1

Excellence in Science Performance

INTRODUCTION

The rapidly growing demand for highly skilled workers has led to global competition for talent (OECD, 2008). While basic competencies are generally considered important for the absorption of new technologies, high-level competencies are critical for the creation of new knowledge, technologies and innovation. For countries near the technology frontier, this implies that the share of highly educated workers in the labour force is an important determinant of economic growth and social development. There is also mounting evidence that individuals with high level skills generate relatively large amounts of knowledge creation and ways of using it, compared to other individuals, which in turn suggests that investing in excellence may benefit all (Minne *et al.,* 2007).[1] This happens, for example, because highly skilled individuals create innovations in various areas (for example, organisation, marketing, design) that benefit all or that boost technological progress at the frontier. Research has also shown that the effect of the skill level one standard deviation above the mean in the International Adult Literacy Study on economic growth is about six times larger than the effect of the skill level one standard deviation below the mean (Hanushek and Woessmann, 2007).[2]

When parents or policy-makers are asked to describe an excellent education, they often describe in fairly abstract terms the presence of a rich curriculum with highly qualified teachers, outstanding school resources and extensive educational opportunities. Nevertheless, excellent inputs to science education provide no guarantee for excellent outcomes. The approach to educational excellence in PISA is therefore to directly measure the academic accomplishments and attitudes of students and to explore how these relate to the characteristics of individual students, schools and education systems. From this perspective, the report aims to identify the characteristics and educational situations of those students performing at top levels of the PISA assessment and to compare them with the characteristics and situations of those with more modest performance. Such comparisons might hint at potential policy interventions that could raise the performance of all students.

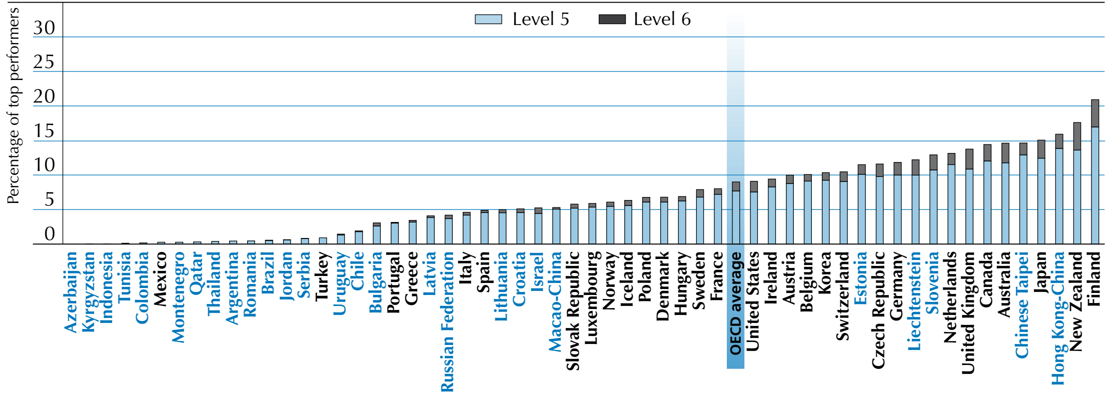
The report looks specifically at top-performing students in the PISA 2006 science assessment, their learning environment and at the schools in which they are enrolled. This report seeks to address the following questions:

- Who are the students who meet the highest performance standards, using top performance as the criterion for educational excellence? What types of families and communities do these students come from?
- What are the characteristics of the schools that they are attending? What kinds of instructional experiences are provided to them in science? How often do they engage in science-related activities outside school?
- What motivations drive them in their study of science? What are their attitudes towards science and what are their intentions regarding science careers?

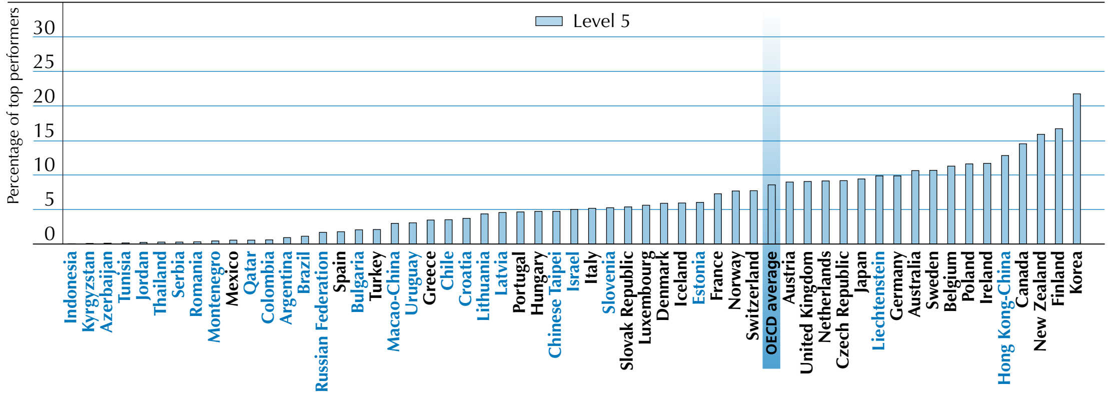
Top-performers are defined as those students who are proficient at Levels 5 and 6 on the PISA 2006 science scale, strong performers are proficient at Level 4, moderate performers are proficient at Levels 2 and 3, and the lowest performers, those who are at risk, are only proficient at Level 1 or below. At age 15, top-performing students can consistently identify, explain and apply scientific knowledge and knowledge about science in a variety of complex life situations. They can link different information sources and explanations and use evidence from those sources to justify decisions. They clearly and consistently demonstrate advanced scientific thinking and reasoning, and they demonstrate use of their scientific understanding in support of solutions to unfamiliar scientific and technological situations. Students at this level can use scientific knowledge and develop arguments in support of recommendations and decisions that centre on personal, social, or global situations.

Figure 1.1
Top performers in science, reading and mathematics

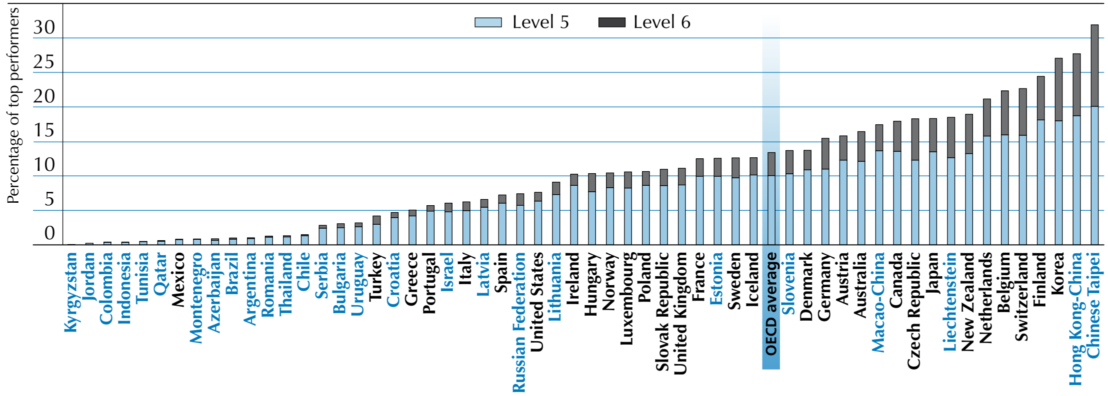
Top performers in science



Top performers in reading



Top performers in mathematics



Countries are ranked in ascending order of the percentage of top performers in each domain of assessment.
Source: *OECD PISA 2006 Database*, Table A1.1.

The proportion of top performers in science varies widely across countries. Figure 1.1 shows the proportions of top performers for each country in science, reading and mathematics. Although on average across OECD countries, 9% of 15-year-olds reach Level 5 in science, and slightly more than 1% reach Level 6, these proportions vary substantially across countries. For example, among the OECD countries, seven have at least 13% of top performers in science, whereas there are six with 5% or less. Among the partner countries and economies the overall proportions of these top performers also vary considerably from country-to-country with many countries almost absent from representation at Level 6 in science. Similar variability is shown in reading and mathematics with only slight differences in the patterns of these results among countries.

It is noteworthy that the share of 15-year-olds who are top performers in science is distributed unevenly across countries. Of the 57 countries, nearly one-half (25) have 5% or fewer (based on a round percentage) of their 15-year-olds reaching Level 5 or Level 6, whereas four countries have at least 15% – *i.e.* three times as many – with high science proficiency [See Table 2.1a and Table 2.1c, *PISA 2006: Science Competencies For Tomorrow's World* (OECD, 2007)]. However, the variability in percentages in each country with high science proficiency suggests a difference in countries' abilities to staff future knowledge-driven industries with home-grown talent.[3] Among countries with similar mean scores in PISA there is a remarkable diversity in the percentage of top-performing students. For example, France has a mean score of 495 points in science in PISA 2006 and a proportion of 8% of students at high proficiency levels in science (both very close to the OECD average), Latvia is also close to the OECD average in science with 490 points but has only 4% of students at high proficiency, which is less than half the OECD average of 9%. Although Latvia has a small percentage of students at the lowest levels, the result could indicate the relative lack of a highly educated talent pool for the future.

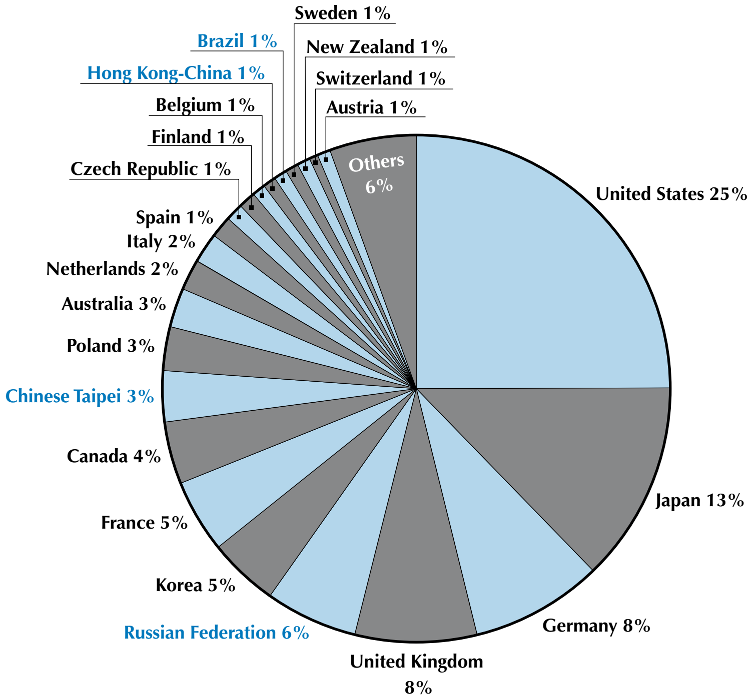
Despite similarities across countries for each subject area, a high rank in one is no guarantee for a high rank in the others. The cross country correlation among these measures is above 0.8 but the definition of top performance is subject area specific and therefore any comparison across subject areas should be interpreted with caution. It is possible however to compare the relative position of countries when compared with others in each subject area. For instance, Ireland is in the top 10% of the distribution of reading top performers across countries but it is in the bottom half of the distribution of mathematics top performers. The partner economy Chinese Taipei for example is in the top 10% of the distribution of mathematics and top performers in science across countries but in the bottom half of the distribution for reading top performers.

These results highlight the need for a rigorous analysis of excellence patterns across countries. The high variance across countries in the proportion of top performers in science shows that some educational systems give rise to higher proportions of high competency students than others. The differences across subject areas show that different educational experiences result in different types of top performers. The following chapters of this report are devoted to understanding better why educational systems result in different proportions of top performers in science, what characteristics these students have, what schools they tend to attend, how they experience teaching and learning science, their attitudes towards science and their motivations and aspirations for science learning in their future careers.

Figure 1.2 depicts the number of 15-year-old students proficient at Levels 5 and 6 on the PISA science scale by country. Both the proportion of top performers within a country and the size of countries matter when establishing the contribution of countries to the global talent pool: even though the proportion of top performers in science is comparatively low in the United States, the United States takes up a quarter of the pie shown in Figure 1.2, simply because of the size of the country. In contrast Finland, that educates the

Figure 1.2
The global talent pool: a perspective from PISA

Percentage of top performers across all PISA countries and economies



Note: "Others" includes countries that account for 0.5% or less: Hungary, Turkey, Ireland, Israel, Chile, Slovak Republic, Denmark, Norway, Mexico, Greece, Portugal, Slovenia, Thailand, Lithuania, Argentina, Croatia, Bulgaria, Estonia, Latvia, Romania, Colombia, Indonesia, Serbia, Jordan, Uruguay, Macao-China, Iceland, Luxembourg, Tunisia, Liechtenstein, Qatar, Azerbaijan, Kyrgyzstan, Montenegro.

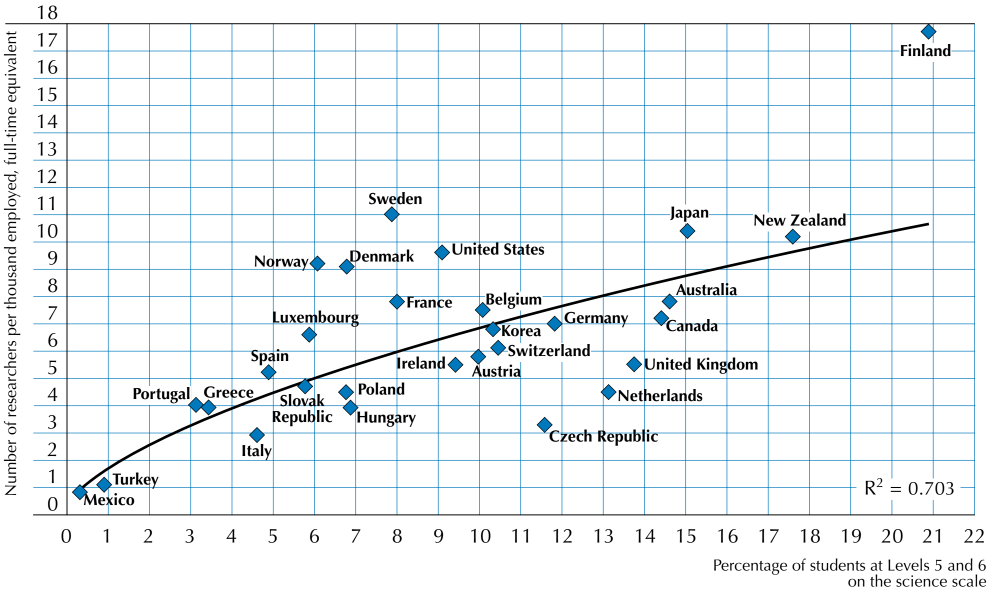
Source: *OECD PISA 2006 Database.*

highest share of 15-year-olds to Levels 5 and 6 in the PISA science scale, only contributes 1% to the OECD pool of top-performing 15-year-old students, because of its small size.

It is not possible to predict to what extent the performance of today's 15-year-olds in science will influence a country's future performance in research and innovation. However, Figure 1.3 portrays the close relationship between a country's proportion of 15-year-olds who scored at Levels 5 and 6 on the PISA science scale and the current number of full-time equivalent researchers per thousand employed. For example, New Zealand with 18% of students in the top two levels has around 10 full time researchers per thousand employees, while Korea with 10% of students in the top two levels has 7 full time researchers per thousand employees. In addition, the correlations between the proportion of 15-year-olds who scored at Levels 5 and 6 and the number of triadic patent families relative to total populations and the gross domestic expenditure on research and development (two other important indicators of the innovative capacity of countries) both exceed 0.5. The corresponding correlations with the PISA mean scores in science are of a similar magnitude. The existence of such correlations does, of course, not imply a causal relationship, as there are many other factors involved.

Figure 1.3
Science top performers in PISA and countries' research intensity

Top performers in the PISA science assessment and countries' research intensity



Source: *OECD Main Science and Technology Indicators 2006,* OECD, Paris. Table 2.1a.

THE OECD PROGRAMME FOR INTERNATIONAL STUDENT ASSESSMENT

Main features of PISA

PISA is the most comprehensive and rigorous international programme to assess student performance and to collect data on student, family and institutional factors that can help to explain differences in performance. Decisions about the scope and nature of the assessments and the background information to be collected are made by leading experts in participating countries, and are steered jointly by governments on the basis of shared, policy-driven interests. Substantial efforts and resources are devoted to achieving cultural and linguistic breadth and balance in the assessment materials. Stringent quality assurance mechanisms are applied in translation, sampling and data collection. As a consequence, the results of PISA have a high degree of validity and reliability, and can significantly improve understanding of the outcomes of education in the world's economically most developed countries, as well as in a growing number of countries at earlier stages of economic development.

Key features of PISA are its:

- *Policy orientation,* with the design and reporting methods determined by the goal of informing policy and practice.
- *Innovative approach to "literacy",* which is concerned with the capacity of students to extrapolate from what they have learned and to analyse and reason as they pose, solve and interpret problems in a variety of situations. The relevance of the knowledge and skills measured by PISA is confirmed by recent studies tracking young people in the years after they have been assessed by PISA.[4]

- *Relevance to lifelong learning,* which does not limit PISA to assessing students' knowledge and skills but also asks them to report on their own motivation to learn, their beliefs about themselves and their attitudes to what they are learning.
- *Regularity,* enabling countries to monitor changes in educational outcomes over time and in the light of other countries' performances.
- *Consideration of student performance alongside characteristics of students and schools,* in order to explore some of the main features associated with educational success.
- *Breadth of geographical coverage,* with the 57 countries participating in the PISA 2006 assessment representing almost nine-tenths of the world economy.

Three PISA surveys have taken place so far, in 2000, 2003 and 2006, focusing on reading, mathematics and science, respectively but with each subject area assessed to some extent in each administration. This sequence will be repeated with surveys in 2009, 2012 and 2015, allowing continuous and consistent monitoring of educational outcomes.

PISA will also continue to develop new assessment instruments and tools according to the needs of participating countries. These efforts will involve collecting more detailed information on educational policies and practices. They will also include making use of computer-based assessments, not only to measure Information and Communication Technology skills but also to allow for a wider range of dynamic and interactive tasks to assess student knowledge and skills.

Unlike many traditional assessments of student performance in science, PISA seeks to assess not merely whether students can reproduce what they have learned, but also to examine how well they can extrapolate from what they have learned and apply their knowledge in novel settings, ones related to school and non-school contexts. It measures the capacity of students to identify scientific issues, explain phenomena scientifically and use scientific evidence as they encounter, interpret, solve and make decisions in life situations involving science and technology. This approach was taken to reflect the nature of the competencies valued in modern societies, which involve many aspects of life, from success at work to active citizenship. It also reflects the reality of how globalisation and computerisation are changing societies and labour markets. Work that can be done at a lower cost by computers or workers in lower wage countries can be expected to continue to disappear in OECD countries. This is particularly true for jobs in which information can be represented in forms usable by a computer and/or in which the process follows simple, easy-to-explain rules. This suggests that many jobs on offer for young people leaving school will require more developed reasoning skills and the ability to solve non-routine problems. In fact, there is evidence that in the United States labour market there has been a sharp increase in the need for non-routine analytical and interactive tasks (Levy and Murnane, 2007). A growing literature shows that phenomenon is of course not restricted to the United States labour markets. For example, Goos and Manning (2007) offer evidence for the United Kingdom and Dustmann et al. (2007) for Germany. High competency is therefore a tool for pursuing higher productivity, greater innovation, and generally more social well-being. Educational excellence is not only a goal in itself, but a key source of high productivity, innovation and individual and social well-being.

2006 PISA assessment

More than 400 000 students in 57 countries participated in the PISA 2006 assessment, which involved a two-hour test with both open and multiple-choice tasks. Nationally-representative samples were drawn, representing 20 million 15-year-olds. Students also answered a half-hour questionnaire about themselves, and their principals answered a questionnaire about their schools. In 16 countries parents completed a questionnaire about their investment in their children's education and about their views on science related issues and careers. New features of the PISA 2006 assessment included the following:

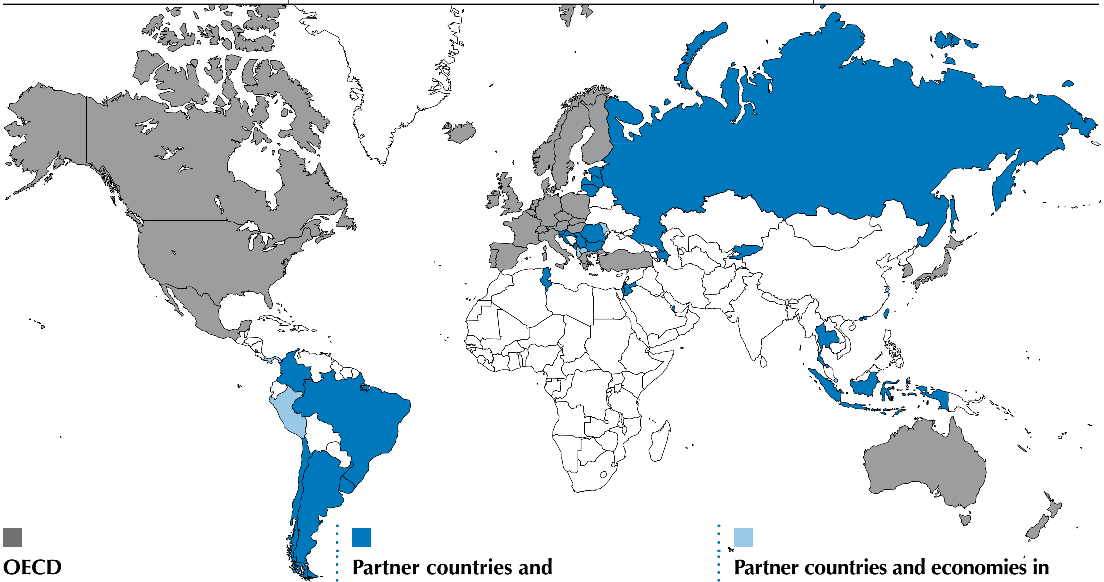
- A detailed profile of student performance in science with reading and mathematics functioning as minor subject areas (in PISA 2000, the focus was on reading, and in PISA 2003, on mathematics).
- Measures of students' attitudes to learning science, the extent to which they are aware of the life opportunities that possessing science competencies may open, and the science learning opportunities and environments which their schools offer.
- Measures of school contexts, instruction, and parental perceptions of students and schools.
- Performance changes in reading over three PISA administrations (six years) and changes in mathematics over two PISA administrations (three years).

The value of PISA in monitoring performance over time is growing, although it is not yet possible to assess to what extent the observed differences in performance are indicative of longer-term trends. With science being the main assessment area for the first time, results in PISA 2006 provided the baseline for future measures of change in this subject.

Figure 1.4 shows the 30 OECD countries and the 27 partner countries and economies that participated in PISA 2006.

Figure 1.4

A map of PISA countries and economies



■ **OECD countries**

Australia
Austria
Belgium
Canada
Czech Republic
Denmark
Finland
France
Germany
Greece
Hungary
Iceland
Ireland
Italy
Japan
Korea
Luxembourg
Mexico
Netherlands
New Zealand
Norway
Poland
Portugal
Slovak Republic
Spain
Sweden
Switzerland
Turkey
United Kingdom
United States

■ **Partner countries and economies in PISA 2006**

Argentina
Azerbaijan
Brazil
Bulgaria
Chile
Colombia
Croatia
Estonia
Hong Kong-China
Indonesia
Israel
Jordan
Kyrgyzstan
Latvia
Liechtenstein
Lithuania
Macao-China
Montenegro
Qatar
Romania
Russian Federation
Serbia
Slovenia
Chinese Taipei
Thailand
Tunisia
Uruguay

■ **Partner countries and economies in previous PISA surveys or in PISA 2009**

Albania
Shanghai-China
Former Yugoslav Republic of Macedonia
Moldova
Panama
Peru
Singapore
Trinidad and Tobago

With more than one-half of the assessment time devoted to science, the initial PISA 2006 report provided much greater detail on science performance than was possible in PISA 2000 and PISA 2003. As well as calculating overall performance scores, it was possible to report separately on different science competencies and to establish for each performance scale conceptually grounded proficiency levels that relate student performance scores to what students are typically able to do. Students received scores for their capacity in each of the three science competencies (*identifying scientific issues, explaining phenomena scientifically* and *using scientific evidence*). Estimates were also obtained at the country level for students' knowledge about science (*i.e.* their knowledge of the processes of science as a form of enquiry) and knowledge of science (*i.e.* their capacity in the science content areas of "Earth and space systems", "Physical systems" and "Living systems").

Definition of top performers in science

PISA 2006 was devoted to assessing students' science knowledge and application of this knowledge, although testing was also done in reading and mathematics. It divided student science performance into six proficiency levels (OECD, 2006a). At Level 1 students have very limited scientific knowledge and are only able to provide possible explanations in familiar contexts. At Level 2 students draw conclusions from simple investigations. At Level 3 students can identify clearly scientific issues in a variety of contexts and apply scientific principles, facts and knowledge to explain phenomena. At Level 4 students can address specific phenomena and situations, making inferences about science or technology, and they can reflect and communicate decisions using scientific knowledge and evidence. In addition, at Level 5:

> *…students can identify the scientific components of many complex life situations, apply both scientific concepts and knowledge about science to these situations, and compare, select and evaluate appropriate scientific evidence for responding to life situations. Students at this level can use well-developed inquiry abilities, link knowledge appropriately and bring critical insights to situations. They can construct explanations based on evidence and arguments based on their critical analysis.*

And additionally, at the most advanced level (Level 6):

> *…students can consistently identify, explain and apply scientific knowledge and knowledge about science in a variety of complex life situations. They can link different information sources and explanations and use evidence from those sources to justify decisions. They clearly and consistently demonstrate advanced scientific thinking and reasoning, and they demonstrate willingness to use their scientific understanding in support of solutions to unfamiliar scientific and technological situations. Students at this level can use scientific knowledge and develop arguments in support of recommendations and decisions that centre on personal, social or global situations.*

For the purposes of this report the top performers in science are defined as those students who performed at the top two levels of science proficiency, that is at Levels 5 and 6. This definition captures the potential global talent pool (at least for the part emerging from those countries that participated in PISA 2006). One clear benefit from a definition based on such an international standard is that it allows for straight forward comparability across countries. It is clear what these students can do regardless of their educational system. Strong performers are defined as those who performed at Level 4, moderate performers as those who performed at Levels 2 and 3, and lowest performers as those who performed at Level 1 or below.

This is only one possible way of defining top performing students. An alternative approach could have been to consider the top of the distribution of performance within each country. The advantage of this approach is its focus on the relative performance of students. As top performers are more likely to compare themselves with their peers, it is possible that students at the top end of the distribution in each country (*e.g.* the top 10%)

share some similarities across countries. An obvious drawback to this approach is that these students have very different proficiency levels. One clear benefit from a definition based on an international standard, such as performance at Levels 5 and 6, is that it allows for straightforward comparability across countries. It is clear what these students can do regardless of their educational system. In practical terms however, both definitions classify many of the same students as top performers. Only for countries with very low proportions of students scoring at Levels 5 and 6 in the PISA science scale is the set of students captured very different. It is precisely for these cases that the biggest differences in performance come about. The comparison between these two definitions in countries with less than 3% of top performers in science among all students is further complicated by the fact that evidence based on such a small sample of students is not reliable. Whenever a comparison is possible and reliable, the main results discussed below do not vary significantly across these two definitions.

Although across the OECD on average about 95% of students were at least able to perform tasks at Level 1, 81% at Level 2, 57% at Level 3, and 29% at Level 4, only 9% reached Levels 5 and 6 (with only 1% reaching Level 6). Thus, only 9% of the 15-year-old student population across the OECD countries are top performers in science, as defined by this report - a highly selective group. It is this talented group of top performers that is the focus of this report (see Box 1 for definitions of top performers for all three subject areas).

Box 1.1 **Defining and comparing top performers in PISA**

Definitions used in this report

Top performers in science – students proficient at Levels 5 and 6 of the PISA 2006 science assessment (*i.e.* higher than 633.33 score points)

Top performers in reading – students proficient at Level 5 of the PISA 2006 reading assessment (*i.e.* higher than 625.61 score points)

Top performers in mathematics – students proficient at Levels 5 and 6 of the PISA 2006 mathematics assessment (*i.e.* higher than 606.99 score points)

Note that this paper uses the term “top performers” as shorthand for students’ proficient at Levels 5 and 6 in science in PISA 2006. Unless otherwise specified, “top performers” does not necessarily comprise top performers in reading and mathematics. The cutoff points for each level varies by subject area and the levels of proficiency are not equivalent across subject areas. In other words, it is not the same to be proficient at Levels 5 and 6 in science, mathematics or reading. Because of the different nature and content of the three testing areas the cutoff points for Levels 5 and 6 for each subject area are different and can therefore result in different proportions of top performers.

Comparing top performers in science to other students

Four “performance groups” are used in this report to facilitate comparison of top performers in science with other students. In addition to the top performers:

Strong performers – students proficient at Level 4 of the PISA 2006 science assessment

Moderate performers – students proficient at Levels 2 and 3 of the PISA 2006 science assessment

Lowest performers – students proficient at Level 1 or below of the PISA 2006 science assessment

Examples of tasks that top performers in science can typically do

This section presents a selection of the questions that are representative of tasks that the top performers can typically complete, including two examples of questions classified at Level 6 (ACID RAIN – Question 5 and GREENHOUSE – Question 5) and one example of a question classified at Level 5 (GREENHOUSE – Question 4). For a selection of released items see *Take the Test: Sample Questions from OECD's PISA Assessments* (OECD, 2009). While all three questions require students to construct a response, each tests different scientific knowledge and requires students to draw upon different scientific competencies.

Questions at the highest levels of proficiency in PISA science (Levels 5 and 6) require students to demonstrate strong understanding of scientific knowledge in different areas, as well as insight and analytical skill. Further, these questions often require students to construct and clearly communicate a response, by way of an argument or explanation. Each example is further elaborated below.

ACID RAIN – Question 5 belongs to the PISA knowledge category "scientific enquiry", because it requires students to exhibit knowledge about the structure of an experiment. This question falls in the PISA competency area of *identifying scientific issues*. To answer this question correctly, students need to both understand the experimental modelling used and to articulate the method used to control a major variable. Specifically, students need to demonstrate understanding that a reaction will not occur in water and that vinegar is the necessary reactant. This question tests students' knowledge of the use of a control in scientific experiments. Students need to develop an explanation and communicate this clearly. Those students who provide an explanation to include this step in the experiment in order to compare with the test of vinegar and marble, but who do not show that the acid (vinegar) is necessary for the reaction, are given partial credit, with the item classified as Level 3.

GREENHOUSE – Question 5 belongs to the PISA knowledge category "Earth and space systems", because it requires students to exhibit knowledge about different factors in the Earth's atmosphere. This question falls in the PISA competency area of *explaining phenomena scientifically*. To answer this correctly, students need first to identify the variables and have sufficient understanding of methods of investigation to recognise the influence of other factors. Second, students need to recognise the scenario in context and identify its major components. This involves a number of abstract concepts and their relationships in determining what other factors might affect the relationship between the Earth's temperature and the amount of carbon dioxide emissions in the atmosphere.

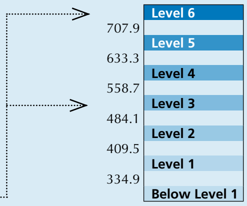
GREENHOUSE – Question 4 belongs to the PISA knowledge category "scientific explanations", because it requires students to exhibit knowledge in reading and interpreting data presented in graphs. This question falls in the PISA competency area of *using scientific evidence*. To answer this correctly, students need to identify a portion of a graph that does not provide evidence supporting a conclusion. Specifically, students need to locate a portion of the graphs where curves are not both ascending or descending and provide this finding as part of a justification for a conclusion. Therefore, students need to explain the difference they have identified. Those students that only identify that there is a difference but provide no explanation of this are classified at Level 4.

Figure 1.5
ACID RAIN

Below is a photo of statues called Caryatids that were built on the Acropolis in Athens more than 2500 years ago. The statues are made of a type of rock called marble. Marble is composed of calcium carbonate.

In 1980, the original statues were transferred inside the museum of the Acropolis and were replaced by replicas. The original statues were being eaten away by acid rain.

ACID RAIN – *QUESTION 5 (S485Q05)*



Question type: *Open-constructed response*
Competency: *Identifying scientific issues*
Knowledge category: *"Scientific enquiry" (knowledge about science)*
Application area: *"Hazards"*
Setting: *Personal*
Difficulty: *Full credit 717; Partial credit 513*
Percentage of correct answers (OECD countries): *35.6 %*

Students who did this experiment also placed marble chips in pure (distilled) water overnight.
Explain why the students included this step in their experiment.

....

....

Scoring

Full Credit: To show that the acid (vinegar) is necessary for the reaction. For example:

- To make sure that rainwater must be acidic like acid rain to cause this reaction.
- To see whether there are other reasons for the holes in the marble chips.
- Because it shows that the marble chips don't just react with any fluid since water is neutral.

Partial Credit: To compare with the test of vinegar and marble, but it is not made clear that this is being done to show that the acid (vinegar) is necessary for the reaction. For example:

- To compare with the other test tube.
- To see whether the marble chip changes in pure water.
- The students included this step to show what happens when it rains normally on the marble.
- Because distilled water is not acid.
- To act as a control.
- To see the difference between normal water and acidic water (vinegar).

Comment

Students gaining full credit for this question understand that it is necessary to show that the reaction will not occur in water. Vinegar is a necessary reactant. Placing marble chips in distilled water demonstrates an understanding of a control in scientific experiments.

Students who gain partial credit show an awareness that the experiment involves a comparison but do not communicate this in a way that demonstrates they know that the purpose is to show that vinegar is a necessary reactant.

The question requires students to exhibit knowledge about the structure of an experiment and therefore it belongs in the "Scientific enquiry" category. The application is dealing with the hazard of acid rain but the experiment relates to the individual and thus the setting is personal.

A student obtaining credit for the Level 6 component of this question is able to both understand the experimental modelling used and to articulate the method used to control a major variable. A student correctly responding at Level 3 (partial credit) is only able to recognise the comparison that is being made without appreciating the purpose of the comparison.

Figure 1.6
GREENHOUSE

Read the texts and answer the questions that follow.

THE GREENHOUSE EFFECT: FACT OR FICTION?

Living things need energy to survive. The energy that sustains life on the Earth comes from the Sun, which radiates energy into space because it is so hot. A tiny proportion of this energy reaches the Earth.

The Earth's atmosphere acts like a protective blanket over the surface of our planet, preventing the variations in temperature that would exist in an airless world.

Most of the radiated energy coming from the Sun passes through the Earth's atmosphere. The Earth absorbs some of this energy, and some is reflected back from the Earth's surface. Part of this reflected energy is absorbed by the atmosphere.

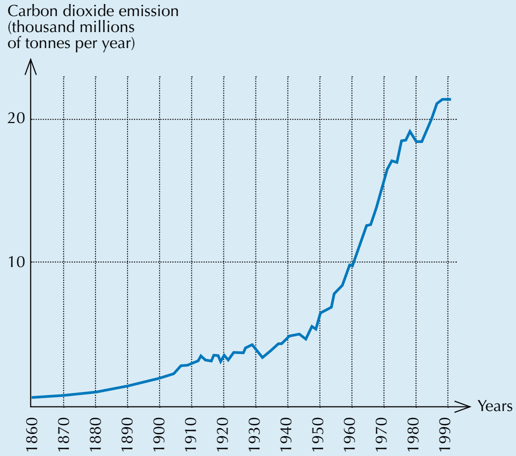
As a result of this the average temperature above the Earth's surface is higher than it would be if there were no atmosphere. The Earth's atmosphere has the same effect as a greenhouse, hence the term greenhouse effect.

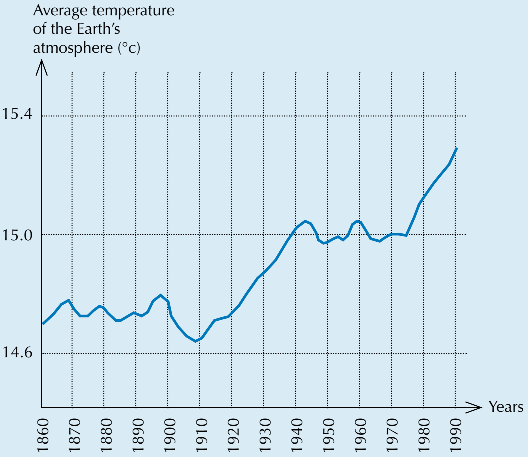
The greenhouse effect is said to have become more pronounced during the twentieth century.

It is a fact that the average temperature of the Earth's atmosphere has increased. In newspapers and periodicals the increased carbon dioxide emission is often stated as the main source of the temperature rise in the twentieth century.

A student named André becomes interested in the possible relationship between the average temperature of the Earth's atmosphere and the carbon dioxide emission on the Earth.

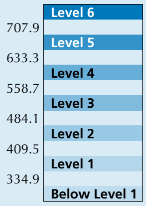
In a library he comes across the following two graphs.





André concludes from these two graphs that it is certain that the increase in the average temperature of the Earth's atmosphere is due to the increase in the carbon dioxide emission.

GREENHOUSE – *QUESTION 5 (S114Q)*



Question type: *Open-constructed response*
Competency: *Explaining phenomena scientifically*
Knowledge category: *"Earth and space systems" (knowledge of science)*
Application area: *"Environment"*
Setting: *Global*
Difficulty: *709*
Percentage of correct answers (OECD countries): *18.9%*

André persists in his conclusion that the average temperature rise of the Earth's atmosphere is caused by the increase in the carbon dioxide emission. But Jeanne thinks that his conclusion is premature. She says: "Before accepting this conclusion you must be sure that other factors that could influence the greenhouse effect are constant".

Name one of the factors that Jeanne means.

....

....

Scoring

Full Credit:

Gives a factor referring to the energy/radiation coming from the Sun. For example:

- The sun heating and maybe the earth changing position.
- Energy reflected back from Earth. *[Assuming that by "Earth" the student means "the ground".]*

Gives a factor referring to a natural component or a potential pollutant. For example:

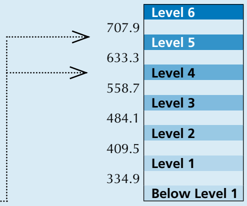
- Water vapour in the air.
- Clouds.
- The things such as volcanic eruptions.
- Atmospheric pollution (gas, fuel).
- The amount of exhaust gas.
- CFC's.
- The number of cars.
- Ozone (as a component of air). *[Note: for references to depletion, use Code 03.]*

Comment

Question 5 of GREENHOUSE is an example of Level 6 and of the competency explaining phenomena scientifically. In this question, students must analyse a conclusion to account for other factors that could influence the greenhouse effect. This question combines aspects of the two competencies identifying scientific issues and explaining phenomena scientifically. The student needs to understand the necessity of controlling factors outside the change and measured variables and to recognise those variables. The student must possess sufficient knowledge of "Earth systems" to be able to identify at least one of the factors that should be controlled. The latter criterion is considered the critical scientific skill involved so this question is categorised as explaining phenomena scientifically. The effects of this environmental issue are global which defines the setting.

As a first step in gaining credit for this question the student must be able to identify the change and measured variables and have sufficient understanding of methods of investigation to recognise the influence of other factors. However, the student also needs to recognise the scenario in context and identify its major components. This involves a number of abstract concepts and their relationships in determining what "other" factors might affect the relationship between the Earth's temperature and the amount of carbon dioxide emissions into the atmosphere. This locates the question near the boundary between Level 5 and 6 in the explaining phenomena scientifically category.

GREENHOUSE – *QUESTION 4 (S114Q04)*



Question type: *Open-constructed response*
Competency: *Using scientific evidence*
Knowledge category: *"Scientific explanations" (knowledge about science)*
Application area: *"Environment"*
Setting: *Global*
Difficulty: *Full credit 659; Partial credit 568*
Percentage of correct answers (OECD countries): *34.5%*

Another student, Jeanne, disagrees with André's conclusion. She compares the two graphs and says that some parts of the graphs do not support his conclusion.

Give an example of a part of the graphs that does not support André's conclusion. Explain your answer.

....

....

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Scoring

Full Credit:

Refers to one particular part of the graphs in which the curves are not both descending or both climbing and gives the corresponding explanation. For example:

- In 1900–1910 (about) CO_2 was increasing, whilst the temperature was going down.
- In 1980–1983 carbon dioxide went down and the temperature rose.
- The temperature in the 1800s is much the same but the first graph keeps climbing.
- Between 1950 and 1980 the temperature didn't increase but the CO_2 did.
- From 1940 until 1975 the temperature stays about the same but the carbon dioxide emission shows a sharp rise.
- In 1940 the temperature is a lot higher than in 1920 and they have similar carbon dioxide emissions.

Partial Credit:

Mentions a correct period, without any explanation. For example:

- 1930–1933.
- before 1910.

Mentions only one particular year (not a period of time), with an acceptable explanation. For example:

- In 1980 the emissions were down but the temperature still rose.

Gives an example that doesn't support André's conclusion but makes a mistake in mentioning the period. *[Note: There should be evidence of this mistake – e.g. an area clearly illustrating a correct answer is marked on the graph and then a mistake made in transferring this information to the text.]* For example:

- Between 1950 and 1960 the temperature decreased and the carbon dioxide emission increased.

Refers to differences between the two curves, without mentioning a specific period. For example:

- At some places the temperature rises even if the emission decreases.
- Earlier there was little emission but nevertheless high temperature.
- When there is a steady increase in graph 1, there isn't an increase in graph 2, it stays constant. *[Note: It stays constant "overall".]*
- Because at the start the temperature is still high where the carbon dioxide was very low.

Refers to an irregularity in one of the graphs. For example:

- It is about 1910 when the temperature had dropped and went on for a certain period of time.
- In the second graph there is a decrease in temperature of the Earth's atmosphere just before 1910.

Indicates difference in the graphs, but explanation is poor. For example:

- In the 1940s the heat was very high but the carbon dioxide very low. *[Note: The explanation is very poor, but the difference that is indicated is clear.]*

Comment

Another example from GREENHOUSE centres on the competency using scientific evidence and asks students to identify a portion of a graph that does not provide evidence supporting a conclusion. This question requires the student to look for specific differences that vary from positively correlated general trends in these two graphical datasets. Students must locate a portion where curves are not both ascending or descending and provide this finding as part of a justification for a conclusion. As a consequence it involves a greater amount of insight and analytical skill than is required for Q03. Rather than a generalisation about the relation between the graphs, the student is asked to accompany the nominated period of difference with an explanation of that difference in order to gain full credit.

The ability to effectively compare the detail of two datasets and give a critique of a given conclusion locates the full credit question at Level 5 of the scientific literacy scale. If the student understands what the question requires of them and correctly identifies a difference in the two graphs, but is unable to explain this difference, the student gains partial credit for the question and is identified at Level 4 of the scientific literacy scale.

This environmental issue is global which defines the setting. The skill required by students is to interpret data graphically presented so the question belongs in the "Scientific explanations" category.

Notes

1. At the macro-economic level, skills can lead to positive external effects through research and development activity. Research and development creates new knowledge that is often difficult to appropriate by the producer of the knowledge. This is because new knowledge is at least partially non-excludable and non-rival. Once the new knowledge is produced, other individuals in society can obtain at least a part of it at no cost. The social return to the new knowledge is thus larger than the private return of the producer of the knowledge.

2. Hanushek and Woessmann (2007) have included the shares of individuals that performed one standard deviation above (600 score points) and below (400 score points) on the International Adult Literacy Survey (IALS) scale jointly into a growth regression. The threshold of 400 IALS score points approximated basic literacy and numeracy while the threshold of 600 sought to capture top performance. They found that the effect of the high performance level was about six times larger than the effect of the lower level (and this relationship remained essentially unchanged when various control variables were added).

3. The proportion of science and engineering occupations in the United States that are filled by tertiary-educated workers born abroad increased from 14 to 22% between 1990 and 2000, and from 24 to 38% when considering solely doctorate-level science and engineering workers (US National Science Board, 2003). In the European Union, 700 000 additional researchers will be required merely to reach the Lisbon Goals on research in 2010. In acknowledgement of these growing needs for highly-skilled workers, most European economies have started to review their immigration legislation to encourage the settlement of tertiary-educated individuals, and in some cases, to recruit large numbers of international students with a view to granting them residence status upon completion of their studies.

4. There are at least three interesting country case studies in Canada (for more information, visit *www.pisa.gc.ca/yits.shtml*), Denmark (for more information see *www.sfi.dk/sw19649.asp*) and Australia (for more information see *www.acer.edu.au*).

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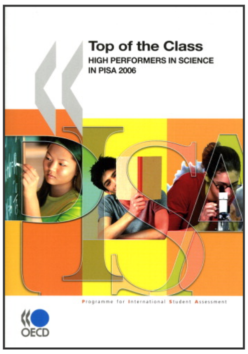

Top of the Class

High Performers in Science in PISA 2006

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