Findings for Science

The purpose of Achieve's analysis was to determine similarities and differences among the 10 participating APEC member economies' organizational patterns and expectations in three main areas:

(A) Qualitative aspects of standards (determining whether the standards are organized into single grade levels or multiple grade bands; how the standards are organized in regard to key strands and broad topics; and what level of detail they contain);

(B) Core content expectations (describing what topics economies address in their standards, the extent to which those topics are common across most or all of the economies and the proportion of economies' standards that is made up of the common topics); and

(C) Performance expectations (determining the emphasis given to various kinds of performance expectations evident in the member economies' standards – with the two major categories being those that are mainly concerned with developing conceptual understanding and those concerned with developing students' ability to conduct investigations.

Ten APEC economies volunteered for participation in the science portion of this study: Australia, Canada, Chinese Taipei, Hong Kong, Japan, Korea, Malaysia, New Zealand, Singapore and the United States. (Some economies that otherwise would have chosen to participate could not because an English translation of the standards for comparison was required for the analysis.) In addition, secondary level course standards from five economies are included in the study. The complete list of standards coded for this study is available in Appendix A.

As stated earlier, economies structure their standards quite differently. Achieve observed great variety from economy to economy in terms of their organization, emphasis, level of detail and the beginning and ending years of the standards. These differences not withstanding, Achieve also found that across the 10 economies included in our science analysis, there is a *core set of topics* that is addressed by the majority of economies at each grade span.

What follows are the detailed findings of Achieve's analysis.

A. QUALITATIVE ASPECTS OF THE STANDARDS

To understand the similarities and differences in the way standards are crafted across the economies, Achieve examined how the standards are structured (grade by grade vs. by grade spans) and what science strands and topics they included. In general, there is more agreement among economies as to the content topics that should be addressed in the upper grade spans than in the lower grade spans.

Grade Level v. Grade Span Approach

Economies follow diverse paths in organizing science content and skills, often presenting subject matter in very different ways from each other. They also tend to group grades together indicating

there is not necessarily a strict sequential pattern in which science content and skills must be organized. The table below shows that at the primary and lower secondary levels a greater number of economies uses multiple grade bands to organize their science standards than single grade-level standards .[10] Only three economies use a single grade approach for their science standards. Two use a blended approach and five use only grade spans.

TABLE 12: Organization of Science Standards: Single Grades v. Grade Spans

Economy	BY GRADE & GRADE SPAN												BY COURSE			
	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8	Grade 9	Grade 10	Grade 11	Grade 12	Biology	Chemistry	Physics	Earth Science
Australia		✓			✓			✓								
Canada	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓
Chinese Taipei		✓		✓		✓		✓					✓	✓	✓	✓
Hong Kong		✓			✓			✓		✓			✓	✓	✓	
Japan			✓	✓	✓	✓		✓		✓			✓	✓	✓	✓
Korea	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓					✓	
Malaysia	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
New Zealand[3]		✓		✓		✓		✓		✓	✓					
Singapore			✓		✓			✓								
United States[4]		✓			✓			✓								

[3] *New Zealand presents its "blended" science standards in overlapping bands in recognition of the varying pace at which students master material. For the purpose of this report, each set of standards are placed in the chart above in the grade or grade span in which the heaviest emphasis on that set of skills takes place and the grade or grade span in which a majority of students will likely master those skills.*

[4] *The United States has not established national standards (there are 50 different sets of state standards), but Achieve included the National Assessment of Educational Progress (NAEP) assessment framework for science (2009) in this study.*

[10] This does not include the subject-specific courses in science at the upper secondary level.

Years of Required Science Instruction

There is great variation across economies in science course requirements – including both how many are required and which ones. Some economies require students to complete a certain number of years of standardized courses. Others require students to complete some standardized courses as well as additional credit hours in courses of their choice. Still others vary course requirements based on whether students are enrolled in a humanities course of study or a math/science course of study. The table below summarizes economies' course requirements for science.

TABLE 13: Years of Science Instruction Required by Economies

Economy	Years of Required Science Instruction
Australia	Varies depending on the state or territory
Canada	Varies depending on the province or territory
Chinese Taipei	11 2 credit hours in each science subject (biology, chemistry, physics & Earth science) & 4-6 credit hours in one of the four
Hong Kong	9
Japan	4 credit hours (2 courses at 2 hours/ week/ year) in general secondary science is the minimum requirement. Additional courses depend on track. Starts at grade 3
Korea	10
Malaysia	9
New Zealand	Varies depending on local requirements
Singapore	7 Starts at grade 3
United States[1]	Varies depending on the state

Despite differences in course requirements, most economies begin mathematics and science instruction at grade one, with three exceptions: Japan and Singapore begin science instruction at year three, while Australia begins science instruction at year two. Interestingly, in the early grades, science instruction often includes concepts that overlap with basic mathematics instruction, such as classification, counting, ordering, using whole numbers and fractions in describing objects, measuring and identifying patterns including geometric shapes. Young students are often encouraged to make their descriptions of phenomena quantitative by answering the questions "How many?" or "How much?" Therefore, it is possible that despite the absence of dedicated science standards in the early grades in these particular economies, students may receive foundational science instruction via mathematics or other content areas.

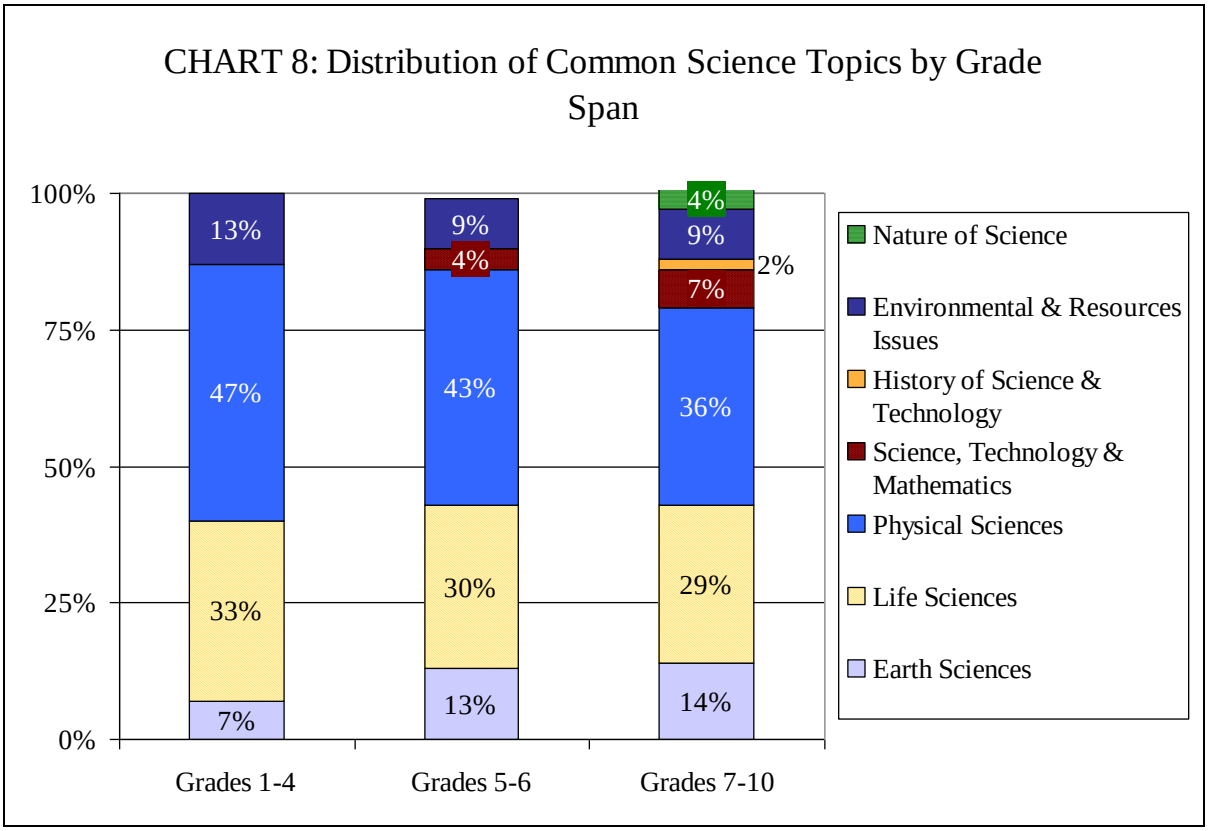
[1] In the United States, all but four states have set statewide graduation requirements. Of the remaining states, five require four years of high school science, 31 require three years, and the remaining 10 require two years. For more information about state graduation requirements, visit http://www.achieve.org/GradRequirements.

Strand Organization & Emphasis by Grade Span

To analyze the standards in the 10 economies in this study, Achieve used a science coding framework developed by Michigan State University that is organized into seven content strands:

1. Earth Sciences
2. Life Sciences
3. Physical Sciences
4. Science, Technology & Mathematics
5. History of Science & Technology
6. Environmental & Resources Issues
7. Nature of Science

While economies may not use exactly the same strand titles, their standards generally address topics in these areas. Most economies in grade spans 1-10 have strands based on the major science fields, i.e., life sciences, physical sciences and Earth sciences. In addition, most economies treat topics that fall under the "nature of science" (including science inquiry) and "science, technology and society" (including environmental and resource issues). In grade spans 1-10, economies take an integrated approach in organizing their content standards, meaning that they do not limit their instruction to one or two fields, but rather draw topics from all the major fields. Beyond grade span 7-10, the pattern shifts with most economies developing specific course standards for biology, chemistry, physics and Earth science. For a complete listing of economies and content categories, see Appendix C.



The science strands in the coding framework address primarily the three major fields – Earth Sciences, Life Sciences and Physical Sciences (Chemistry and Physics) – which are maintained across each grade span. These are supplemented by cross-cutting areas such as the Nature of Science and Environmental & Resource Issues. While the emphasis shifts slightly across grade spans, the three major fields combined account for the majority of the topics of each grade span. All grade spans are characterized by a more noticeable emphasis on Physical Science topics than on Life Science or Earth Science. Two factors may explain the relatively low emphasis on Earth Science topics. First, some economies include Earth science topics, such as landforms (mountains, valleys, continents, etc.) in their geography standards. Additionally, the Environmental and Resource Issues strand, as defined by Achieve's coding framework, contains content that might otherwise be assigned to the Earth Sciences.

Level of Detail

The economies' science standards vary in regard to their level of detail. Some use descriptive language and are very specific about learning outcomes, while others are written at a more general level (see table below). As a result, the standards also vary considerably in terms of their length. Because Achieve analyzed English language translations of the standards, some of the differences detected by the content experts may be a result of translation challenges.

TABLE 14: Level of Detail: Examples from the Upper Secondary Level in Two Economies

Subject	Topic Description	Canada	Chinese Taipei
Biology/Life Science	Cell structure (membranes, nucleus, mitochondria, vacuoles) and basic function	"It is expected that students will…explain the cell theory; describe cell organelles visible with light and electron microscopes..."	**Basic Biology** 3-1 Cell formation and structure; 3-2 Organelles structure and function; • Only briefly discuss the substance synthesis and decomposition • Only briefly discuss the cell nucleus, cell membrane, chloroplast, mitochondrion, ribosome, endoplasmic reticulum, etc. • Observe animal and plant cells, cells of onion root tips
Chemistry	Chemical Reactions	"It is expected that students will...represent chemical reactions and the conservation of mass using molecular models, and balanced symbolic equations"	**Chemical reactions** 1-1 Concepts of subatomic particles and chemical reactions ▪ Law of conservation of mass 1-2 Chemical formulas and chemical reactions ▪ Relationship between Mass and energy in chemical reactions Hess' law. 1-3 Changes of mass and energy between reactants and products

Subject	Topic Description	Canada	Chinese Taipei
Earth Science	Earth, sun, moon in the solar system (Earth/sun/moon system, earthshine, eclipses, features of sun and moon, night/day, tides, north/south hemisphere, seasons)	"analyse why scientific and technological activities take place in a variety of individual and group settings (e.g., analyse the individual and group activities required to study various components of the universe)"	"Know the general environmental conditions in space that surrounds the Earth, including solar radiation, solar wind, cosmic rays, small celestial bodies (i.e. comet, meteor, etc.);" "Know the meanings of the brightness and color of fixed stars." "Know that besides the solar system, there are nebula, star cluster, and galaxies in the immense universe."
Physics	Laws of motion, momentum and collisions	"It is expected that students will...use vectors to represent force, velocity, and acceleration; analyse quantitatively the horizontal and vertical motion of a projectile; identify the frame of reference for a given motion; apply Newton's laws of motion to explain inertia, the relationship between force, mass, and acceleration, and the interaction of forces between two objects..."	2-1 Utilize two-dimensional concepts to discuss displacement, speed, and acceleration in two dimensions; 2-2 Explain constant acceleration in 2-D with projectile motion

B. CORE CONTENT EXPECTATIONS.

Achieve set out to examine the core content included in the standards across the different economies to determine the extent to which there is commonality. To do this, we analyzed the topics treated by each economy at each grade level or span. Although there is variation across economies, Achieve found a number of topics to be common to most economies. Achieve focused its analysis at three grade spans: early primary (grades 1-4); late primary (grades 5-6); and lower secondary (grades 7-10). Achieve also analyzed Biology course standards from five economies as an example of subject-specific standards from upper secondary.

Common Topics across Economies by Grade Span

Achieve's analysis indicates that there is a set of topics for each grade span that are common across the 10 participating economies. The decision rule for inclusion requires that 67 percent or more of the economies' standards included in any grade span must address the topic for it to be considered common. Since the number of economies included in each grade span varies slightly, the number of economies required for inclusion is different for grade span 5-6 than for grade spans 1-4 and 7-10.

The topics included at each grade span are listed below alongside the percentage of economies addressing that topic in their standards. The topics are organized by the categories in the coding framework (Earth Sciences, Life Sciences, Physical Sciences, etc.).

TABLE 15: Common Science Topics across Economies by Grade Span

	GRADES 1-4 (10 ECONOMIES) 100%=10 Economies 90%=9 Economies 80%=8 Economies 70%=7 Economies	GRADES 5-6 (9 ECONOMIES) 100%=9 Economies 89%=8 Economies 78%=7 Economies 67%=6 Economies	GRADES 7-10 (10 ECONOMIES) 100%=10 Economies 90%=9 Economies 80%=8 Economies 70%=7 Economies
TOPICS	**GRADES 1-4 % of Economies**	**GRADES 5-6 % of Economies**	**GRADES 7-10 % of Economies**
EARTH SCIENCES			
Earth Features			70%
Atmosphere			70%
Rocks, soil			70%
Weather & climate	80%	78%	70%
Physical & Chemical Cycles		67%	70%
Earth's history			70%
Earth, sun, moon		78%	90%
Planets in the solar system			70%
LIFE SCIENCES			
Diversity, Organization, Structure of Living Things		67%	90%
Plants	70%	67%	
Animals	80%		
Systems, organs, tissues		67%	90%
Cells			100%
Energy handling, biochemistry of systems			70%
Sensing and responding			70%
Life cycles	70%	67%	90%
Reproduction			80%
Variation and inheritance			80%
Evolution, speciation, diversity			70%
Biochemistry of genetics			70%
Biomes & ecosystems			70%
Habitats & niches	70%	67%	90%
Interdependence of life			70%
Food webs, adaptations to habitats			70%
Needs of living things		78%	90%
Human biology & health	80%	89%	80%
PHYSICAL SCIENCES			
Classification of matter	90%	78%	90%

TOPICS	GRADES 1-4 % of Economies	GRADES 5-6 % of Economies	GRADES 7-10 % of Economies
Physical properties	100%	67%	100%
Chemical properties	90%		100%
Atoms, ions, molecules			80%
Energy types, conversions, sources		67%	90%
Work, Power, Simple machines		67%	70%
Heat and temperature	90%	89%	80%
Wave phenomena			70%
Sound & vibration			70%
Light	80%		80%
Electricity		89%	80%
Magnetism/electromagnetism	70%		80%
Physical changes	70%	78%	80%
Explanations of physical changes		67%	70%
Chemical changes			80%
Definition & evidence of chemical change			70%
Types of reactions			70%
First law of thermodynamics			70%
Contact forces and forces acting at a distance			70%
Time, space and motion		67%	
Dynamics of motion		89%	100%
SCIENCE, TECHNOLOGY, & MATHEMATICS			
Nature or Conceptions of Technology		78%	80%
Science applications in mathematics, technology			70%
Influence of science, technology on society			90%
Influence of society on science, technology			70%
HISTORY OF SCIENCE & TECHNOLOGY			
History of Science & Technology			70%
ENVIRONMENTAL & RESOURCE ISSUES RELATED TO SCIENCE			
Pollution – Causes and Treatment		67%	80%
Land, Water, Sea Resource Conservation	80%		90%
Material & Energy Resource Conservation	70%	78%	100%
World Population			70%
Food Production, Storage			80%
NATURE OF SCIENCE			

TOPICS	GRADES 1-4 % of Economies	GRADES 5-6 % of Economies	GRADES 7-10 % of Economies
Nature of Scientific Knowledge			90%
The Scientific Enterprise			90%
	Total Topics = 15	**Total Topics = 23**	**Total Topics = 56**

Early Primary School: Grades 1-4

Grade span 1-4 includes only 15 common topics – the least number of any of the grade spans, indicating little agreement among economies about what should be taught in science at the early grades. As mentioned earlier, it is important to note in this regard that Japan and Singapore do not formally teach science until students' third year in school, and Australia begins science in the second grade. Ten of the primary core topics appear again in grade span 5-6 and nine appear in all three grade spans. Ninety percent or more of the economies include four Physical Science topics: classification of matter, heat and temperature, physical properties of matter and physical changes.

Late Primary School: Grades 5-6

Between grade span 1-4 and grade span 5-6, the number of topics that are common across the economies increases significantly, by more than 50 percent, from 15 to 23. Topics new to the Earth Sciences include Physical & Chemical Cycles, and Earth, sun, moon. The Life Sciences category expands to include four additional topics: Diversity, Organization, Structure of Living Things; Systems, Organs, Tissues; Life cycles; and Needs of living things. One topic, "Animals," that was treated by most economies in the 1-4 grade span does not receive the equivalent emphasis in grade span 5-6. The Physical Sciences category expands the most with the introduction of eight topics: Energy types, conversions, sources; Work, Power, Simple Machines; Heat and Temperature; Light; Electricity; Physical Changes; Explanations of physical changes; Time, space and motion; and Dynamics of motion. One topic included in grade span 1-4 that is not included by 67 percent of the economies at grade span 5-6 is Chemical properties. An additional three topics – Nature or Conceptions of Technology, Pollution – Causes and Treatment, and Material and Energy Resource Conservation – are included in the cross-cutting categories of Science, Technology, & Mathematics, History of Science & Technology and Environmental & Resource Issues Related to Science. It is difficult to discern patterns in the topics that are added at grade span 5-6 beyond the overall increase in emphasis on physical science and technology topics.

Featured Economy: Canada & Technology Integration

Canada's science standards provide a noteworthy treatment of the scientific enterprise and the relationship between science and technology, as described below.

- The standards include substantial information on the scientific enterprise, such as *explain how a major scientific milestone revolutionized thinking in the scientific communities* and *describe the importance of peer review in the development of scientific knowledge.*
- The standards clearly and accurately portray the complementary nature of science and technology. For example, students are expected to *distinguish between scientific questions and technological problems* and *compare processes used in science with those used in technology.*
- Every standard is accompanied by a related example, often from the history of science and technology. For instance: *Analyze and describe examples where scientific understanding was enhanced or revised as a result of the invention of a technology (e.g., describe examples such as how the equipment used by Coulomb and Cavendish enhanced our scientific understanding.)*
- The standards detail the critical thinking skills that underlie science inquiry and the problem-solving strategies basic related to technology and engineering.

Lower Secondary School: Grades 7-10

The set of topics that are commonly addressed across the economies in grade span 7-10 is larger than that at either of the earlier grade spans. Indeed, grade span 7-10 includes almost all of the content covered at grades 5-6, as well as additional topics that make it more than double the size of the earlier grade span. In the Earth Sciences category, economies include all of the topics listed in Table 15. The Life Sciences category shows a similar expansion with all but two topics – Plants and Animals – addressed by 67 percent of the economies. (By grades 7-10, these broad topics have likely been supplanted by finer-grained topics.) All Physical Science topics included in grade span 5-6 – except the category of time, space and motion – carry over into the 7-10 grade span. The set of topics common to 67 percent of economies expands further to include more chemistry concepts, such as types of reactions.

In grade span 7-10, nearly all economies address the synergistic relationships between Science, Technology and Society, including Applications of Science in Technology and Mathematics, the History of Science and Technology, and the Nature of Science. Most economies also include attention to global problems, incorporating the topics of world population and food production and storage into their standards.

Upper Secondary School: Biology

Achieve also analyzed the Biology courses from five economies, two of which included a two-year sequence of courses (Japan: Biology I and II; Chinese Taipei: Basic Biology and Biology). Achieve found that the comprehensive *Diversity, Organization, Structure of Living Things* topic is presented in greater depth in Secondary School Biology than in earlier grade spans, expanding to include organisms represented by Bacteria, Viruses and Archaea, along with plants, animals.

There are 23 shared topics, as described in the Life Science Content category of Achieve's coding framework, in the sets of Biology standards reviewed. In comparing common standards in Biology with the individual grade spans, Achieve found five Life Science topics in grade span

1-4, seven in grade span 5-6 and 16 in grade span 7-10 that overlap with the set of standards in Biology.

Approximately 70 percent of the Life Science topics in grade span 7-10 are revisited in Biology, while only three topics that were common to all lower grade spans are included in Secondary School Biology, i.e., *life cycles, habitats and niches,* and *human biology and health*.

As would be expected, Secondary School Biology standards are more demanding than the lower grade spans, as they include topics such as *Biochemical processes in cells* (related to the functions of cells, organs and systems), *Population genetics, biotechnology, Genetic engineering* (focusing on the mechanisms and biochemistry of genetics/DNA and RNA), and *Competition among organisms* (fundamental to the mechanism of evolution).

The set of common standards in Biology also included several crosscutting concepts and themes, for example: *Pollution – Causes and Treatment*, *Land, Water, Sea Resource Conservation* and the *Nature of Science.*

Featured Economy: Japan's focus on Scientific Inquiry
Japan's science standards for Upper Secondary promote scientific inquiry and highlight the habits of mind that are fundamental to research. The way in which Japan presents and describes its standards in all four of the major fields of natural science – biology, chemistry, Earth science and physics – underscores the central concern that students develop investigative skills. Teachers are instructed to "*make observations and experiments the core of your teaching … and get the students to engage in the production and presentation of creative reports*."

Courses are organized in a two-part sequence with the second part building directly on the knowledge and skills delivered in the first. For example, the standards for Chemistry I note the importance of students *setting up hypotheses, designing experiments, providing experimental proofs, analyzing and interpreting experimental data and identifying regularities*. The Chemistry II standards reinforce the emphasis on investigative work but raise the level of rigor significantly with explicit mention of a *Research Project* that stresses the preparation and presentation of research reports that show originality. The standards for Biology I and II, Earth Science I and II and Physics I and II follow the same pattern.

Summary of Common Topics
Achieve's analysis indicates that at the Early Primary School level, there is a comparatively small set of 15 common topics, indicating a lack of agreement across economies about what students should be taught. This may in part be a result of the fact that economies vary in terms of when formal instruction in science begins. By Late Primary School, the set of common topics increases significantly to 23 and by Lower Secondary there is an even greater increase in the common topics to 56. The expansion at Lower Secondary adds key topics in Life Science and Physical Science, and shows an increased focus on Science, Technology and Society, Applications of Science in Technology and Mathematics, and the History of Science and

Technology. The Biology standards across economies share a significant set of common topics, indicating there is a good deal of agreement about the topics that should be treated in a year-long high school biology course. Since Biology courses are principally based on the Life Science strand of the coding framework, it follows that there would be greater agreement among economies as to topics addressed in high school Biology than in the earlier grades when science standards draw content from across the major strands.

Topics that persist across grades spans

Achieve found that a limited set of common topics are covered across economies in all three grade spans. The topics listed in TABLE 16 are addressed in 67 percent or more of the economies' standards; in addition, the table indicates the percent of economies that address the topic in each grade span.

TABLE 16: Science Topics that Persist across Grades Spans

MAJOR SCIENCE AREAS **Sub-topics**	**Grades 1-4** **(10 economies)**	**Grades 5-6** **(9 economies)**	**Grades 7-10** **(10 economies)**
EARTH SCIENCES			
Weather & climate	80% (8/10)	78% (7/9)	70% (7/10)
LIFE SCIENCES			
Life cycles	70% (7/10)	67% (6/9)	90% (9/10)
Habitat & niches	70% (7/10)	67% (6/9)	90% (9/10)
Human biology & health	80% (8/10)	89% (8/9)	80% (8/10)
PHYSICAL SCIENCES			
Classification of matter	90% (9/10)	78% (7/9)	90% (9/10)
Physical properties	100% (10/10)	67% (6/9)	100% (10/10)
Heat & temperature	90% (9/10)	89% (8/9)	80% (8/10)
Physical changes	70% (7/10)	78% (7/9)	80% (8/10)
ENVIRONMENTAL ISSUES			
Material & Energy Resource Conservation	70% (7/10)	78% (7/9)	100% (10/10)

Only a few topics appear in the core set of topics at all grade spans, with slightly more of them falling under the Physical Sciences strand. When economies introduce topics and whether they revisit them in subsequent grade spans is partly a function of the centrality of a topic to the field and its complexity. If a topic is core and complex – composed of multiple interrelated and often abstract concepts – then understanding is likely to be developing over time, and instruction moves from developing qualitative conceptual understanding to deepening over time. Instruction will tend to advance from an emphasis on qualitative conceptual understanding to thinking that is more quantitative and rigorous. This type of progression is especially common in the physical sciences, where concepts are based on mathematical relationships. To illustrate, while aspects of heat and temperature are accessible to elementary students, we find that they are revisited by most economies in successive grade spans.

Chinese Taipei's treatment of Heat and Temperature (displayed in Table 17) provides a specific illustration of this point. The performances expected of students in grades 1-6 focus on general descriptions of heat and temperature and guided observations. In grades 7-9, Chinese Taipei's treatment of the concepts of heat and temperature remains essentially qualitative, but the change

in emphasis shifts in its Basic Physics course, where students are expected to know what a calorie is and how to measure it. In its subsequent Required Physics course, Chinese Taipei calls for students to offer quantitative explanations of the relationships between concepts, such that between the boiling point of water and pressure and the relationship among heat energy, work and internal energy. In this example, Chinese Taipei does not just cover content once, but rather scaffolds the content, requiring students to "know" the content with more depth and increased quantitative understanding in each successive grade span or course.

TABLE 17: Heat and Temperature across Grades Spans from Chinese Taipei's Science Standards

Learning Areas in Science and Technology 1-9	Grades 1-2	**Heat Sources** 1a. learn that heat can be generated from sun, combustion, and friction; learn to use a thermometer.
	Grades 3-4	**Heat can be Transmitted, Temperature can be Changed** 2a. learn the methods to compare temperature and notice heat can be transmitted from high to low temperature. **Relationship between Temperature and Properties Changes of Substances** 2b. notice that temperature causes the three stage of water.
	Grades 5-6	**Heat Transmission and Change of Temperature** 3a. learn that heat can be transmitted by conduction, convection, and radiation; utilize these properties in daily life (such as reserving or distributing heat). **Evaporation** 3b. notice evaporation can absorb heat.
	Grades 7-9	**Relationship between Temperature and Calorific Capacity** 4a. explore the relationship between temperature and calorific capacity; define a calorific capacity unit. **Heat Transmission** 4b. explore means of heat transmission: conduction, convection, and radiation. **Relationship between Temperature and Property Changes of Substances** 4c. understand qualitatively about the relationship among volume, temperature, and pressure of a gas. 4d. understand heating can change forms of substances that causes expansion, fusion, evaporation, or diffusion.
Required Subject Basic Physics in Senior High Schools	First Year High School Content Area – iii. Heat	**Temperature and heat** 1-1 Explain how to measure temperature 1-2 Introduce the unit of calorie, and its measurement; briefly introduce specific heat and heat capacity **Heat and change of state** 2-1 Explain the phenomena that things expand in hot temperature and shrink in cold temperature and give examples in everyday life 2-2 Explain the changes of state for water **Heat and life** 3-1 Briefly introduce heat conduction; introduce the application of the law of heat conduction in everyday life (such as air conditioners, refrigerators, heaters etc.) from the perspective of heat loss

Required Subject Physics in Senior High Schools	Senior High School Content Area XI – Heat	**Change of state of a material and latent heat** 2-1 Use water as an example to explain change of state and the energy changes among molecules by heating 2-2 Define boiling point, fusing point, and freezing point; explain the relationship between these points and pressure 2-3 Introduce concepts of change of state and latent heat **Joule's experiment and the mechanical equivalent of heat** 3-1 Explain that heat is one kind of energy 3-2 Introduce Joule's experiment and the mechanical equivalent of heat 3-3 Briefly introduce the concept of internal energy and explain the relationship among heat energy, work, and internal energy **Thermal expansion** 4-1 Introduce the coefficient of thermal expansion; explain applications of thermal expansion in everyday life

Progression across Life Science topics is more difficult to discern without a more fine-grained analysis of each economy's standards. Still, one illustration can be seen in the way Singapore develops student understanding of life cycles and reproduction (TABLE 18). In its Lower Block (P3-P4), Singapore introduces students to similarities and differences in the life cycles of plants and animals. In its Upper Block (P5-P6), Singapore establishes basic concepts about reproduction in plants and animals, drawing students' attention to the processes characteristic of sexual reproduction in flowering plants, including fertilization and germination, and linking these to the process of fertilization in the sexual reproduction of humans. At Lower Secondary, Singapore builds on the previous conceptions, focusing on heredity and the transfer of genetic information from parents to offspring. Ultimately, in its Biology H2 course, Singapore emphasizes the importance of mitosis in the growth, repair and asexual reproduction of cells, and the significance of controlled and uncontrolled replication. As evident from this example, concept development is as important in the life sciences as in the physical sciences, but generally has less dependence on application of mathematical skills.

TABLE 18: Life Cycles/Reproduction across Grades Spans from Singapore's Science Standards

SINGAPORE PRIMARY SCIENCE 2008 LOWER BLOCK (P3 – P4)	**SINGAPORE PRIMARY SCIENCE 2008** UPPER BLOCK (P5 – P6)	**SINGAPORE LOWER SECONDARY 2007**	**SINGAPORE BIOLOGY H2**
CYCLES IN PLANTS AND ANIMALS	CYCLES IN PLANTS AND ANIMALS	SEXUAL REPRODUCTION IN HUMAN BEINGS	REPLICATION AND DIVISION OF NUCLEI AND CELLS
Show an understanding that different organisms have different life cycles. - Plants - Animals	Show an understanding that living things reproduce to ensure continuity of their kind and that many characteristics of an organism are passed on from parents to offspring.	recognize that heredity is a process where genetic information is transmitted from one generation to another	Explain the importance of mitosis in growth, repair and asexual reproduction.

SINGAPORE PRIMARY SCIENCE 2008 LOWER BLOCK (P3 – P4)	**SINGAPORE PRIMARY SCIENCE 2008** UPPER BLOCK (P5 – P6)	**SINGAPORE LOWER SECONDARY 2007**	**SINGAPORE BIOLOGY H2**
Observe and compare the life cycles of plants grown from seeds over a period of time.	Investigate the various ways in which plants reproduce and communicate findings. - spores - seeds	recognize that in sexual reproduction a new individual is formed through the union of an egg and a sperm	Explain the need for the production of genetically identical cells and fine control of replication.
Observe and compare the life cycles of animals over a period of time. e.g. butterfly, mealworm, grasshopper, cockroach, chicken, frog	Recognize the processes in the sexual reproduction of flowering plants. - pollination - fertilization (seed production) - seed dispersal - germination	recognize that a new individual formed through sexual reproduction receives genetic information from its mother (via the egg) and its father (via the sperm)	Explain how uncontrolled cell division can result in cancer, and identify factors which can increase the chances of cancerous growth.
	Recognize the process of fertilisation in the sexual reproduction of humans.	state some of the physical changes that occur during puberty and early adolescence	Describe with the aid of diagrams, the behaviour of chromosomes during the mitotic cell cycle and the associated behaviour of the nuclear envelope, cell membrane and centrioles. (Names of the main stages are expected)
	Recognize the similarity in terms of fertilisation in the sexual reproduction of flowering plants and humans.	describe briefly the structures and functions of human male and female reproductive systems	Explain what is meant by homologous pairs of chromosomes.
			Describe, with the aid of diagrams, the behaviour of chromosomes during meiosis, and the associated behaviour of the nuclear envelope, cell membrane and centrioles. (Names of the main stages are expected, but not the sub-divisions of prophase)

Common Topics as Proportion of Economy Standards at Different Grade Spans
Having identified a set of common topics that economies address at each grade span, Achieve was then able to determine what proportion of the content addressed in each economy's standards is comprised of that set of common topics. In other words, Achieve was able to quantify the extent to which each economy's standards focus on the common set of topics and whether the standards include additional topics as well. In science, on average the proportion of the economies' standards that is comprised of the set of topics that are common across the economies increases across the grade spans. The proportion increases from an average of 35 percent at grade 1-4, to 43 percent in grades 5-6 and to 67 percent in grades 7-10.

In general, the larger the number of science topics defined as common across economies, the more likely it is that the set of common topics represents a larger part of the standards in any given economy. For example, in grade span 1-4, 35 percent of the content included in the standards across the economies is made up of 15 common topics. In grade span 5-6, 43 percent of the content included in the standards across the economies are made up of 23 common topics. In grade span 7-10, which contains 56 common topics – the largest number of topics of the grade spans examined – 67 percent of the content included in the standards across the economies are made up of the common topics.

TABLE 19: Common Topics as Proportion of Economies' Standards

Grade 1-4 Average	Grade 5-6 Average	Grade 7-10 Average
35% Range: 22%-53%	**43%** Range: 31%-53%	**67%** Range: 56%-82%

The data suggest that, on average, the proportion of the topics addressed by the economies that fall in the set of common topics increases across the grade spans. As the number of common topics increases, the number of additional topics addressed by economies decreases, indicating greater agreement across economies about what is most important to teach.

C. PERFORMANCE EXPECTATIONS

In addition to the content, Achieve also analyzed the performance expectations from the standards of the 10 economies in this study. Our goal was to determine the relative emphasis given to basic and advance skills in each economy and in aggregate across all economies.

Science Performance Categories & Levels
Science performance expectations can be viewed as falling into two major categories – Science Inquiry and Science Knowledge. The Science Inquiry category is concerned with the skills essential for learning how to conduct research, whereas the Science Knowledge category includes the various kinds of performances involved in learning science content.[11]

[11] To look beyond performance expectations and compare the rigor of economies' standards was not the intent or purpose of this study. To answer questions regarding comparative rigor of expectations would require additional analysis.

Science Inquiry

The performance expectations included in the inquiry or research category are unique to science in that they reflect the empirical nature of science and the methodologies scientists employ in pursuit of new knowledge. (These skills are distinct from those delineated in the Science Knowledge category, described below, although there is certainly overlap. Evidence-based reasoning, for example, is characteristic of both categories.) Inquiry skills are divided into two sub-categories:

1. Basic Inquiry Skills[xiii]
2. Advanced Inquiry Skills[xiv]

Basic inquiry skills are foundational and consist of such proficiencies as gathering data by making observations and measurements, using laboratory equipment and simple computer applications, and carrying out routine experimental operations. As expected, advanced inquiry skills build upon and take introductory skills to a higher level, essentially shifting to an emphasis on skills required for carrying out independent investigations, as opposed to those needed for executing prescribed procedures.

Science Knowledge

The performance expectations included in the knowledge category have been grouped into levels of generally increasing cognitive demand, or rigor. These levels (or categories) of performance expectations are neither discrete nor strictly hierarchical, although there is a general increase in cognitive demand from Level 1 to Level 5. The levels are as follows:

1. Acquiring Knowledge[xv]
2. Explaining Knowledge[xvi]
3. Applying Knowledge[xvii]
4. Analyzing Knowledge[xviii]
5. Constructing Knowledge[xix]

Level 1 skills are concerned with recalling simple information such as facts, definitions, symbols or describing simple concepts. Level 2 skills have a wider range and include using knowledge to explain phenomena, understanding complex information, organizing, representing and interpreting data, and processing and sharing information. Level 3 skills include solving quantitative problems, using scientific laws or principles to develop explanations or make predictions, and applying science and technology to solve practical problems. Level 4 skills call for students to relate and interpret cross-cutting themes common to multiple fields; construct, interpret and apply models; and debate and make decisions based on the weight of evidence. Level 5 skills involve abstracting or deducing underlying principles when presented with data.[12]

[12] It should be noted that the assignment of the codes in regard to the higher-level categories in science knowledge (that is, analyzing and constructing knowledge) was adjusted to the developmental level of the students in the given grade span. For example, asking a grade 1 student to describe the relationship between water and the growth of a bean plant meets the criteria of "Constructing Knowledge," whereas if the same was asked of a student in the 5-6 grade span it would more appropriately be coded at a lower level – perhaps "Applying Science Knowledge."

For the full listing of skills included in each category, the average percent of emphasis across economies and the range of percent of emphasis across economies, please see Appendix E.

Emphasis of Performance or Cognitive Skills across Grade Spans

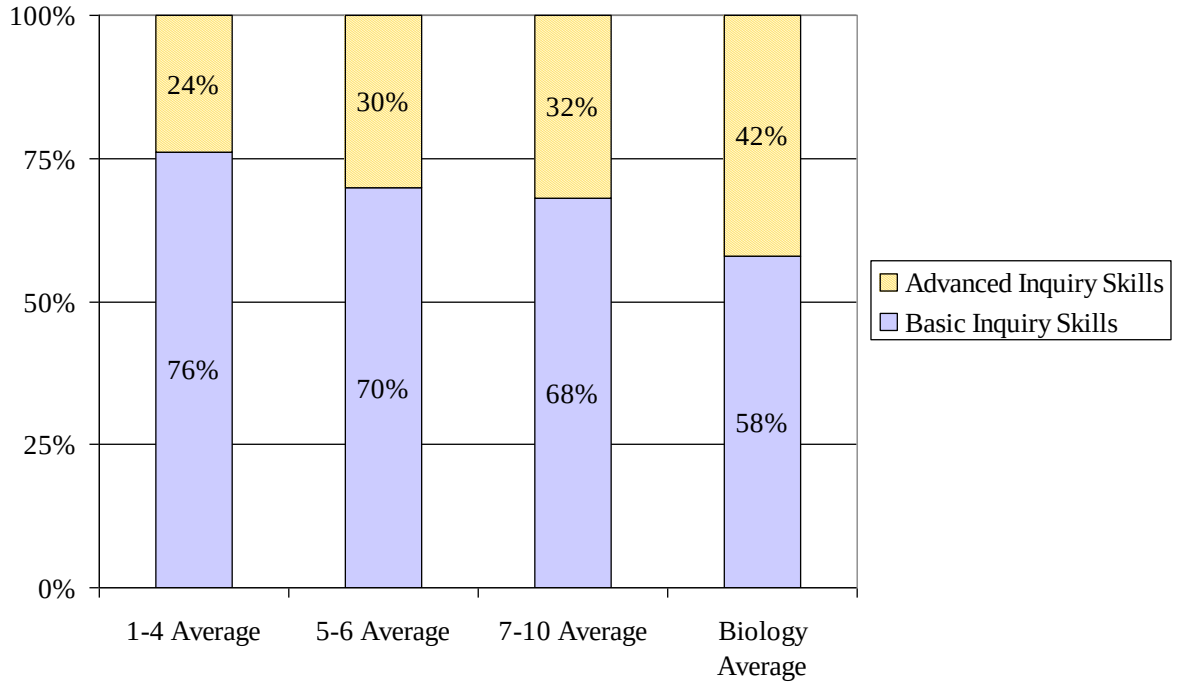
Science Performance Overview

Across the grade spans, the emphasis on each category for both science inquiry and science knowledge remains very consistent on average across the economies. In the Science Knowledge category, the greatest amount of emphasis is placed on lower level performances such as Acquiring Knowledge, with much less emphasis given to more cognitively demanding performances, such as Analyzing Knowledge. In the Science Inquiry category, the same trend is evident, with more emphasis on basic than advanced skills.

Science Inquiry Skills

The balance between basic and advanced inquiry skills changes more than the balance among the five categories of knowledge skills across the grade spans. As grade spans increase, the emphasis on Advanced Science Inquiry becomes more pronounced, from 24 percent in grades 1-4 to 42 percent in Biology, as shown in the table below. As noted above, Advanced Inquiry is concerned with students being able to pursue independent research.

CHART 9: Science Inquiry Skills



Science Knowledge Skills

Primary School Knowledge Skills: Grades 1-4 & 5-6

On average, over 80 percent of the performances expected of students across the economies in grades 1-4 and 5-6 involve Acquiring or Explaining Knowledge, as shown in Charts 10 and 11. The emphasis on the more cognitively demanding skills (Applying, Analyzing and Constructing Knowledge) is less than 20 percent for both grade spans. Although the emphasis on higher-level performances is slightly greater in grades 5 and 6, this trend is not sustained into the secondary grades.

CHART 10: Science Knowledge across the Economies, Grades 1-4

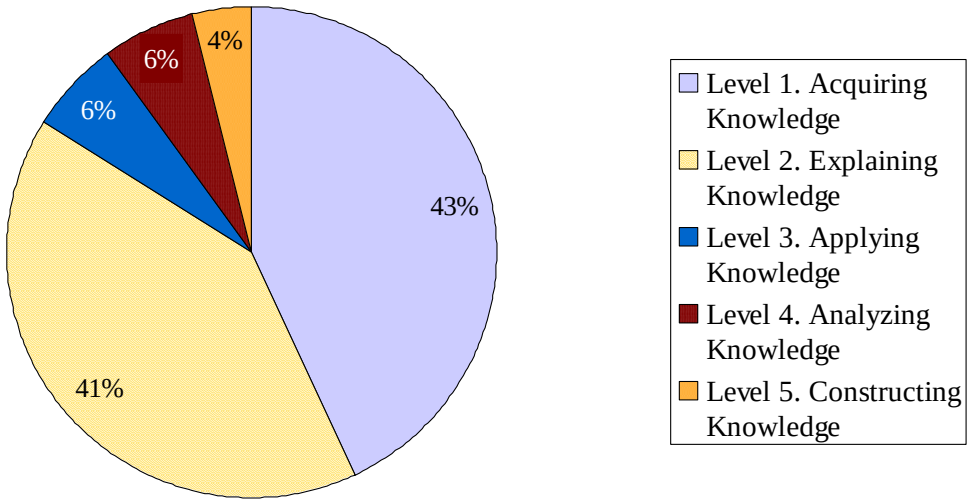
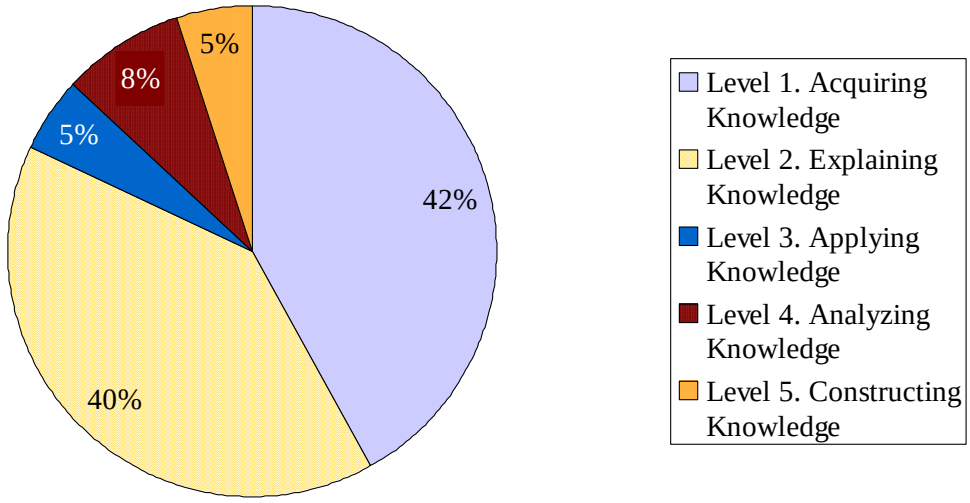


CHART 11: Science Knowledge across the Economies, Grades 5-6

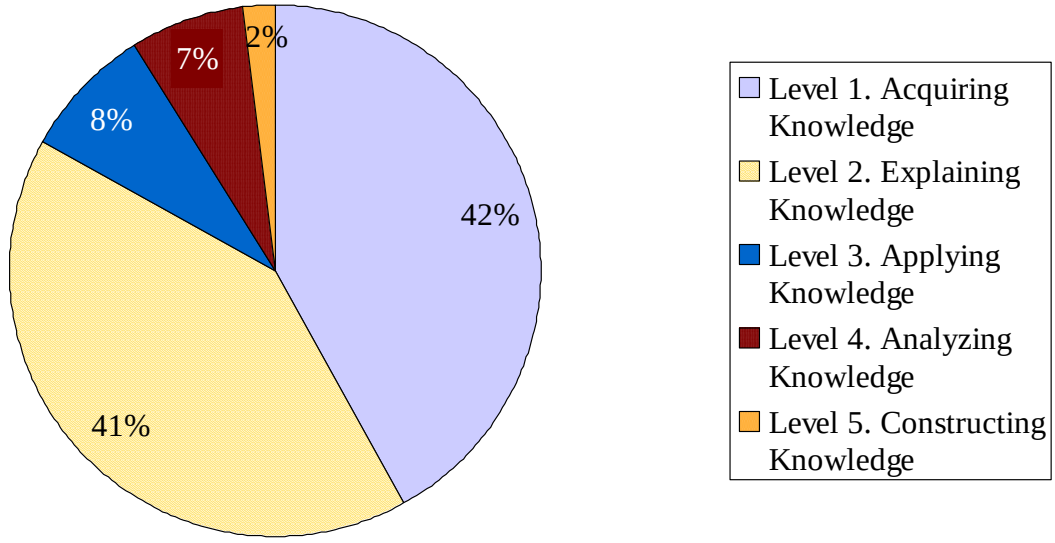


Lower Secondary School Knowledge Skills: Grades 7-10
As in grade spans 1-4 and 5-6, over 80 percent of performances expected of students across the economies at grade span 7-10 are lower level skills, i.e., Acquiring or Explaining Knowledge.

Less than 20 percent of the performances expected are in the three most demanding categories. Emphasis on the skill that requires the greatest cognitive demand, Constructing Knowledge, declines to only two percent.

However, as noted below in the Biology discussion, this apparent decline may be accounted for in that the Advanced Inquiry Skills include the kinds of performances that result in the construction of new knowledge through formal experimentation procedures.

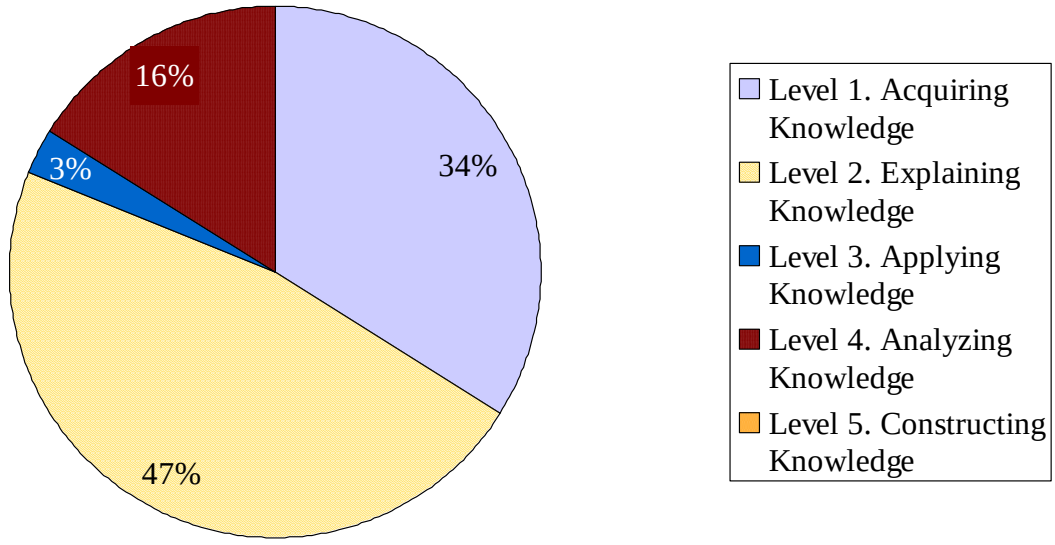
CHART 12: Science Knowledge across the Economies, Grades 7-10



Upper Secondary School Knowledge Skills: Biology
The balance between the lower and higher levels of knowledge skills for the Biology course standards is similar to that found for the primary school, lower secondary and upper secondary standards: over 80 percent of lower-level skills and less than 20 percent of upper level skills. This analysis is limited to the expectations set at the individual standard statement level – economies may reinforce, expand or raise expectations to a higher level in other ways (e.g., through curricular guides, instructional materials and assessments)

Constructing Knowledge, the highest level of cognitive demand among science knowledge skills, averaged less than one percent across the five economies. However, it is important to note that Advanced Inquiry skills received considerable attention in Biology courses. In the upper level categories of both knowledge and inquiry, students are engaged in the construction of new knowledge. Therefore, a view incorporating both knowledge and inquiry indicates economies do expect some higher-level skills of students in Biology.

CHART 13: Science Knowledge across the Economies, Biology

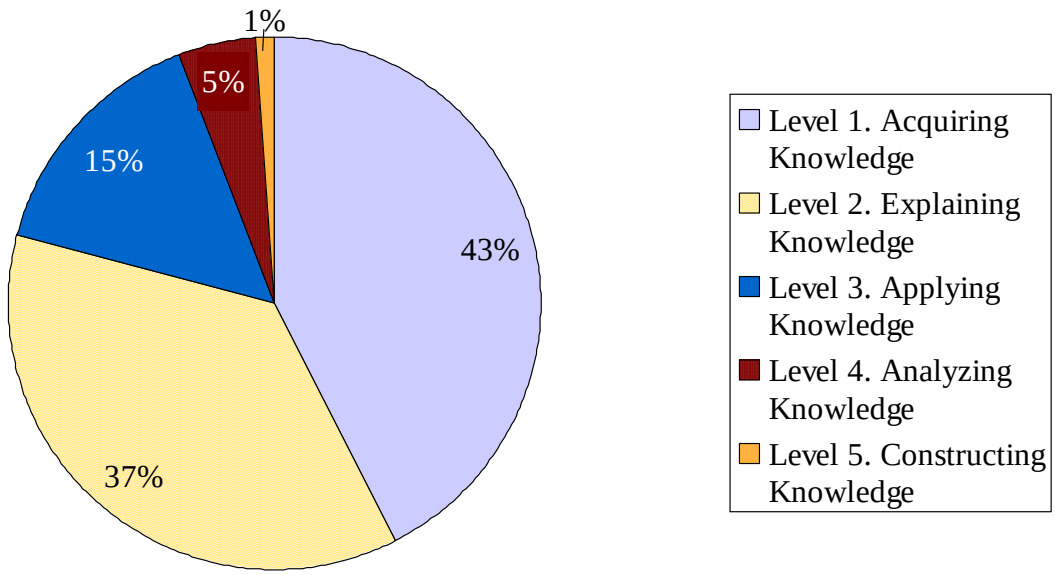


Summary of Inquiry and Knowledge Skills
In science, economies generally show an increase in emphasis from basic to advanced inquiry skills in going from grade span 1-4 to 7-10 and Biology. In contrast, the focus on Level 1 and Level 2 Knowledge categories – Acquiring and Explaining – is quite consistent across grade spans.

Variation among Economies
At the individual economy level, economies differ significantly from each other in their emphases on science knowledge skills. The three economies highlighted below provide a glimpse into the diversity in balance among levels of cognitive demand at the 7-10 grade span.

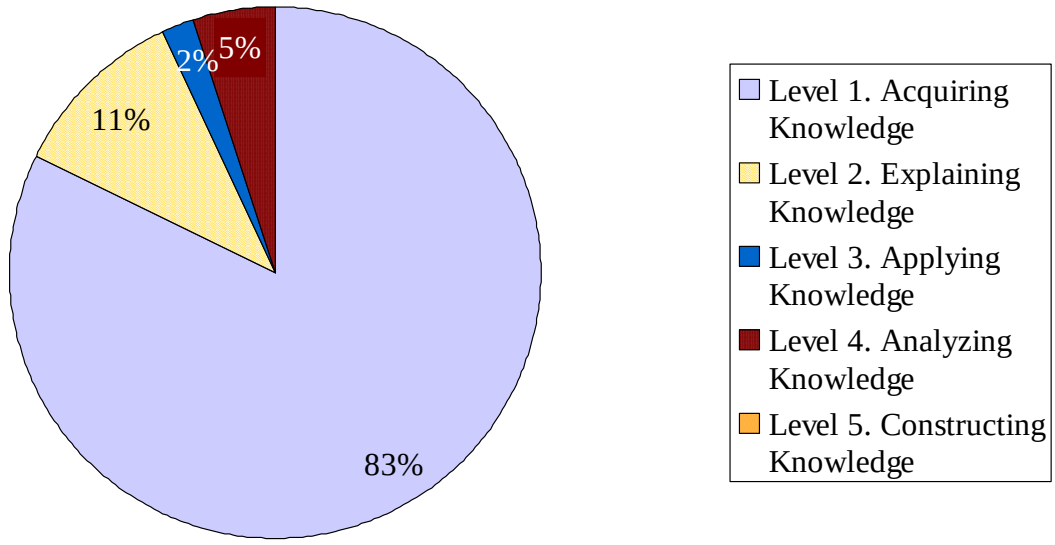
The balance of performance expectations in the grades 7-10 standards from Singapore displayed in Chart 14 resembles the average balance of performance expectations. The top three categories of cognitive demand compose roughly 20 percent of the expectations, and the lower two levels compose roughly 80 percent. Each category of cognitive demand receives some attention in this economy.

CHART 14: Singapore, Science Knowledge, Grades 7-10



Chinese Taipei, represented in the chart below, places less emphasis on the top three performance skill categories overall with no attention to the highest level – Constructing Knowledge. Indeed, 83 percent of its standards – the heaviest emphasis among the economies coded – focuses on Acquiring Knowledge.

CHART 15: Chinese Taipei, Science Knowledge, Grades 7-10



Hong Kong's standards include only references to the two levels of performance expectations – Acquiring Knowledge and Explaining Knowledge.

CHART 16: Hong Kong, Science Knowledge, Grades 7-10