and their education and training, as well as professional development. The questionnaire also collects information on characteristics of the classes tested in TIMSS Advanced, instructional time, materials, and activities for teaching mathematics and science and promoting students' interest in the subjects, use of computers, assessment practices, and homework.

Although the general background questions are parallel across advanced mathematics and physics versions of the teacher questionnaire, questions pertaining to instructional and assessment practices, content coverage, and teachers' views about teaching the subject matter are tailored toward advanced mathematics or physics. Many questions, such as those related to classroom activities, are specific to the classes sampled for TIMSS Advanced. This questionnaire requires about 30 minutes of teachers' time to complete.

School Questionnaire

The principal of each school participating in TIMSS Advanced is asked to respond to this questionnaire. It asks about school characteristics, instructional time, resources and technology, parental involvement, school climate for learning, teaching staff, and the role of the principal. This questionnaire is designed to take about 30 minutes to complete.

Curriculum Questionnaires

The National Research Coordinator in each country is responsible for completing the advanced mathematics and physics curriculum questionnaire, drawing on the expertise of curriculum specialists and educators. The questionnaire is designed to collect basic information about the organization of the advanced mathematics and physics curriculum in each country, and about the content of these subjects intended to be covered by the end of secondary schooling.

TIMSS 2015 Encyclopedia

The *TIMSS 2015 Encyclopedia* provides context for mathematics and science instruction in the participating countries. Countries participating in TIMSS 2015 at the fourth and/or eighth grades each contribute a chapter to the encyclopedia. Those countries participating in TIMSS Advanced 2015 also will include information about advanced mathematics and physics curricula and instruction.

References

Ainley, J., Kos, J., & Nicholas, M. (2008). *Participation in science, mathematics and technology in Australian education* (ACER research monograph No. 63). Camberwell, Victoria, Australia: The Australian Council for Educational Research Ltd. Retrieved from http://www.acer.edu.au/documents/Mono63_MathsSciTechSept08.pdf

Airey, J. & Linder, C. (2006). Language and the experience of learning university physics in Sweden. *European Journal of Physics, 27*(3), 553–560.

Akiba, M., LeTendre, G.K., & Scribner, J.P. (2007). Teacher quality, opportunity gap, and national achievement in 46 countries. *Educational Researcher*, *36*(7), 369–387.

Andrew, M. & Hauser, R.M. (2011). Adoption? Adaptation? Evaluating the formation of educational expectations. *Social Forces, 90*(2), 497–520.

American Association for Employment in Education. (2010). *Educator supply and demand in the United States*. Columbus, OH: Author.

Australian Primary Principals' Association. (2007). *Experiences of beginning teachers.* Canberra: Author.

Baker, D.P., Akiba, M., LeTendre, G.K., & Wiseman, A.W. (2001). Worldwide shadow education: Outside-school learning, institutional quality of schooling, and cross-national mathematics achievement. *Educational Evaluation and Policy Analysis, 23*(1), 1–17.

Baker, D.P. & LeTendre, G.K. (2005). *National differences, global similarities: World culture and the future of schooling.* Stanford, CA: Stanford University Press.

Bandura, A. (1997). *Self-efficacy: The exercise of control.* New York, NY: W.H. Freeman and Company.

Becker, M., McElvany, N., & Kortenbruck, M. (2010). Intrinsic and extrinsic reading motivation as predictors of reading literacy: A longitudinal study. *Journal of Educational Psychology, 102*(4), 773–785.

Blank, R.K. & de las Alas, N. (2009). *Effects of teacher professional development on gains in student achievement. How meta analysis provides scientific evidence useful to education leaders*. Washington, DC: Council of Chief State School Officers. Retrieved from http://www.ccsso.org/Documents/2009/Effects_of_Teacher_Professional_2009.pdf

Bradley, R.H. & Corwyn, R.F. (2002). Socioeconomic status and child development. *Annual Review of Psychology*, *53*(1), 371–399.

Bray, M. (2007). *The shadow education system: Private tutoring and its implications for planners (Second edition).* Paris: UNESCO, International Institute for Education Planning. Retrieved from http://unesdoc.unesco.org/images/0011/001184/118486e.pdf

Buchman, C., Condron, D.J., & Roscigno, V.J. (2010). Shadow education, American style: Test preparation, the SAT and college enrollment. *Social Forces, 89*(2), 435–461.

Caprara, G.V., Barbaranelli, C., Steca, P., & Malone, P.S. (2006). Teachers' self-efficacy beliefs as determinants of job satisfaction and students' academic achievement: A study at the school level. *Journal of School Psychology, 44*(6), 473–490.

Clotfelter, C.T., Ladd, H.F., & Vigdor, J.L. (2010). Teacher credentials and student achievement in high school: A cross-subject analysis with student fixed effects. *The Journal of Human Resources, 45*(3), 655–681.

Cohen, J., McCabe, E.M., Michelli, N.M., & Pickeral, T. (2009). School climate:

Research, policy, practice and teacher education. *Teachers College Record, 111*(1), 180–213.

The College Board. (2012). *AP calculus course description*. New York, NY: Author. Retrieved from http://apcentral.collegeboard.com/apc/public/repository/ap-calculus-course-description.pdf

The College Board. (2012). *AP physics course description*. New York, NY: Author. Retrieved from http://apcentral.collegeboard.com/apc/public/repository/ap-physics-course-description.pdf

Cornelius-White, J. (2007). Learner-centered teacher-student relationships are effective: A meta-analysis. *Review of Educational Research*, *77*(1), 113–143.

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. New York, NY: Harper & Row.

Dahl, G.B. & Lochner, L. (2012). The impact of family income on child achievement: Evidence from the earned income tax credit. *American Economic Review, 102*(5), 1927–1956.

Darling-Hammond, L. (2000). How teacher education matters. *Journal of Teacher Education, 51*(3), 166–173.

Davis-Kean, P.E. (2005). The influence of parent education and family income on child achievement: The indirect role of parental expectations and the home environment. *Journal of Family Psychology, 19*(2), 294–304.

Deci, E.L. & Ryan, R.M. (1985). *Intrinsic motivation and self-determination in human behavior*. New York, NY: Plenum Press.

Education Bureau, Hong Kong SAR. (2007). *Mathematics curriculum and assessment guide (Secondary 4–6)*. Kowloon, Hong Kong: Author. Retrieved from http://www.edb.gov.hk/en/curriculum-development/kla/ma/curr/ss-math-2007.html

Education Bureau, Hong Kong SAR. (2007). *Physics curriculum and assessment guide (Secondary 4-6)*. Kowloon Tong, Hong Kong: Author. Retrieved from http://www.edb.gov.hk/attachment/en/curriculum-development/kla/science-edu/phy_final_e_20091005.pdf

Ellington, A.J. (2006). The effects of Non-CAS graphing calculators on student achievement and attitude levels in mathematics: A meta-analysis. *School Science and Mathematics, 106*(1), 16–26.

Entorf, H. & Minoiu, N. (2005). What a difference immigration policy makes: A comparison of PISA scores in Europe and traditional countries of immigration. *German Economic Review, 6*(3), 355–376.

European Commission. (2004). *Increasing human resources for science and technology in Europe*. Brussels, Belgium: European Communities. Retrieved from http://ec.europa.eu/research/conferences/2004/sciprof/pdf/final_en.pdf

Garden, R.A., Lie, S., Robitaille, D.F., Angell, C., Martin, M.O., Mullis, I.V.S., Foy, P., & Arora, A. (2006). TIMSS advanced 2008 assessment frameworks. Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.

Gasbarra, P. & Johnson, J. (2008). *Out before the game begins: Hispanic leaders talk about what's needed to bring more Hispanic youngsters into science, technology and math professions*. New York, NY: Public Agenda.

Goddard, Y.L., Goddard, R.D., & Tschannen-Moran, M. (2007). A theoretical and empirical investigation of teacher collaboration for school improvement and student achievement in public elementary schools. *The Teachers College Record*, *109*(4), 877–896.

Goodenow, C. & Grady, K.E. (1993). The relationship of school belonging and friends' values to academic motivation among urban adolescent students. *Journal of Experimental Education, 62*(1), 60–71.

Greenwald, R., Hedges, L.V., & Laine, R.D. (1996). The effect of school resources on student achievement. *Review of Educational Research*, *66*(3), 361–396.

Guarino, C.M., Sanitibañez, L., & Daley, G.A. (2006). Teacher recruitment and retention: A review of the recent empirical literature. *Review of Educational Research, 76*(2), 173–208.

Hamm, J.V. & Faircloth, B.S. (2005). The role of friendship in adolescents' sense of belonging. *New Directions for Child and Adolescent Development*, *2005*(107), 61–78.

Hancock, C.B. & Sherff, L. (2010). Who will stay and who will leave? Predicting secondary English teacher attrition risk. *Journal of Teacher Education, 61*(4), 328–338.

Harris, D.N. & Sass, T.R. (2011). Teacher training, teacher quality and student achievement. *Journal of Public Economics, 95*(7–8), 798–812.

Hattie, J. (2009). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement.* New York, NY: Routledge.

Henson, R.K. (2002). From adolescent angst to adulthood: Substantive implications and measurement dilemmas in the development of teacher efficacy research. *Educational Psychologist, 37*(3), 137–150.

Hill, H.C., Rowan, B., & Ball, D.L. (2005). Effects of teachers' mathematical knowledge for teaching on student achievement. *American Educational Research Journal, 42*(2), 371–406.

Johnson, S.M. (2006). *The workplace matters: Teacher quality, retention and effectiveness*. Washington, DC: National Education Association.

Johnson, S.M., Kraft, M.A., & Papay, J.P. (2012). How context matters in high-need schools: The effects of teachers' working conditions on their professional satisfaction and their students' achievement. *Teachers College Record, 114*(10), 1–39.

Juvonen, J. (2007). Reforming middle schools: Focus on continuity, social connectedness, and engagement. *Educational Psychologist*, *42*(4), 197–208.

Kearney, C. (2011). *Efforts to increase students' interest in pursuing science, technology, engineering, and mathematics studies and careers: National measures taken by 21 of European Schoolnet's member countries—2011 report.* Brussels: European Schoolnet (EUN Partnership AISBL). Retrieved from http://spice.eun.org/c/document_library/get_file?p_l_d=16294&folderId=16435&name= DLFE-9323.pdf

Klein, H.J., Wesson, M.J., Hollenbeck, J.R., & Alge, B.J. (1999). Goal commitment and the goal-setting process: Conceptual clarification and empirical synthesis. *Journal of Applied Psychology, 84*(6), 885–896.

Klieme, E., Pauli, C., & Reusser, K. (2009). The Pythagoras study—Investigating effects of teaching and learning in Swiss and German mathematics classrooms. In T. Janik & T. Seidel (Eds.), *The power of video studies in investigating teaching and learning in the classroom*. (pp. 137–160). Münster: Waxmann.

Konishi, C., Hymel, S., Zumbo, B.D., & Li, Z. (2010). Do school bullying and student-teacher relationships matter for academic achievement? A multilevel analysis. *Canadian Journal of School Psychology, 25*(1), 19–39.

Lee, J.-W. & Barro, R.J. (2001). Schooling quality in a cross-section of countries. *Economica, New Series*, *68*(272), 465–488.

Lee, V.E. & Zuze, T.L. (2011). School resources and academic performance in Sub-Saharan Africa. *Comparative Education Review*, *55*(3), 369–397.

Leigh, A. (2010). Estimating teacher effectiveness from two-year changes in students' test scores. *Economics of Education Review, 29*(3), 480–488.

Li, Q. & Ma, X. (2010). A meta-analysis of the effects of computer technology on school students' mathematics learning. *Educational Psychology Review, 22*(3), 215–243.

Liao, Y.-K. & Chen, Y-W. (2007). The effect of computer simulation instruction on student learning: A meta-analysis of studies in Taiwan. *Journal of Information Technology and Applications, 2*(2), 69–79.

Lipowsky, F., Rakoczy, K., Pauli, C., Drollinger-Vetter, B., Klieme, E., & Reusser, K. (2009). Quality of geometry instruction and its short-term impact on students' understanding of the Pythagorean Theorem. *Learning and Instruction, 19*(6), 527–537.

Maltese, A.V. & Tai, R.H. (2011). Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among US students. *Science Education Policy*, *95*(5), 877–907.

Martin, A.J. (2006). Personal bests (PBs): A proposed multidimensional model and empirical analysis. *British Journal of Educational Psychology, 76*(4), 803–825.

Martin, M.O., Foy, P., Mullis, I.V.S., & O'Dwyer, L.M. (2013). Effective schools in reading, mathematics, and science at the fourth grade. In M.O. Martin & I.V.S. Mullis (Eds.), *TIMSS and PIRLS 2011: Relationships among reading, mathematics, and science achievement at the fourth grade—Implications for early learning*. Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College. Retrieved from http://timssandpirls.bc.edu/timsspirls2011/relationships.html

Marzano, R.J., Marzano, J.S., & Pickering, D.J. (2003). *Classroom management that works: Research-based strategies for every teacher.* Alexandria, VA: Association of Supervision and Curriculum Development.

McLaughlin, M., Mc.Grath, D.J., Burian-Fitzgerald, M.A., Lanahan, L., Scotchmer, M., Enyeart, C., & Salganik, L. (2005, April). *Student content engagement as a construct for the measurement of effective classroom instruction and teacher knowledge*. Paper presented at the annual meeting of the American Educational Researchers Association, Montreal, Canada.

Morgan, S.L. (2005). *On the edge of commitment: Educational attainment and race in the United States*. Stanford, CA: Stanford University Press.

Moskowitz, J. & Stephens, M. (Eds.). (1997). *From students of teaching to teachers of students: Teacher induction around the Pacific rim*. Washington, DC: US Department of Education.

Mueller, J., Wood, E., Willoughby, T., Ross, C., & Specht, J. (2008). Identifying discriminating variables between teachers who fully integrate computers and teachers with limited integration. *Computers & Education, 51*(4), 1523–1537.

Mullis, I.V.S. & Martin, M.O. (2013). *TIMSS 2015 item writing guidelines*. Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.

Mullis, I.V.S., Martin, M.O., Robitaille, D.F., & Foy, P. (2009). *TIMSS advanced 2008 international report: Findings from IEA's study of achievement in advanced mathematics and physics in the final year of secondary school*. Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College. Retrieved from http://timssandpirls.bc.edu/timss_advanced/ir.html

National Committee for the Mathematical Sciences of the Australian Academy of Science. (2006). *Mathematics and statistics: Critical skills for Australia's* *future. The national strategic review of mathematical sciences research in Australia*. Canberra: Australian Academy of Science. Retrieved from http://www.review.ms.unimelb.edu.au/FullReport2006.pdf

National Governors Association Center for Best Practices, Council of Chief State School Officers. (2010). *Common core state standards for mathematics.* Washington, DC: National Governors Association Center for Best Practices, Council of Chief State School Officers.

National Research Council. (2010). *Rising above the gathering storm, revisited: Rapidly approaching category 5*. Washington, DC: The National Academies Press.

National Research Council. (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. Washington, DC: The National Academies Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.

Organisation for Economic Co-operation and Development (OECD). (2006). *Evolution of student Interest in science and technology studies: Policy report*. Paris: OECD Publications. Retrieved from http://www.oecd.org/science/sci-tech/36645825.pdf

Organisation for Economic Co-operation and Development (OECD). (2008). *Encouraging student interest in science and technology studies*. Paris: OECD Publishing. Retrieved from http://www.oecd.org/sti/sci-tech/encouragingstudentinterestinscienceandtechnologystudies.htm

Robinson, V.M.J., Lloyd, C.A., & Rowe, K.J. (2008). The impact of leadership on student outcomes: An analysis of the differential effects of leadership types. *Educational Administration Quarterly, 44*(5), 635–674.

Rumberger, R.W. & Palardy, G.J. (2005). Does segregation still matter? The impact of student composition on academic achievement in high school. *The Teachers College Record*, *107*(9), 1999–2045.

Russell, M., Bebell, D., O'Dwyer, L., & O'Connor, K. (2003). Examining teacher technology use: Implications for preservice and inservice teacher preparation. *Journal of Teacher Education, 54*(4), 297–310.

Schleicher, A. (Ed.). (2012). *Preparing teachers and developing school leaders for the 21st century*: *Lessons from around the world*. Paris: OECD Publishing. Retrieved from http://www.oecd.org/site/eduistp2012/49850576.pdf

Schneider, M. (2002). *Do school facilities affect academic outcomes?* Washington, DC: National Clearinghouse for Educational Facilities.

Schnepf, S.V. (2007). Immigrants' educational disadvantage: An examination across ten countries and three surveys. *Journal of Population Economics, 20*(3), 527–545.

Shernoff, D.J., Csikszentmihalyi, M., Schneider, B., & Shernoff, E.S. (2003). Student engagement in high school classrooms from the perspective of flow theory. *School Psychology Quarterly, 18*(2), 158–176.

Sikora, J. & Saha, L.J. (2007). Corrosive inequality? Structural determinants of educational and occupational expectations in comparative perspective. *International Education Journal: Comparative Perspectives, 8*(3), 57–78.

Singapore Examinations and Assessment Board. (2013). *Mathematics higher 2 syllabus*. Singapore: Author.

Retrieved from http://seab.gov.sg/aLevel/2013Syllabus/9740_2013.pdf

Singapore Examinations and Assessment Board. (2013). *Physics higher 2 syllabus*. Singapore: Author. Retrieved from http://seab.gov.sg/aLevel/2013Syllabus/9646_2013.pdf

Sirin, S.R. (2005). Socioeconomic status and academic achievement: A meta-analytic review of research. *Review of Educational Research*, *75*(3), 417–453.

Springer, L., Stanne, M.E., & Donovan, S.S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis. *Review of Educational Research, 69*(21), 21–51.

Tai, R.H., Liu, C.Q., Maltese, A.V., & Fan, X. (2006, May 26). Planning early for careers in science. *Science, 312*(5777), 1143–1144.

Tamim, R.M., Bernard, R.M., Borokhovski, E., Abrami, P.C., & Schmid, R.F. (2011). What forty years of research says about the impact of technology on learning: A second-order meta-analysis and validation study. *Review of Educational Research, 81*(1), 4–28.

Tesfaye, C.L. & White, S. (2012, February). High school physics teacher preparation. *Focus On*. Retrieved from: http://www.aip.org/sites/default/files/statistics/highschool/hs-teacherprep-09.pdf

Tillmann, L.C. (2005). Mentoring new teachers: Implications for leadership practice in an urban school. *Educational Administration Quarterly*, *41*(4), 609–629.

Trong, K. (2009). *Using PIRLS 2006 to measure equity in reading achievement internationally* (Doctoral dissertation, Boston College). Retrieved from http://dcollections.bc.edu/webclient/StreamGate?folder_id=0&dvs=1393864682579~72

Vansteenkiste, M., Timmermans, T., Lens, W., Soenens, B., & Van den Broeck, A. (2008). Does extrinsic goal framing enhance extrinsic goal-oriented individuals' learning and performance? An experimental test of the match perspective versus self-determination theory. *Journal of Educational Psychology, 100*(2), 387–397.

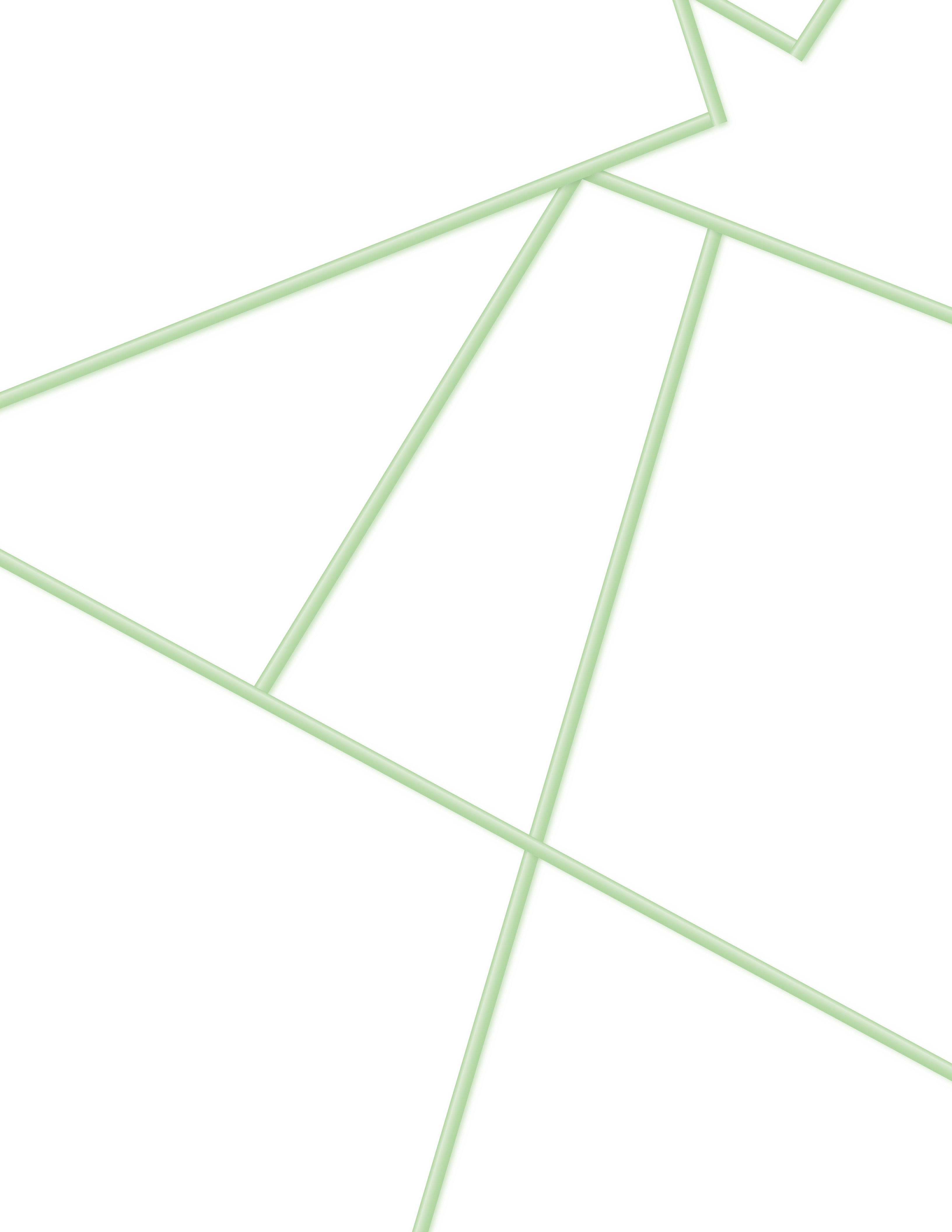
Wheelan, S.A. & Kesselring, J. (2005). Link between faculty group development and elementary student performance on standardized tests. *The Journal of Educational Research*, *98*(6), 323–330.

Willms, J.D. (2006). *Learning divides: Ten policy questions about the performance and equity of schools and schooling systems.* Montreal, Canada: UNESCO Institute for Statistics. Retrieved from http://unesdoc.unesco.org/images/0014/001470/147066e.pdf

Witziers, B., Bosker, R.J., & Krüger, M.L. (2003). Educational leadership and student achievement: The elusive search for an association. *Educational Administration Quarterly, 39*(3), 398–425.

Yair, G. (2000). Educational battlefields in America: The tug-of-war over students' engagement with instruction. *Sociology of Education, 73*(4), 247–269.

Yoon, K.S., Duncan, T., Lee, S.W.-Y., Scarloss, B., & Shapley, K.L. (2007). *Reviewing the evidence on how teacher professional development affects student achievement* (Institute of Education Sciences Report No. REL 2007-No.033). Washington, DC: US Department of Education. Retrieved from http://ies.ed.gov/ncee/edlabs/regions/southwest/pdf/rel_2007033.pdf



APPENDIX A

Acknowledgements

As an assessment of the achievement of students with advanced preparation in mathematics and physics at the end of secondary school, TIMSS Advanced is designed to complement the fourth and eighth grade mathematics and science assessments of TIMSS, the Trends in International Mathematics and Science Study. TIMSS and TIMSS Advanced are undertakings of IEA, an international cooperative of national research institutions and government agencies that has been conducting studies of cross-national achievement since 1959. With more than 60 member countries, IEA has a Secretariat in Amsterdam and a large Data Processing and Research Center in Hamburg.

The TIMSS & PIRLS International Study Center at Boston College, led by Executive Directors Ina V.S. Mullis and Michael O. Martin, is responsible for the direction and management of TIMSS, TIMSS Advanced, and PIRLS (Progress in International Reading Literacy Study). To carry out these ambitious international studies, the TIMSS & PIRLS International Study Center works closely with the IEA Secretariat in Amsterdam and the IEA Data Processing and Research Center in Hamburg. Also, Statistics Canada is responsible for school and sampling activities, and Educational Testing Service in Princeton, New Jersey provides guidance on psychometric methodology. Of fundamental importance, the TIMSS & PIRLS International Study Center relies on the National Research Coordinators designated by the participating countries to be responsible for the complex tasks involved in implementing the studies in their countries.

With each new assessment cycle of a study, one of the most important tasks is to update the assessment frameworks. Updating the TIMSS Advanced assessment frameworks for 2015 began in September of 2012, and has involved extensive input and reviews by individuals at the TIMSS & PIRLS International Study Center, the IEA, the TIMSS Advanced 2015 National Research Coordinators, and the two TIMSS expert committees: the TIMSS 2015 Science and Mathematics Item Review Committee, and the TIMSS 2015 Questionnaire Item Review Committee. Of the many individuals around the world who help make TIMSS Advanced a success, the intention here is to specifically acknowledge some of those who had particular responsibility and involvement in developing and producing the *TIMSS Advanced 2015 Assessment Frameworks*.

TIMSS Advanced 2015 Framework Development at the TIMSS & PIRLS International Study Center at Boston College

Ina V.S. Mullis, Executive Director, TIMSS & PIRLS

Michael O. Martin, Executive Director, TIMSS & PIRLS

Pierre Foy, Director of Sampling, Psychometrics, and Data Analysis

Alka Arora, Assistant Research Director–TIMSS Mathematics (up to 2014)

Victoria Centurino, TIMSS Science Coordinator

Martin Hooper, Senior Research Specialist, Technical Reporting

Kerry Cotter, TIMSS Research Associate

Amy Semerjian, Graduate Assistant

TIMSS Advanced 2015 Assessment Development Consultants

TIMSS Advanced 2015 owes a debt of gratitude to the Chief Mathematics and Chief Science Consultants as well as the two members of the TIMSS 2015 Science and Mathematics Item Review Committee (SMIRC) who worked with the TIMSS & PIRLS International Study Center Staff to draft updated advanced mathematics and physics frameworks for subsequent reviews by SMIRC and the TIMSS Advanced 2015 National Research Coordinators.

Liv Sissel Grønmo, Chief Mathematics Consultant

Lee Jones, Chief Science Consultant

Mary Lindquist, TIMSS 2015 Science and Mathematics Item Review Committee

Gerald Wheeler, TIMSS 2015 Science and Mathematics Item Review Committee

TIMSS 2015 Science and Mathematics Item Review Committee

The Science and Mathematics Item Review Committee (SMIRC), comprised of internationally recognized mathematics and science experts, reviewed and recommended updates for the TIMSS Advanced 2015 advanced mathematics and physics frameworks. The SMIRC also reviews the TIMSS Advanced 2015 items at key points in the development process.

Mathematics

Kiril Bankov
University of Sofia
Bulgaria

Sean Close
Educational Research Centre
St. Patrick's College
Ireland

Khattab Mohammad Ahmad Abulibdeh
National Center for Human Resources Development
Jordan

Sun Sook Noh
College of Education
Ewha Womans University
Korea

Torgeir Onstad
Department of Teacher Education and School Research
University of Oslo, ILS
Norway

Mary Lindquist
United States

Science

Jouni Viiri
University of Jyvaskyla
Finland

Alice Wong
University of Hong Kong
Hong Kong SAR

Berenice Michels
National Institute for Curriculum Development
The Netherlands

Gabriela Noveanu
Institute for Educational Sciences
Romania

Galina Kovaleva
Russian Academy of Education
Russian Federation

Vitaly Gribov
Moscow Lomonosov State University
Russian Federation

Gorazd Planinšič
University of Ljubljana
Slovenia

Wolfgang Dietrich
National Agency for Education
Sweden

Christopher Lazzaro
The College Board
United States

Gerald Wheeler
National Science Teachers' Association
United States

TIMSS 2015 Questionnaire Item Review Committee

The TIMSS 2015 Questionnaire Item Review Committee (QIRC) is comprised of National Research Coordinators from TIMSS and TIMSS Advanced 2015 who have special responsibility for providing guidance in updating the TIMSS Advanced 2015 Contextual Framework and the TIMSS Advanced 2015 Context Questionnaires.

Sue Thomson
Australian Council for Educational Research
Australia

Josef Basl
Czech School Inspectorate
Czech Republic

Wilfried Bos
University of Dortmund
Germany

Martina Meelissen
University of Twente
The Netherlands

Chew Leng Poon
Ministry of Education
Singapore

Oliver Neuschmidt
IEA Data Processing and Research Center

Peter Nyström
Umea University
Sweden

Stephen Provasnik
National Center for Education Statistics
United States

TIMSS Advanced 2015 National Research Coordinators

The TIMSS Advanced 2015 National Research Coordinators (NRCs) are responsible for implementing the study in their countries, and participated in a series of reviews of the updated frameworks.

France
Franck Salles
Ministere de l'Education Nationale

Georgia
Mamuka Jibladze
David Gabelaia
National Examinations Center

Italy
Elisa Caponera
Istituto Nazionale per la Valutazione del Sistema Educativo di Istruzione e di Formazione (INVALSI)

Lebanon

Leila Maliha Fayad
Educational Center for Research & Development
Ministry of Education

Norway

Liv S. Gronmo
University of Oslo, ILS

Portugal

João Maroco
Ministry of Education and Science

Russian Federation

Galina Kovaleva
Russian Academy of Education

Slovenia

Barbara Japelj Pavesic
Educational Research Institute

Sweden

Carola Borg
Skolverket

United States

Stephen Provasnik
National Center for Education Statistics

APPENDIX B

Example Advanced Mathematics Items

Two mathematical models are proposed to predict the return y, in dollars, from the sale of x thousand units of an article (where $0 < x < 5$). Each of these models, P and Q, is based on different marketing methods.

model P: $y = 6x - x^2$
model Q: $y = 2x$

For what values of x does model Q predict a greater return than model P?

Ⓐ $0 < x < 4$

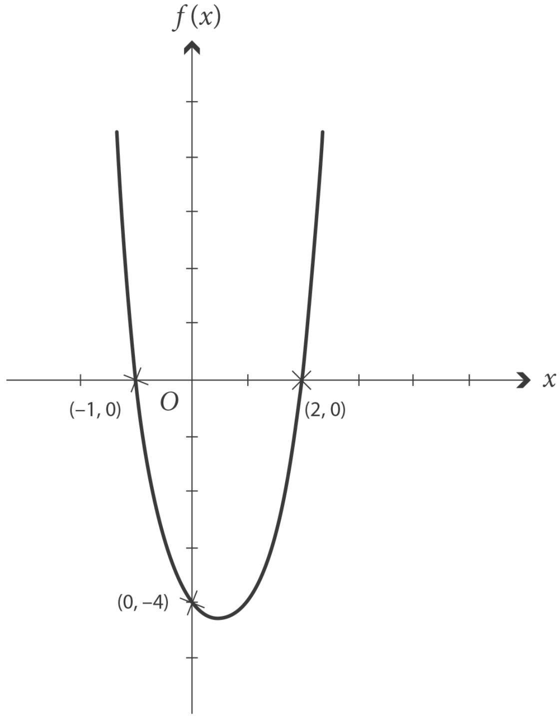
Ⓑ $0 < x < 5$

Ⓒ $3 < x < 5$

Ⓓ $3 < x < 4$

● $4 < x < 5$

MA13003



The graph of the function *f* is shown above. The equation of the function *f* is given by $f(x) = ax^2 + bx + c$. Find the values of *a*, *b*, and *c*.

Show your work.

$0 = a(-1)^2 + b(-1) + c$

$-4 = a(0)^2 + b(0) + c$ → $\boxed{c = -4}$

$0 = a(2)^2 + b(2) + c$

$0 = a - b - 4$ → $a = 4 + b$

$0 = 4a + 2b - 4$ → $\boxed{a = 2}$

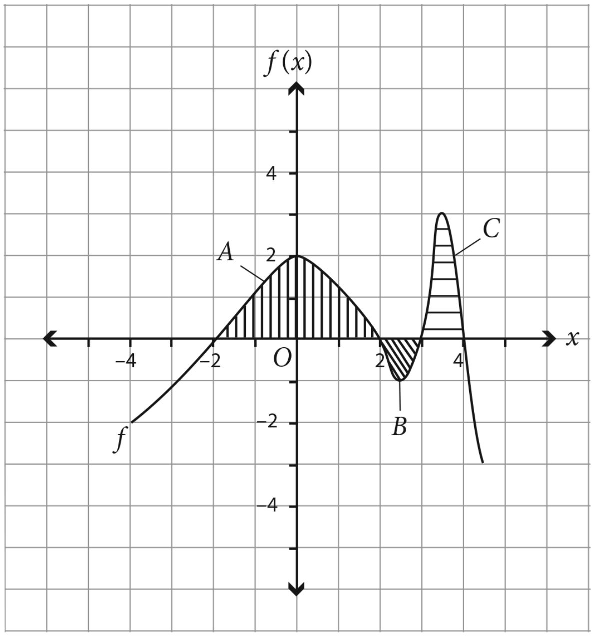
$0 = 4(4 + b) + 2b - 4$

$0 = 12 + 6b$

$\boxed{b = -2}$

$f(x) = 2x^2 - 2x - 4$

MA23141



For the areas between the graph of $f(x)$ and the x-axis shown above, area $A = 4.8$ units, area $B = 0.8$ units, and area $C = 2$ units.

What is the value of the definite integral $\int_{-2}^{4} f(x)dx$?

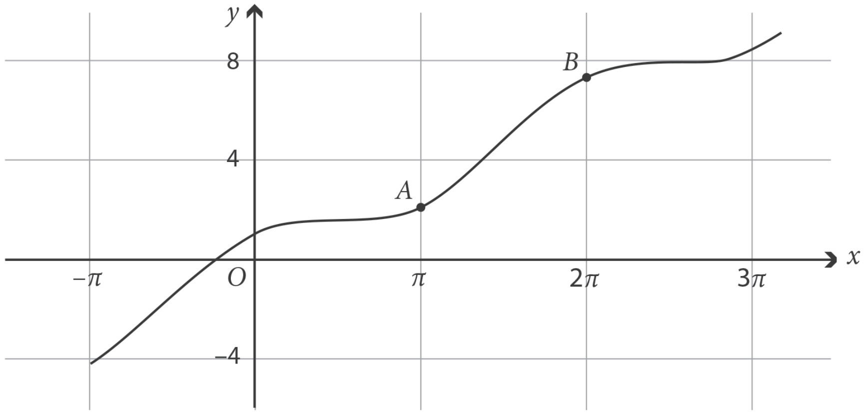
Ⓐ 5.6

● 6.0

Ⓒ 6.8

Ⓓ 7.6

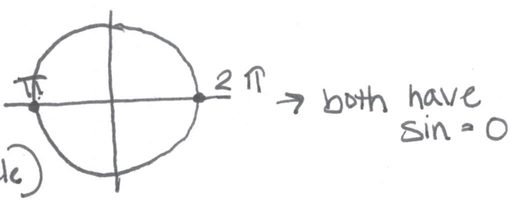
MA23050



Sophia is studying the graph of the function $y = x + \cos x$ shown above. She says that the slope at point *A* is the same as the slope at point *B*. Explain why she is correct.

If $f = x + \cos x$
then $f' = 1 - \sin x$

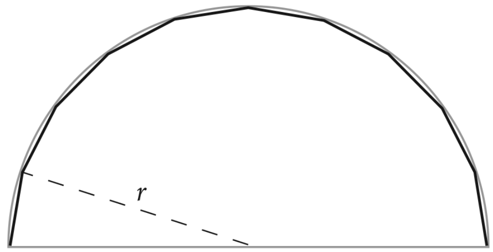
A both π and 2π, the sine (y value on unit circle) is 0.



At both π and 2π, $f' = 1$. So f has the same slope at $x = \pi$ and $x = 2\pi$

MA23198

MA23021



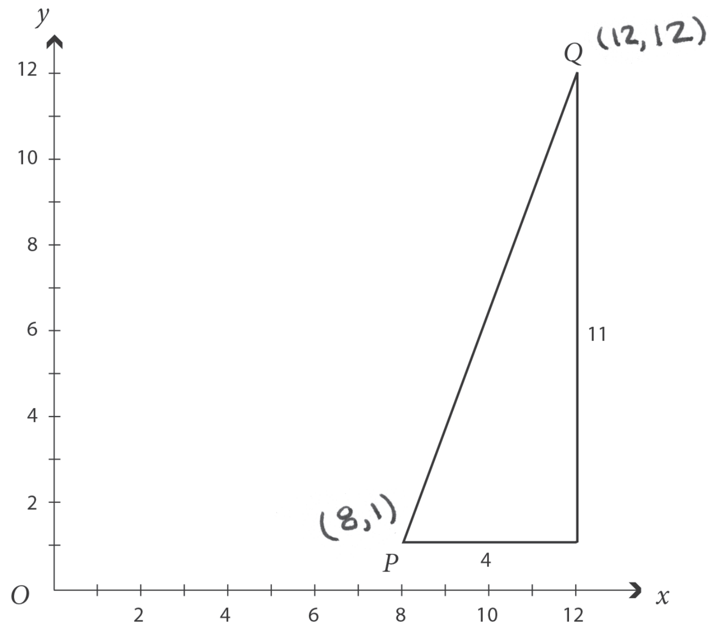
The figure shows a semicircular room seen from above. An architect is placing 10 flat windows in the room as shown. If the radius of the circle is r, which of the following equations would allow the architect to determine the width of each window?

Ⓐ $w = r \sin 9°$

● $w = 2r \sin 9°$

Ⓒ $w = r \cos 18°$

Ⓓ $w = 2r \sin 18°$



A straight line l passes through the points A (1,–2) and B (3, 4).
Is the line l parallel with PQ?

No

Give a reason to support your answer.

Parallel lines have the same slopes.

Slope PQ $= \frac{12-1}{12-8} = \frac{11}{4}$

Slope AB $= \frac{4-(-2)}{3-1} = \frac{6}{2} = 3$

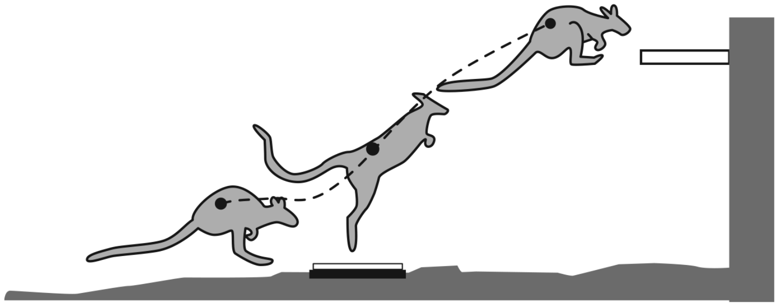
$AB \nparallel PQ$.

MA23170

TIMSS ADVANCED 2015 FRAMEWORKS: B EXAMPLE MATHEMATICS ITEMS

APPENDIX C

Example Physics Items



A kangaroo hops along and then jumps from a flat plate on the ground up to a ledge, as shown above. When a jumping kangaroo is in contact with the plate, its feet exert a force on the plate in the vertical direction, and the plate exerts a force on the kangaroo's feet in the vertical direction. Which statement BEST describes the magnitudes of these forces?

Ⓐ Both forces equal the mass of the kangaroo.

Ⓑ Both forces equal half the mass of the kangaroo.

● They vary in size but stay equal to each other.

Ⓓ The force from the plate becomes larger than the force from the feet.

PA23110

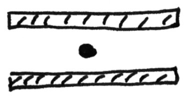
PA23082

The sand on a beach is very hot on a warm and sunny day and is cold at night. As a contrast, the temperature of the sea varies very little between day and night. What does this observation tell you about the specific heat capacity of sand compared to that of water?

The sand has a wider temperature range than the water, so the water retains more heat. The specific heat capacity of sand is much lower than the specific heat of water

A small charged plastic foam ball is held at rest by the electric field between two large horizontal oppositely charged plates.

If the charge on the ball is 5.7 μC and its mass is 1.4×10^{-4} kg, what is the magnitude of the electric field strength? Show your work.



$F_g = mg$

$E = F/q$

$F = qE$

$F_g = F$

$mg = qE$

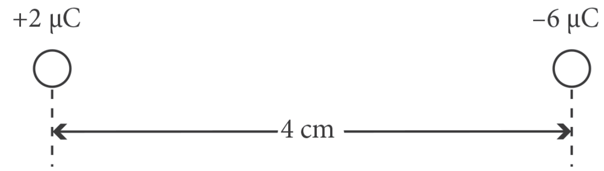
$E = mg/q$

$= \dfrac{(9.8)(1.4 \times 10^{-4})\,N}{5.7 \times 10^{-6}\,C}$

$= 240$ N/C

PA13024

Two small charges of +2 μC (microcoulombs) and −6 μC respectively are placed 4 cm apart as shown.



Where should a third charge −8 μC be placed so that there is no net force on the −6 μC charge?

Ⓐ 4 cm left of the −6 μC charge

Ⓑ 16 cm left of the −6 μC charge

Ⓒ 16 cm right of the −6 μC charge

● 8 cm left of the −6 μC charge

Ⓔ 8 cm right of the −6 μC charge

PA13006

Laser Radiation
Caution: Do not stare into the beam.
Class II Laser Product

Suzanne has a red laser pointer of wavelength 630-680 nm and maximum output of less than 1 mW. The label on Suzanne's laser pointer is shown above. Which statement explains how laser light can damage Suzanne's eyes?

Ⓐ The energy of a photon of red light is large enough to damage the light sensitive cells in her eyes.

Ⓑ Red light from a laser has higher photon energy than red light from an incandescent light globe.

Ⓒ The laser pointer produces more photons per second than a 100 W incandescent light globe.

● Red light photons in the laser pointer beam are spread over a smaller area than photons from a light globe.

PA23113

The speed of waves on the water surface is $0.32\ \text{ms}^{-1}$ in deep water and $0.20\ \text{ms}^{-1}$ in shallow water.

If the wavelength in deep water is 0.016 m, what is the wavelength in shallow water?

$$f_1 = \frac{v_1}{\lambda_1}, \quad f_2 = \frac{v_2}{\lambda_2}, \quad f_1 = f_2$$

$$\lambda_2 = \left(\frac{v_2}{v_1}\right)\lambda_1$$

$$= \left(\frac{.20}{.32}\right)(.016)\ \text{m}$$

$$\lambda_2 = .010\ \text{m}$$

PA13023

TIMSS & PIRLS
International Study Center
Lynch School of Education, Boston College

Typography: Set in Lucida Sans, Minion, and Myriad
Cover Design: Ruthanne Ryan
Book Design: Ruthanne Ryan

International Association
for the Evaluation of
Educational Achievement

BOSTON
COLLEGE

timss.bc.edu

ISBN 978-1-889938-20-2