A Teacher's Guide to PISA Science

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Preface

PISA (Programme for International Student Assessment) is designed to assess the scientific, mathematical, and reading literacy skills of 15-year-olds. It is a project of the Organisation for Economic Co-operation and Development (OECD). First conducted in 2000, PISA runs in three-yearly cycles.

This guide focuses on how Irish students performed on science in PISA 2006, compared to students in other countries. The target audience for the guide is teachers of science in post-primary schools in Ireland. Several reports on PISA 2006 have already been published. Readers who would like more information on PISA 2006 than is presented here are referred to the relevant Irish (Eivers, Shiel & Cunningham, 2007, 2008) and OECD reports (OECD, 2007b).

This guide is divided into seven chapters. Chapter 1 provides some background to PISA and explains how scientific literacy was assessed. Chapter 2 compares the performance of Irish students on science to the OECD average and to the performance of students in other countries. Chapter 3 provides examples of PISA science items, and describes the types of response provided by students. Chapter 4 compares science as conceptualised in PISA and the Junior Certificate science syllabus, and Chapter 5 describes students' science-related attitudes. Chapter 6 examines factors relating to test performance. Finally, Chapter 7 summarises the findings and presents some conclusions.

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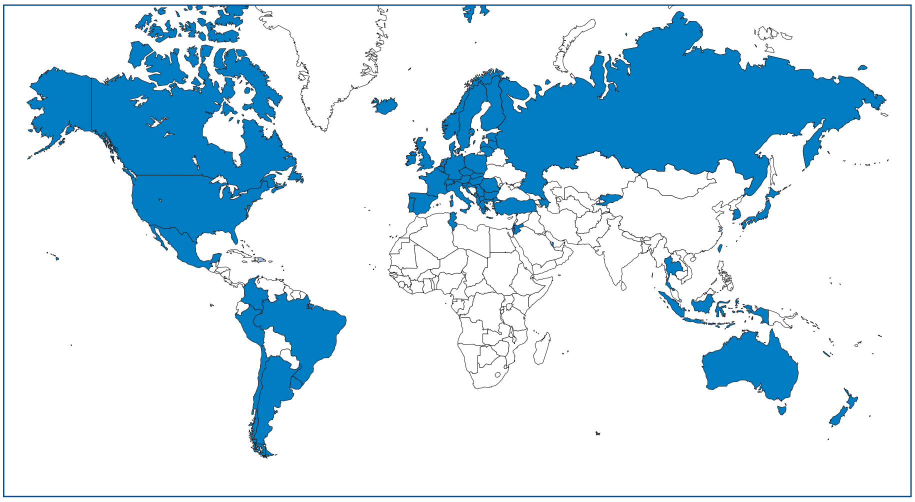
1 What is PISA Science?

What is PISA?

The OECD Programme for International Student Assessment (PISA) is an international survey of 15-year-old students that takes place every three years. First conducted in 2000, PISA has become the world's largest survey of student achievement. In PISA 2006, Ireland was one of the 57 countries (shown in Figure 1.1) that took part. Overall, almost 400,000 students were assessed.

Figure 1.1 Countries participating in PISA 2006



PISA assesses students' literacy in the three domains[1] (or areas) of science, mathematics and reading. The term literacy is used to emphasise the ability to *apply* knowledge, rather than simply to reproduce facts. Thus, PISA aims to assess students' readiness for the scientific, reading, and mathematical demands of future education and adult life. Each time PISA takes place, students are assessed in one major domain and in two minor domains. In PISA 2006 the major domain was science.

PISA produces internationally comparable measures related to education systems. These are used by governments in many countries to guide educational policy. The main purposes of PISA are to:

- assess how students can *use* the knowledge and skills they have acquired to meet real-life challenges, to master processes, and understand concepts;
- provide measures of student performance on science, reading and mathematics that can be compared across countries;
- examine links between test performance and school and student factors;
- examine trends over time;
- provide guidance on developing educational policy.

[1] Shaded text is explained in *Explanation of technical terms used* (at the end of the report).

Irish participation in PISA 2006

In Ireland, 165 randomly selected schools were invited to take part in PISA 2006, and in each school, a random selection of 15-year-old students was asked to take part. Overall, 4,585 students, or 84% of all students selected, took part. Most of those who did not take part were absent on the day of testing, while just under 4% were exempted from assessment or were not eligible to participate. Most students (59%) were in Third Year, while 21% were in Transition Year, 17% in Fifth Year, and almost 3% in Second Year. Just two students were in First Year.

How was science defined and assessed?

Students were assessed using a paper-and-pencil test which contained a mixture of item types (e.g., multiple-choice and open-response questions). In total, 103 science items were used. Items were grouped together in *units*, which presented students with a piece of stimulus material (usually a short text and an accompanying picture, chart or diagram) and then asked between three and five questions about the stimulus.

As with reading and mathematics, the assessment of science was guided by a framework, which is a detailed definition of what is meant by scientific literacy and what sort of skills a scientifically literate person would be expected to have. In this section, we describe the science framework[2]. Some sample test items are presented in Chapter 3.

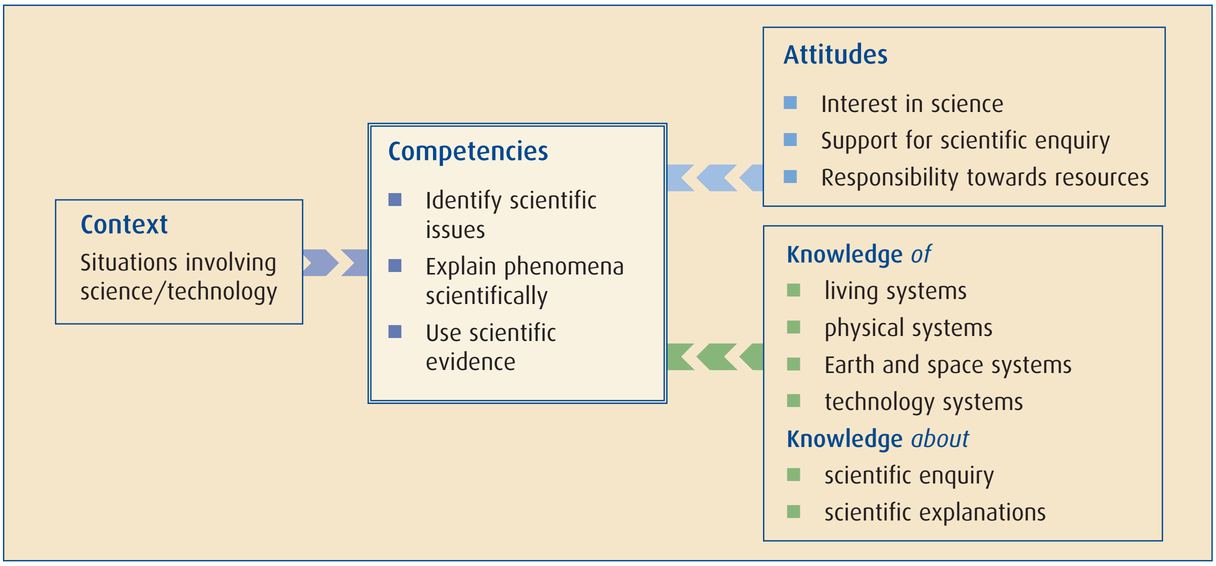
PISA defines scientific literacy as an individual's

- scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues;
- understanding of the characteristic features of science as a form of human knowledge and enquiry;
- awareness of how science and technology shape our material, intellectual, and cultural environments; and
- willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen. (OECD, 2006, p. 23)

The development of the test was based on a framework of four interrelated elements: the context (or setting) of the question, the type of knowledge needed to complete the task, student attitudes to what was being assessed, and the type of scientific competency that was required to respond to the task. The central element of the framework is the notion of scientific competencies – the core skills required to be able to function in society as a scientifically literate person (see Figure 1.2).

[2] The full PISA frameworks for science, reading and mathematics (OECD, 2006) can be downloaded from *www.pisa.oecd.org*.

Figure 1.2: Key features of the PISA science framework



Adapted from Figure 1.1, OECD 2006, p. 26

Each of the three core competencies requires students to demonstrate some or all of a related set of scientific skills.

Identifying scientific issues requires students to recognise issues that can be investigated scientifically, identify keywords to search for scientific information, and recognise the key features of a scientific investigation.

Explaining phenomena scientifically requires students to apply knowledge of science in a given situation, to describe or interpret phenomena scientifically and predict changes, and to identify appropriate descriptions, explanations and predictions.

Using scientific evidence means that students must be able to interpret scientific evidence and make and communicate conclusions, identify the assumptions, evidence and reasoning behind conclusions, and reflect on the societal implications of science and technological developments.

What scores are reported?

As well as an overall scientific literacy scale, PISA provides subscales that reflect the competencies, knowledge components and attitudinal aspects of the framework shown in Figure 1.2[3]. Thus, we can compare students (and countries) on attitudinal scales as well as on scales of achievement. Information on the achievement scales is provided in Chapter 2, and on the attitudinal scales in Chapter 5.

[3] The exception is *knowledge of technology systems*, as there were too few items assessing this element of the framework to develop a reliable scale.

Chapter Summary

PISA (Programme for International Student Assessment) is a survey of students' performance on science, reading and mathematics that takes place every three years. Science was the main focus in 2006. Almost 400,000 students in 57 countries completed a paper-and-pencil test and a questionnaire.

As well as overall scientific literacy, PISA examines students' competencies in the following areas:

- *identifying scientific issues*
- *explaining phenomena scientifically*
- *using scientific evidence*

It does so by examining students' *knowledge about science* (scientific methods and explanations) and *knowledge of* specific scientific topics (such as physical and living systems).

PISA also includes measures of student attitudes to science and engagement in science-related activities.

2 Irish Students' Performance on PISA Science

This chapter describes the performance of Irish students on the overall science scale. It also examines how Irish students performed on various elements of PISA science, and describes gender differences and changes in performance since PISA 2000.

Types of scores

Two main types of scores are used in this chapter: scores on the student achievement scale and scores on an item difficulty scale.

Student achievement scores

The average (or mean) science score for students in OECD countries is 500 and the standard deviation is 100. On the basis of the distribution of scores, we can say that roughly 68% of students have scores between 400 and 600. Table 2.1 shows the mean science scores for all participating countries. Countries are sorted in descending order, with a 'traffic light' system of colour codes showing how each country performed relative to the OECD mean:

Green	= significantly higher than the OECD average
Amber	= not significantly different from the OECD average
Red	= significantly lower than the OECD average.

Countries are further grouped into those that performed significantly better or poorer than Ireland, or did not differ significantly from Ireland.

Item difficulty scores

Each test item, as well as each student, receives a score. The item difficulty score (mean: 500; standard deviation: 100) shows how easy or difficult it was for students to answer correctly. For example, an item with a difficulty score of 630 is difficult and was not answered correctly by most students, while an item with a score of 505 is of average difficulty.

Overall science performance

Irish students achieved a mean score of 508 on the overall science scale, which is statistically significantly higher than the OECD average of 500, albeit by a small margin. Consequently, Irish performance is shown in green in Table 2.1. Ireland's mean score is the 20th highest of the 57 participating countries, and the 14th highest of the 30 OECD countries. Twelve countries (including Finland, Hong Kong-China, Canada, and Estonia) have significantly higher mean scores, while nine (including the UK, Germany and the Czech Republic) have mean scores that do not differ significantly from that of Ireland. Thirty-five countries (including Denmark, France and the US) have mean scores that are significantly lower than the Irish mean.

Table 2.1: Mean scores on overall science for all participating countries, and their position relative to the Irish and OECD mean scores

		Mean			Mean
Mean score significantly higher than Ireland	Finland	563	Mean score significantly lower than Ireland	United States	489
	Hong Kong-Ch.	542		Slovak Republic	488
	Canada	534		Spain	488
	Chinese Taipei	532		*Lithuania*	488
	Estonia	531		Norway	487
	Japan	531		Luxembourg	486
	New Zealand	530		*Russian Fed.*	479
	Australia	527		Italy	475
	Netherlands	525		Portugal	474
	Liechtenstein	522		Greece	473
	Korea	522		*Israel*	454
	Slovenia	519		*Chile*	438
Mean score not significantly different from Ireland	Germany	516		*Serbia*	436
	United Kingdom	515		*Bulgaria*	434
	Czech Republic	513		*Uruguay*	428
	Switzerland	512		Turkey	424
	Macao-China	511		*Jordan*	422
	Austria	511		*Thailand*	421
	Belgium	510		*Romania*	418
	IRELAND	**508**		*Montenegro*	412
	Hungary	504		Mexico	410
	Sweden	503		*Indonesia*	393
Mean score significantly lower than Ireland	**OECD MEAN**	**500**		*Argentina*	391
	Poland	498		*Brazil*	390
	Denmark	496		*Colombia*	388
	France	495		*Tunisia*	386
	Croatia	493		*Azerbaijan*	382
	Iceland	491		*Qatar*	349
	Latvia	490		*Kyrgyzstan*	322

Non-OECD countries shown in italics

Significantly above OECD average (green: Finland to IRELAND) — At/near OECD average (orange: Hungary to France) — Significantly below OECD average (red: Croatia to Kyrgyzstan)

Performance on science subscales

As well as an overall science score, PISA provides scores for seven science subscales. Irish students performed best on *identifying scientific issues*, achieving the 8th highest score among OECD countries, with a mean score of 516 (Table 2.2). The Irish mean for *using scientific evidence* is also significantly above the OECD mean, but the mean for *explaining phenomena scientifically*, although above the OECD mean, is not significantly so. Ireland's mean scores on *knowledge about science* (513) and *knowledge of Earth and space systems*[4] (508) are significantly above the corresponding OECD average scores. However, mean scores for *knowledge of living systems* and *knowledge of physical systems* do not differ significantly from the OECD average scores.

[4] Most of the content of *Earth and space systems* is covered, not in the revised Junior Certificate science syllabus, but in the geography syllabus.

Table 2.2: Mean scores and standard errors on science subscales in PISA 2006 (Ireland and OECD averages)

		Ireland	OECD	Significant difference?
Competency	Identify scientific issues	516	499	Yes
	Explain phenomena scientifically	506	500	No
	Use scientific evidence	506	499	Yes
Knowledge . . .	about science	513	500	Yes
	of Earth & space systems	508	500	Yes
	of living systems	506	502	No
	of physical systems	505	500	No

As is found on average across OECD countries, there is only a small gap between Ireland's mean scores on *knowledge about science* and *knowledge of science* (an average of scores on *physical, living,* and *Earth and Space systems*). This is in contrast to countries such as France, which has a 29-point gap favour of *knowledge about science*, and Hungary and the Czech and Slovak Republics, which have a minimum 24-point gap in favour of *knowledge of science*). According to the OECD (2007b), the large gaps may be attributed to different curricular emphases. For example, the French science curriculum places strong emphasis on scientific reasoning, whereas the Eastern European countries place more emphasis on learning scientific facts. Irish students show a balance between knowledge of the topics of science and knowledge about scientific reasoning, with average-to-good performance on both.

In most countries there are noticeable differences in student performance between the three *knowledge of science* subscales (*physical systems, living systems,* and *Earth and space systems*). For example, although Korean students performed well overall, their mean score for *knowledge of living systems* is below the OECD average, and over 30 points lower than their mean scores on *physical systems* and *Earth and space systems*. This suggests that less emphasis may be placed on living systems (or biology) in the Korean science curriculum than on other elements of science. In contrast, Irish students have similar mean scores across the three *knowledge of science* subscales.

Gender differences in scientific literacy

In Ireland, the overall science scores of females (508.5) and males (508.1) are almost identical. Across all OECD countries, males marginally, but significantly, outperformed females by 2.2 points. However, on a country-by-country basis, gender differences on overall science tend not to be statistically significant. This is in contrast to the marked gender differences found in the PISA domain of reading (females significantly outperform males in all countries) and the less pronounced differences in mathematics (males significantly outperform females in most).

Unlike the overall scale, some of the science subscales show quite large gender differences (Table 2.3). Irish females significantly outperformed males on *identifying scientific issues* and on *knowledge about science*, while Irish males outperformed females on *explaining phenomena scientifically*, on *Earth and space systems* and – by a large margin – on *knowledge of physical systems*. Irish females' mean score of 493 on *physical systems* is the only subscale on which our national performance falls below the corresponding overall (but not female) OECD average.

Table 2.3: Gender differences among Irish students on science subscales

		Male	Female	Significantly higher
Overall	Overall science scale	508.1	508.5	–
Competency	Identify scientific issues	508	524	Female
	Explain phenomena scientifically	510	501	Male
	Use scientific evidence	503	509	–
Knowledge . . .	about science	508	517	Female
	of Earth & space systems	515	501	Male
	of living systems	505	507	–
	of physical systems	516	493	Male

Ireland's pattern of gender differences across science subscales is largely similar to the pattern for the OECD average differences. For example, with the exception of Turkey, males significantly outperformed females on *physical systems* in all OECD countries, by an average of almost 26 points. Broadly speaking, females seem to be better than males at understanding science at a conceptual level while males seem better at the more concrete and factual level, particularly in terms of *knowledge of physical systems* (which in Ireland would be described as physics and chemistry).

There are many possible reasons for the gender differences reported (e.g., culture, parental attitudes, subject choices in school). However, knowing the nature and extent of such differences can be useful information for schools and teachers, as teaching can be targeted at particular areas in which weaknesses have been identified. For example, female students might benefit from more emphasis on the basics of physics and chemistry, while males might need more help in recognising key features of a scientific investigation and issues that are possible to investigate scientifically.

Science proficiency levels

Proficiency levels are test scores grouped into levels. Grouping is based on the skills a student at a given level is likely to be able to demonstrate. Level 6 is the most advanced proficiency level, and Level 1 the least. There is also a "below level 1" category for students who did not demonstrate the most basic competencies required by Level 1 tasks. Table 2.4 describes each proficiency level on the overall science scale, shows the range of scale scores that each level represents, and lists a test item that at least half of students at that level would be expected to answer correctly. The test items referred to are described in detail in the next chapter.

The percentage of Irish students at proficiency levels 5 or 6 (8.4) is very close to the OECD average of 9. According to the OECD, students at Levels 5 and 6 represent the pool from within which countries may be able to find their future talented scientists. Ireland has considerably fewer such students than Finland (21%) or New Zealand (18%). However, we can contrast this with the 15 countries (including Turkey, Argentina and Mexico) where less than one percent attained levels 5 or 6.

Table 2.4: Proficiency levels on the PISA 2006 science scale, examples of test items at each level, and percentages of students achieving each level (Ireland and OECD average)

Level & score range	Sample items & difficulty	At this level, a majority of students can …	IRL %	OECD %
6 707.9	Acid rain Q5 (Full credit: 717) Greenhouse Q5 (709)	consistently identify, explain and apply scientific knowledge and knowledge *about* science in a variety of complex life situations. use evidence from different sources to justify decisions. clearly and consistently demonstrate advanced scientific reasoning to develop arguments and solve problems, including in unfamiliar scientific situations. use scientific knowledge and develop arguments in support of recommendations and decisions that centre on personal, social or global situations.	1.1	1.3
5 633.3	Greenhouse Q4 (Full credit: 659)	identify the scientific components of many complex life situations, and apply both scientific concepts and knowledge *about* science to these situations. compare, select and evaluate appropriate scientific evidence for responding to life situations, and use well-developed inquiry abilities, link knowledge appropriately and bring critical insights to situations. construct explanations based on evidence and arguments based on their critical analysis.	8.3	7.7
4 558.7	Physical Exercise Q5 (583) Greenhouse Q4 (Partial credit: 568)	work effectively with situations and issues that may involve explicit phenomena requiring them to make inferences about the role of science or technology. select and integrate explanations from different disciplines of science or technology and link those explanations directly to aspects of life situations. reflect on their actions and communicate decisions using scientific knowledge and evidence.	21.4	20.3
3 484.1	Acid rain Q5 (Partial credit: 513) Grand Canyon Q7 (485)	identify clearly described scientific issues in a range of contexts. select facts and knowledge to explain phenomena, and apply simple models or inquiry strategies. interpret and use scientific concepts from different disciplines and apply them directly. develop short statements using facts and make decisions based on scientific knowledge.	29.7	27.4
2 409.5	Acid rain Q3 (460) Mary Montagu Q2 (436)	provide possible explanations in familiar contexts or draw conclusions based on simple investigations. engage direct reasoning and make literal interpretations of the results of scientific inquiry or technological problem solving.	24.0	24.0
1 334.9	Physical Exercise Q3 (386)	only apply a limited store of scientific knowledge to a few, familiar situations. present scientific explanations that are obvious and follow explicitly from given evidence.	12.0	14.1
<1		not respond correctly to more than 50% of Level 1 questions. Their scientific literacy is not assessed by PISA.	3.5	5.2

To be classified as achieving proficiency level 6, students must show consistently high levels of scientific understanding and knowledge, and be able to solve complex problems using different sources and types of information and to explain clearly the scientific reasoning behind any conclusions they draw. Two sample questions (Question 5 from the unit *Acid Rain* and *Greenhouse* Q5) are listed in Table 2.4 as examples of the types of questions that students at Level 6 need to be able to address (the items themselves are contained in Chapter 3).

Greenhouse Q5 asks students to analyze a conclusion and consider other factors that could influence the greenhouse effect. It has an item difficulty score of 709 – making it a very difficult item. *Acid Rain* Q5 is an example of an item that can be assigned either a full or a partial credit, depending on the complexity of the answer given. Only a full credit response (item difficulty score of 717) is classified as an exemplar of the skills required at Level 6, while a partial credit (item difficulty score of 513) is classified as an exemplar of Level 3. To obtain a full credit requires a quite complex response from students – including the functions of reactants and the need for a control in scientific experiments – whereas a partial credit can be assigned to answers that show some understanding of a comparison taking place, but not the concept of a control.

Greenhouse Q4 represents an example of the type of item that students must be able to answer to attain either Levels 4 or 5. Students must use evidence from two graphs to contradict a conclusion offered in the text (that the increase in Earth temperature is due to the increase in carbon dioxide emissions). Only a full credit response – where a selected time period from each graph is used in the explanation – is classified at Level 5. A partial credit response – e.g., the student used only one graph in his/her explanation – exemplifies the scientific skills of students at Level 4.

Grand Canyon Q7 is an example of an item that a majority of students at Level 3 would be able to answer. It is a relatively straightforward question, where students are asked to indicate if two questions about the Grand Canyon can be answered by scientific investigation. It does not require complex problem-solving skills, nor does it require students to draw on different sources of evidence. The question only requires a basic understanding of the capacities and limits of scientific investigation, something with which most students who took the revised Junior Certificate science syllabus (rJCSS) would be familiar. Approximately half of students (Ireland: 51%; OECD: 48%) are classified as at either level 3 or 4.

Acid Rain Q3 is an example of the type of item that students at Level 2 might be expected to answer correctly. It is a multiple-choice item which requires students to use information presented to draw a conclusion about the effects of vinegar on marble. It requires direct reasoning from clearly outlined facts. The percentage of Irish students classified as at Level 2 is the same as the average across OECD countries (24).

Level 2 is considered the "baseline" proficiency level for science, meaning that the scientific literacy of students below this level is so poor that they cannot be expected to participate actively in situations related to science and technology. Ireland has fewer students categorised below Level 2 than the OECD average (16% versus an OECD average of 19%, and compares favourably with countries such as the US and Italy, where approximately one-quarter of students do not reach baseline science proficiency. However, it falls far short of Finland, where only 4% of students do not achieve basic proficiency in science.

Proficiency levels on science subscales

Proficiency levels were reported for each science competency (Table 2.5). For *identifying scientific issues*, the percentage of high-achieving students – those at proficiency levels 5 or 6 – is slightly higher in Ireland (11) than the average across OECD countries (8). However, for both *explaining phenomena scientifically* and *using scientific evidence*, the percentage at levels 5 or 6 in Ireland is similar to the OECD average. For each competency, Ireland has proportionally fewer students than the OECD average who fail to reach the baseline proficiency level of 2. The difference was most pronounced for *identifying scientific issues* (Ireland: 14%; OECD: 19%).

Table 2.5: Percentage of students at each proficiency level on the science competencies in PISA 2006 (Ireland and OECD)

	Identify scientific issues		Explain phenomena scientifically		Use scientific evidence	
	Ireland	OECD	Ireland	OECD	Ireland	OECD
Level 6	1.8	1.3	1.8	1.8	1.6	2.4
Level 5	9.2	7.1	8.5	8.0	8.8	9.4
Level 4	22.9	20.0	19.9	19.7	21.5	19.8
Level 3	29.2	28.3	28.0	27.0	27.6	24.7
Level 2	23.2	24.6	24.6	24.0	22.6	21.7
Level 1	10.7	13.5	12.6	14.2	12.5	14.1
< Level 1	3.0	5.2	4.5	5.4	5.4	7.9

Overall, the proficiency scales suggest that Irish students do reasonably well on PISA science because proportionally fewer students are at the lower levels of proficiency. In other words, Ireland does well due to having relatively few very weak students (perhaps aided by above average reading literacy), rather than having many high-flyers.

Trends in science performance

As PISA 2006 was the first time that science was the major PISA domain, we cannot draw many conclusions about trends in Irish students' performance on science[5]. We can, however, make some basic comparisons. Ireland's mean score for science in PISA 2000 was 513, compared to 505 in 2003 and 508 in 2006. Although there has been some (non-significant) fluctuation in Irish scores, in all three years the Irish mean was slightly, but statistically significantly, above the OECD average.

We can also examine how Ireland fared in a "league table" of countries, with the caution that negligible differences in rankings need to be distinguished from substantive differences. For example, if the average scores of the 5th, 6th and 7th ranked countries differ by only a few points, they are unlikely to *significantly* differ, as ranks might easily switch were the assessment re-run a month later. For this reason, it makes more sense to discuss a probable range for Ireland's rank than to discuss an actual rank.

In 2006, Ireland's performance on science places it somewhere between 10th and 16th of 30 OECD countries, compared to between 9th and 16th of 29 OECD countries in 2003 and between 9th and 12th of 27 OECD countries in 2000. Thus, there has been reasonable stability in Ireland's science ranking over the years.

[5] For technical reasons, proper trend analyses can only be carried out in the years *after* a particular subject area has been the major domain. While trend data are already available for reading and mathematics, full trend data for science will only be available after PISA 2009.

Table 2.6: A comparison of Irish and OECD mean scores on scientific literacy, 2000 to 2006

	Ireland	OECD average	Range of rank
2000	513.4	500.0	9th – 12th of 27
2003	505.4	499.6	9th – 16th of 29
2006	508.3	500.0	10th – 16th of 30

Chapter Summary

Irish students achieved a mean score of 508 on the overall science scale, which is slightly (but statistically significantly) above the OECD average of 500. The Irish score ranked 14th among the 30 OECD countries.

Irish students were above the OECD average on the following subscales: *identifying scientific issues; using scientific evidence; knowledge about science*; and *knowledge of Earth and space systems*. Irish students did not differ from the OECD average on *explaining phenomena scientifically*, or *knowledge of living systems* or *knowledge of physical systems*.

Ireland at least matched the OECD average on all elements of PISA science. Irish females were well above the OECD average on *identifying scientific issues* and *knowledge about science*. In contrast, Irish males performed best on *knowledge of Earth and space systems* and *knowledge of physical systems*.

Slightly fewer students in Ireland failed to reach the "baseline" scientific proficiency level of 2 than was average across the OECD (16% versus 19%, respectively). Overall, Ireland's reasonable performance on PISA science may be attributed to having relatively few very weak students, rather than having many high-achieving students.

Irish performance on PISA science has remained relatively stable across the three PISA cycles to date.

3 Sample PISA Science Questions

PISA items are grouped into *units*, which comprise a number of questions that are asked about a common stimulus. After PISA 2006, some units were made public so that teachers and policy makers could see the types of skill assessed. This chapter contains a sample of the released units, chosen to reflect a mixture of scientific skills and topics, difficulty and format. In particular, we selected items where Irish students differ from the OECD average, or where there are notable gender differences.

The sample items shown include a mixture of multiple-choice (pick one of options A to D) and open-response items (write a short or a longer answer). Where appropriate, we explain how items were scored, and include some sample responses offered by Irish students.

General points to note

For each item, we show the percentages of students who answered correctly, who answered incorrectly, and who did not supply any answer ("missing"). Almost all students attempted multiple-choice items, while the missing response rate for open response items – particularly the more difficult ones – was much higher.

Irish students were more likely to attempt an answer than was the norm across OECD countries (in particular, when compared to students in countries such as Austria, Germany or the Czech and Slovak Republics). This may reflect cultural differences. For example, the typical Irish 15-year-old was preparing for the Junior Certificate examination, and probably would have been told to always answer *something*, as marks may be allocated for effort. In contrast, in Austria and the Slovak Republic students only encounter an external "high stakes" examination at the end of post-primary schooling. German 15-year-olds would be familiar with regular continual assessment by their teacher, in which guessing is not encouraged.

Table 3.1 (overleaf) presents a summary of each item, sorted in descending order of difficulty. As noted in Chapter 2, each science test item can be placed on an item difficulty scale (mean = 500) which shows how easy or difficult it was for students to answer correctly. Information shown in Table 3.1 includes

- the item's difficulty score;
- the item's proficiency levels, with Level 6 (see p. 9) representing complex scientific skills and Level 2 representing the most basic skills required to be able to function as a scientifically literate person;
- the item's classification by the PISA scientific competency and knowledge area assessed;
- where the item would fall in the revised Junior Certificate science syllabus[6] (rJCSS).

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[6] A group of science experts familiar with both PISA and the rJCSS analysed all PISA items in terms of location (if any) on the syllabus. More details are provided in the next chapter.

Table 3.1: Examples of items of varying difficulty level, classified by competency, knowledge area, and location on rJCSS

Item Name	Proficiency Level	Item difficulty	PISA competency assessed	PISA Knowledge area	Location on rJCSS
Acid Rain Q5	Level **6** (FC)[7] Level **3** (PC)	717 (FC) 513 (PC)	Identifying Scientific Issues	Scientific enquiry	Chemistry: Section 2C
Greenhouse Q5	Level **6**	709	Explaining Phenomena Scientifically	Earth and space systems	Chemistry: Section 2C
Greenhouse Q4	Level **5** (FC) Level **4** (PC)	659 (FC) 568 (PC)	Using Scientific Evidence	Scientific explanation	Physics: Section 3A
Physical Exercise Q5	Level **4**	583	Explaining Phenomena Scientifically	Living systems	Biology: Section 1A
Acid Rain Q2	Level **3**	506	Explaining Phenomena Scientifically	Physical systems	Chemistry: Section 2C
Grand Canyon Q7	Level **3**	485	Identifying Scientific Issues	Scientific enquiry	General aims (p.4 of syllabus)
Acid Rain Q3	Level **2**	460	Using Scientific Evidence	Physical systems	Chemistry: Section 2B
Grand Canyon Q5	Level **2**	411	Explaining Phenomena Scientifically	Earth and space systems	Not on rJCSS
Grand Canyon Q3	Level **2**	451	Explaining Phenomena Scientifically	Earth and space systems	Physics: Section 3B
Mary Montague Q2	Level **2**	436	Explaining Phenomena Scientifically	Living systems	Biology: Section 1C
Physical Exercise Q3	Level **1**	386	Explaining Phenomena Scientifically	Living systems	Biology: Section 1A

7 Answers to some of the open response items were divided into Full Credit (FC) and Partial Credit (PC) responses, depending on the level of scientific understanding shown in the answer.

Sample Unit: 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.

Question 2: ACID RAIN

Normal rain is slightly acidic because it has absorbed some carbon dioxide from the air. Acid rain is more acidic than normal rain because it has absorbed gases like sulphur oxides and nitrogen oxides as well. Where do these sulphur oxides and nitrogen oxides in the air come from?

	Ireland	OECD	Item difficulty
Correct	69.6	57.7	Scale score 506 Proficiency level 3
Incorrect	21.2	26.2	
Missing	9.2	16.1	

Competency: Explaining phenomena scientifically
Knowledge of: Physical systems
Location in rJCSS: Chemistry Section 2C
Why included? Irish students above OECD average

Question 2 asks students to explain the source of sulphur and nitrogen oxides in the air. Couched in terms of the PISA science framework, it examines students' ability to *explain phenomena scientifically*, by assessing their knowledge of *physical systems*. The topic on which the question is based is covered in some detail in Section 2C (chemistry: atomic structure, reactions and compounds) of the rJCSS, while many teachers will also refer to acid rain when covering Section 1C (as part of the ecology component of the section). Therefore, Irish students who had completed the rJCSS would be expected to be quite familiar with the science behind this item.

The item difficulty score of 506 means that it is of about average difficulty, and it is an example of an item that students at proficiency level 3 (see Chapter 2) are likely to answer correctly. Question 2 is an open response item, meaning that students have to write a sentence or two to answer the question. This may help to explain the relatively large percentage of students who did not attempt to answer the question (16% of students across OECD countries, and 9% of students in Ireland).

As might be expected, Irish students did quite well on the item, with 70% answering correctly compared to an OECD average of 58%. Gender differences were small both in Ireland and on average in OECD countries. In Ireland, 68% of Irish females and 71% of Irish males answered correctly.

For a response to be deemed correct, students needed to show they understood that sulphur and nitrogen oxides arise from oxidation of fossil fuels, from volcanoes, or from "pollution". Thus, a correct response could refer to car exhausts, burning of fossil fuels, factory emissions, gases from volcanoes, or a similar source. Responses which referred to nuclear power plants, fossil fuels (but did not specify *burning* of such fuels), or to industrial waste (considered too vague) were not scored as correct.

As can be seen from some of the sample answers below, students were not penalised for poor grammar or spelling. Credit was assigned once it was possible to understand the point the student was trying to make.

Examples of correct responses offered by Irish students

'They come from burning fossil fuels'

'Cars, vehicles, factories, fires, burning of plastics'

'Sulphur oxides come from factories. Nitrogen oxides come from car exhausts.'

'imissions from car exhausts and factory chimings'

Examples of responses offered by Irish students that received no credit

'From chemcal being used on the earth'

'From smoke in the air'

'The water cycle'

'Clouds that are formed from cooling & condensing on precipitation that has been soaked up from the earth surface.'

'jets and aeroplanes that fly in the sky'

The effect of acid rain on marble can be modelled by placing chips of marble in vinegar overnight. Vinegar and acid rain have about the same acidity level. When a marble chip is placed in vinegar, bubbles of gas form. The mass of the dry marble chip can be found before and after the experiment.

Question 3: ACID RAIN

A marble chip has a mass of 2.0 grams before being immersed in vinegar overnight. The chip is removed and dried the next day. What will the mass of the dried marble chip be?

A. Less than 2.0 grams
B. Exactly 2.0 grams
C. Between 2.0 and 2.4 grams
D. More than 2.4 grams

	Ireland	OECD	Item difficulty
Correct (option **A**)	68.4	66.7	Scale score 460 Level 2
Incorrect	29.7	31.1	
Missing	1.9	2.2	

Competency: Using scientific evidence
Knowledge of: Physical systems
Location in rJCSS: Chemistry Section 2B
Why included? Irish males do well on this item

Question 3 asks students to draw conclusions about the effects of vinegar on marble, using information provided with the question. This is a simplified model for the influence of acid rain on marble. Students must understand that the bubbles are being caused by a chemical reaction, partly due to the marble chip. As the reaction occurs, the marble chip will lose mass. The question examines students' ability to *use scientific evidence*, by assessing their knowledge of *physical systems*. The topic on which the question is based is covered in Section 2B (chemistry: air, oxygen, carbon dioxide and water) of the rJCSS.

It is a relatively easy question (the item difficulty score is 460), and even students at proficiency level 2 are likely to answer correctly. As with most multiple-choice items, very few students did not attempt an answer (2% of students in Ireland and on average in OECD countries).

There is little difference between the percentage of correct responses for Ireland and for OECD countries. However, in Ireland, a much larger percentage of males (73) than females (64) answer correctly. This can be contrasted with the 68% of males and 65% of females who answer correctly in OECD countries (a gender gap of 3%). Thus, Irish males perform particularly well on this question, either when compared to Irish females or to males across OECD countries.

Question 5: ACID RAIN

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

	Ireland	OECD	Scale Score	Proficiency Level
Full Credit	23.0	14.0	717	6
Partial Credit	45.4	43.0	513	3
Incorrect	21.6	25.7	–	–
Missing	9.9	17.3	–	–

Competency: Identifying scientific issues
Knowledge about: Scientific enquiry
Location in rJCSS: Chemistry Section 2C
Why included? Irish females do well on this item

Question 5 requires students to understand the need for the inclusion of a control in scientific experiments. The question examines students' ability to *identify scientific issues*, by assessing their knowledge of *scientific enquiry*. In terms of the rJCSS, it is another item that falls under chemistry (Section 2C: atomic structure, reaction and compounds).

To obtain a full credit response on this item is very difficult (the score on the difficulty scale is 717), and such a response would be expected from a student at proficiency level 6. In contrast, a partial credit response has a difficulty scale score of 513, meaning it is of average difficulty.

Question 5 is another example of an item on which Irish students did well. The percentage of Irish students who obtained full credit is 9% higher than the OECD average (23% versus 14%), while the percentage obtaining a partial credit is similar to the OECD average. A considerable minority (10%) of Irish students did not attempt this question; the average percentage of missing responses across OECD countries is even higher (17%).

Results by gender are only available for an overall percent correct score, not for full and partial credit responses[8]. On average in OECD countries, females did slightly better on this item (38% correct, versus 34% of males answering correctly). However, in Ireland the female "advantage" on this item is almost 10 percentage points (50% versus 41% answering correctly). Thus, Irish females seem to have a particularly good understanding of the issues underlying this question, relative both to Irish males and to females in other countries, possibly reflecting the good performance of Irish females on *knowledge about science*.

A full credit response requires students to show that they understand the need for a control in a scientific experiment AND that vinegar is the reactant. A partial credit is given to students who show awareness that the experiment involves a comparison but do not demonstrate that they understand the purpose of the control is to show that vinegar is a necessary reactant.

[8] The overall percent correct for an item with full and partial credit is obtained by adding the percent of students obtaining full credit to half of the percent obtaining partial credit (e.g., 40% + 20%/2 = 50%).

Examples of full credit responses offered by Irish students

'To make sure it was the acid making the difference and not just because of a liquid.'

'As a control, to show that it was the acid that caused the change in weight and not anything else.'

'To show that it was vinegar that weared it away and that water doesn't.'

Examples of partial credit responses offered by Irish students

'to see what the difference would be and how big it would be.'

'to see if the chip would get lighter.'

'To show the change or difference between the distilled water and vinegar.'

Examples of responses offered by Irish students that received no credit

'To prove that there is less acid in water.'

'To show that water contains small amounts of acid.'

'To show that the test was fair because it would be equal.'

Sample Unit: Greenhouse

Read the texts and answer the questions that follow.

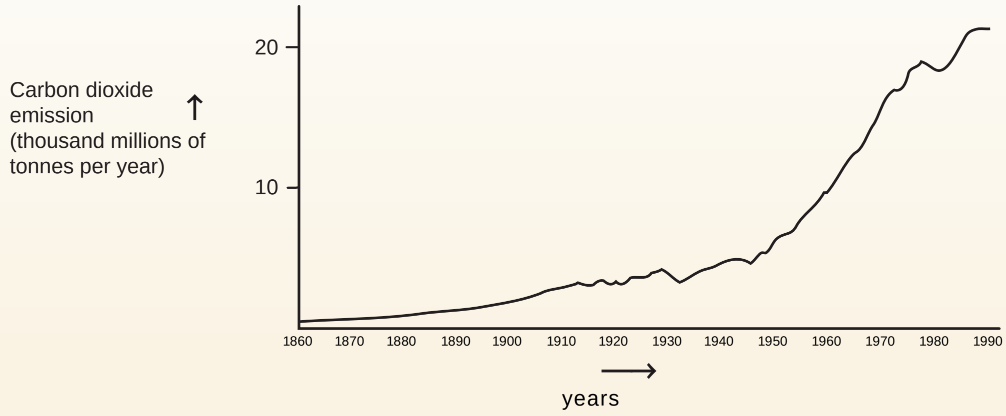
THE GREENHOUSE EFFECT: FACT OR FICTION?

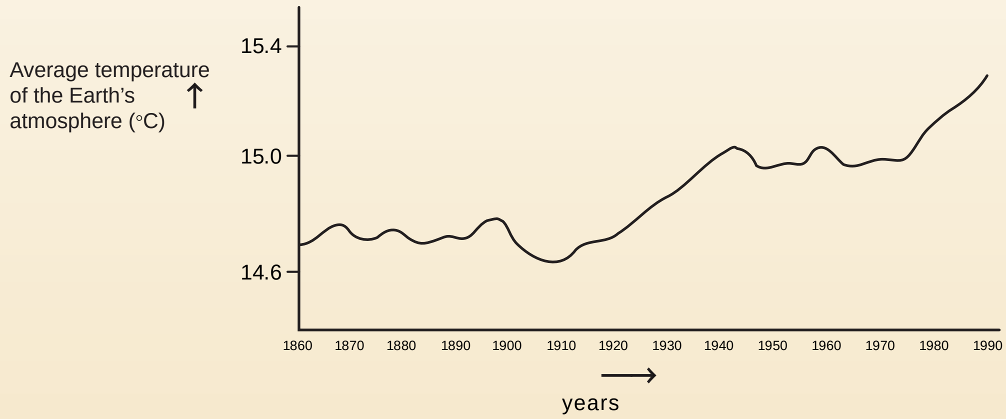
Living things need energy to survive. The energy that sustains life on the Earth comes from the Sun, which radiates energy into space because it is so hot. A tiny proportion of this energy reaches the Earth. The Earth's atmosphere acts like a protective blanket over the surface of our planet, preventing 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 Andrew 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.





Andrew 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.

Question 4: GREENHOUSE

Another student, Jeanne, disagrees with Andrew'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 Andrew's conclusion. Explain your answer.

	Ireland	OECD	Scale Score	Proficiency Level
Full Credit	23.0	22.4	659	5
Partial Credit	27.8	24.1	568	4
Incorrect	30.5	27.6	–	–
Missing	18.7	25.9	–	–

Competency: Using scientific evidence
Knowledge about: Scientific explanation
Location in rJCSS: Physics, Section 3A
Why included? Irish males do well on this item

Question 4 from the *Greenhouse* unit examines students' ability to *use scientific evidence* by assessing their knowledge about *scientific explanations*. Students need to use the two graphs provided to locate evidence in support of an argument. The topic on which the question is based is covered in Section 3A of the rJCSS (physics: force and energy). It is an item on which students can receive either partial or full credit. To obtain a full credit is fairly difficult (the item has an above average difficulty scale score of 659, at proficiency level 5). Even obtaining a partial credit on this item is not easy (item difficulty score of 568 and a proficiency level of 4).

The 23% of Irish students who achieved a full credit is close to the OECD average (22%). A slightly larger percentage of Irish students received partial credit, compared to the OECD average (28% versus 24%). Possibly due to its difficulty, many students did not answer this item. However, as was the case generally, the percentage of missing answers was lower in Ireland (19%) than on average across OECD countries (26%). Although gender differences on this item were negligible at OECD level, Irish males did better than Irish females on this item. The overall percent correct for Irish males is 40%, compared to 34% for their female counterparts.

The question requires students to show how the two graphs contradict the theory that the increase in the average temperature of the Earth's atmosphere is due to the increase in the carbon dioxide emission. Full credit answers must link a particular part of both graphs in which the curves are not both ascending or both descending and explain that this contradicts Andrew's conclusion. Partial credit is given if a student mentions a correct period, but without explanation, or provides an explanation, but no specified period, or refers to a correct period and provides a very poor explanation or refers to only one of the graphs.

Examples of full credit responses offered by Irish students

'From 1860-1880 the level of carbon dioxide emissions remained the same yet the average temperature varied.'

'In the CO2 graph from 1860 to 1910 the graph is steadily rising whereas in the temperature graph from 1860 to 1910 there is significant fluctuations This contradicts Andrews theory.'

'In 1910 the carbon dioxide emissions increased from 1900 but the temperatures in 1910 dropped to a lower point than in 1900.'

Examples of partial credit responses offered by Irish students

'In graph 2 (Average temperature of earths atmosphere) in the 1900 it was a lot higher than in 1910.'

'In 1910 the temperature dropped but the CO2 was still increasing'

Examples of responses offered by Irish students that received no credit

'that the temperatures of the earth are always rising & falling'

'As the temperature from 1860 to 1900 is steadily similar.'

'In 1990 they are almost similar except the Average is kind of lower than the emmisson.'

Question 5: GREENHOUSE

Andrew 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.

	Ireland	OECD	Item difficulty
Correct	19.1	18.9	Scale score 709 Level 6
Incorrect	50.4	45.6	
Missing	30.5	35.5	

Competency: Explaining phenomena scientifically
Knowledge of: Earth and space systems
Location in rJCSS: Chemistry, Section 2C
Why included? An example of a very difficult item

Question 5 examines students' ability to *explain phenomena scientifically*, using their knowledge of *Earth and space systems*. They must suggest other factors that could influence the greenhouse effect. The topic is covered in Section 2C (chemistry: atomic structure, reactions and compounds) in the rJCSS.

Question 5, although an open response item like Question 4, does not allow for partial credit responses. It is an example of a hard item, with a difficulty score of 709 and a proficiency level of 6. A very large minority of students (31% in Ireland and an average of 35% in OECD countries) did not attempt this question, perhaps providing further evidence of its difficulty. Only 19% of students (Ireland and OECD) answered the item correctly, with no notable gender differences.

Two types of response received a credit for this item: those referring to the energy/radiation coming from the sun, and those referring to a natural component or potential pollutant (e.g. CFCs). To be able to answer this item, students must grasp the concept of controlling external factors and have an adequate understanding of *Earth and space systems* (so they can identify potential factors that need to be controlled). As such, it requires fairly complex analysis and scientific reasoning.

Examples of correct responses offered by Irish students

'The amount of heat the earth gets from the sun.'

'The production of other gases such as methane which is produced from grazing cows.'

'The presence of the ozone layer as if this decreases the amount of sun entering and hitting the earth will increase & therefore increase the average temp.'

'Jeanne might think that the earth is moving closer to the sun.'

'An increase in CFC's or other greenhouse-gases.'

Examples of responses offered by Irish students that received no credit

'Pollution'

'the levels used of oil and other non-renewable sources.'

'like the constant production of CO2 gas or the same amount of trees cut down each year.'

'The melting of the Polar ice caps.'

'Burning of fossil fuels.'

Sample Unit: Physical Exercise

Regular but moderate physical exercise is good for our health.

Question 3: PHYSICAL EXERCISE

What happens when muscles are exercised? Circle "Yes" or "No" for each statement.

Does this happen when muscles are exercised?	Yes or No?
Muscles get an increased flow of blood.	Yes / No
Fats are formed in the muscles.	Yes / No

	Ireland	OECD	Item difficulty
Correct (**Yes, No**)	75.6	82.4	Scale score 386 Level 1
Incorrect	25.1	17.0	
Missing	0.3	0.6	

Competency: Explaining phenomena scientifically
Knowledge of: Living systems
Location in rJCSS: Biology, Section 1A
Why included? Irish students do relatively poorly on this item

Question 3 from *Physical Exercise* examines students' ability to *explain phenomena scientifically*, assessing their knowledge of *living systems*. Specifically, it requires knowledge about how muscles operate and how fat forms. The topic is covered in Section 1A (human biology: food, digestion and associated body systems) in the rJCSS.

The question is very easy, relative to other questions in this report. The item's score on the difficulty scale is 386, and is classified as exemplifying the types of scientific literacy that a student at proficiency level 1 can demonstrate. As such, even those who do not demonstrate baseline scientific literacy might be expected to answer the item. Although 76% of Irish students answered correctly, Irish performance is still noticeably poorer than the average in OECD countries (82% correct). Indeed, only Korea had a lower percentage of students answering the item correctly. Gender differences were minimal on this item.

As a complex multiple-choice item, students had to answer "Yes" to the first part **and** "No" to the second in order to get a credit for this item. Doing so required two distinct pieces of scientific knowledge: there is an increase in blood flow in active muscles, and fats do not form when muscles are exercised. As well as the 76% who answered both parts correctly, 15% of Irish students got one part of the item correct. Thus, 9% did not get any part of this very easy item correct, compared to an OECD average of 5%.

It may be that this item is reflecting knowledge picked up outside of science lessons – specifically, in physical education and health education classes. Irish students (primary and post-primary) spend far less time in PE lessons than is average in OECD countries (OECD, 2007a). Further, we do not have a notable tradition of health education in schools, nor do we use specialist teachers for PE lessons at primary school. The weak performance of Irish students on the question might be attributable to any or all of these factors.

Question 5: PHYSICAL EXERCISE

Why do you have to breathe more heavily when you're doing physical exercise than when your body is resting?

	Ireland	OECD	Item difficulty
Correct	41.8	45.1	Scale score 583 Level 4
Incorrect	56.0	50.2	
Missing	2.2	4.7	

Competency: Explaining phenomena scientifically
Knowledge of: Living systems
Location in rJCSS: Biology, Section 1A
Why included? Irish males perform poorer than OECD average for males

Question 5 examines students' ability to *explain phenomena scientifically*, by means of a topic based on knowledge of *living systems*. This open response item requires a written answer that links breathing more heavily to an increase in physical activity. The topic underlying the item is covered in Section 1A (human biology: food, digestion and associated body systems) in the rJCSS.

It is a somewhat difficult item (583 on the difficulty scale), and is an example of an item that students at proficiency level 4 or above are likely to be able to answer correctly. The percentage of Irish students answering correctly was slightly below average (42%, compared to the OECD average of 45%). This was in part attributable to a relatively weaker performance by Irish male students. While proportionally more Irish males than females answered correctly, Irish males nonetheless lagged behind the OECD average for males (43% correct versus 49%, respectively).

Responses scored as correct needed to indicate that heavy breathing took place because of one or both of the following: the need to remove elevated levels of carbon dioxide, and the need to increase oxygen levels. Responses that referred to "air" instead of oxygen, or did not explicitly refer to an *increased* need for oxygen, were not scored as correct. The Chief Examiner's report on the 2006 Junior Certificate science papers (State Examinations Commission, 2006) noted a tendency for Ordinary level students to confuse carbon dioxide and oxygen when describing differences between inhaled and exhaled air. While this may have explained some of the incorrect responses, many Irish students who did not gain a credit referred to heavier breathing being caused by a faster heart rate (without further explanation).

Examples of correct responses offered by Irish students

'Because our hearths are pumping a lot faster which increases the blood flow which means we need more oxygen.'

'This is because your body demands more oxygen since it has to work harder during exercise e.g. muscles demand more oxygen so you breathy more heavily.'

'You are taking in more oxygen which is being pumped around your body by your heart.'

'Your bodys metabolism is going at a faster rate and needs more oxygen in the bodys cells.'

Examples of responses offered by Irish students that received no credit

'By moving and doing exercise your heart rate increases and you get out of breath. Breathing more heavily helps catch your breath.'

'to pump more blood around your body to stop you from getting heart failure.'

'Because you heart is pumping faster to circulate blood quicker and needs more air.'

Sample Unit: The Grand Canyon

The Grand Canyon is located in a desert in the USA. It is a very large and deep canyon containing many layers of rock. Sometime in the past, movements in the Earth's crust lifted these layers up. The Grand Canyon is now 1.6 km deep in parts. The Colorado River runs through the bottom of the canyon. See the picture below of the Grand Canyon taken from its south rim. Several different layers of rock can be seen in the walls of the canyon.

Question 7: GRAND CANYON

About five million people visit the Grand Canyon national park every year. There is concern about the damage that is being caused to the park by so many visitors. Can the following questions be answered by scientific investigation? Circle "Yes" or "No" for each question.

Can this question be answered by scientific investigation?	Yes or No?
How much erosion is caused by use of the walking tracks?	Yes / No
Is the park area as beautiful as it was 100 years ago?	Yes / No

	Ireland	OECD	Item difficulty
Correct (**Yes, No**)	74.1	61.3	Scale score 485 Level 3
Incorrect	25.2	37.3	
Missing	0.7	1.4	

Competency: Identifying scientific issues
Knowledge about: Scientific enquiry
Location in rJCSS: General aims and objectives of syllabus
Why included? Irish students do well on this item

Question 7 in the *Grand Canyon* unit tests students' skills at *identifying scientific issues*, assessing their knowledge of *scientific enquiry*. To answer correctly, students need to understand what can and cannot be studied using scientific investigation. The syllabus location assigned to this item was the introduction to the rJCSS. Thus, while the specific topic discussed in the question is not included in the syllabus, the central skills required to answer it are outlined on page 4 of the syllabus (Department of Education and Science, 2003), under the heading "Syllabus aims and objectives".

The item is of easy-to-average difficulty (485 on the item difficulty scale) and has a proficiency level of 3. Irish students did very well on this item, with 74% answering correctly compared to the OECD average of 61%. Gender differences were negligible in Ireland, but Irish males did noticeably better than males on average in OECD countries. The percent of correct responses among Irish females was 11% higher than the OECD female average, while for Irish males it was 15% higher than the OECD average for males.

It is a complex multiple-choice question, meaning that the student has to mark yes or no beside a set of options. For full credit, students must have answered both options correctly in the order 'Yes', then 'No'.

Question 3: THE GRAND CANYON

The temperature in the Grand Canyon ranges from below 0°C to over 40°C. Although it is a desert area, cracks in the rocks sometimes contain water. How do these temperature changes and the water in rock cracks help to speed up the breakdown of rocks?

A. Freezing water dissolves warm rocks.
B. Water cements rocks together.
C. Ice smoothes the surface of rocks.
D. Freezing water expands in the rock cracks.

	Ireland	OECD	Item difficulty
Correct (option **D**)	87.2	67.6	Scale score 451 Level 2
Incorrect	11.4	29.0	
Missing	1.4	3.4	

Competency: Explaining phenomena scientifically
Knowledge of: Earth and space systems
Location in rJCSS: Physics, Section 3B
Why included? Irish students do very well on this item

To answer Question 3 in the *Grand Canyon* unit, students need to know the freezing point of water, and that expansion occurs as water turns to ice. The item requires students to *explain phenomena scientifically* by drawing on their knowledge of *Earth and space systems*. The topic is covered in Section 3B (physics: heat, light and sound) in the rJCSS. Irish students performed extremely well on the item (87% correct, compared to an OECD average of 68%). Gender differences were small, both in Ireland and at OECD level.

It is an easy item (difficulty score of 451), and is an example of an item that students at proficiency level 2 or above are likely to answer correctly. Students do not need to draw on multiple sources of information or develop a reasoned argument in order to answer correctly. All that is needed is for the student to remember two facts (water freezes at 0°C; water expands as it becomes solid), and to apply them in a clearly defined setting. Doing so reveals that the correct answer is option D "Freezing water expands in the rock cracks".

Question 5: THE GRAND CANYON

There are many fossils of marine animals, such as clams, fish and corals, in the Limestone A layer of the Grand Canyon. What happened millions of years ago that explains why such fossils are found there?

A. In ancient times, people brought seafood to the area from the ocean.
B. Oceans were once much rougher and sea life washed inland on giant waves.
C. An ocean covered this area at that time and then receded later.
D. Some sea animals once lived on land before migrating to the sea.

	Ireland	OECD	Item difficulty
Correct (option **C**)	70.2	75.8	Scale score 411 Level 2
Incorrect	26.4	20.6	
Missing	3.5	3.6	

Competency: Explaining phenomena scientifically
Knowledge of: Earth and space systems
Location in rJCSS: Not on the revised syllabus
Why included? Irish students, especially females, do poorly on this item

Question 5 examines student's ability to *explain phenomena scientifically* by using their knowledge of *Earth and space systems*. Some knowledge is needed about how fossils are formed. Although the topic is not covered on the rJCSS, it is covered in the geography syllabus, meaning that most students should be familiar with it. The item is quite easy (411 on the difficulty scale), and is an example of an item that is located on the border of proficiency levels 1 and 2. A correct response does not require complex analysis or argumentation. To identify option C as the answer, students need to know that fossils are formed in water and that receding seas may reveal fossils.

Although most (70%) Irish students answered the item correctly, their performance is disappointing when compared to the OECD average of 76% correct. Further, while there was only a 2% gender gap (in favour of males) on average across all OECD countries, in Ireland the gap was larger: 73% of males got the right answer, compared to 68% of females.

Sample Item: Mary Montagu

Read the following newspaper article and answer the questions that follow.

THE HISTORY OF VACCINATION

Mary Montagu was a beautiful woman. She survived an attack of smallpox in 1715 but she was left covered with scars. While living in Turkey in 1717, she observed a method called inoculation that was commonly used there. This treatment involved scratching a weak type of smallpox virus into the skin of healthy young people who then became sick, but in most cases only with a mild form of the disease. Mary Montagu was so convinced of the safety of these inoculations that she allowed her son and daughter to be inoculated.

In 1796, Edward Jenner used inoculations of a related disease, cowpox, to produce antibodies against smallpox. Compared with the inoculation of smallpox, this treatment had less side effects and the treated person could not infect others. The treatment became known as vaccination.

Question 2: MARY MONTAGU

What kinds of diseases can people be vaccinated against?

A. Inherited diseases like haemophilia.
B. Diseases that are caused by viruses, like polio.
C. Diseases from the malfunctioning of the body, like diabetes.
D. Any sort of disease that has no cure.

	Ireland	OECD	Item difficulty
Correct (option **B**)	74.3	74.9	Scale score 436 Level 2
Incorrect	24.2	23.3	
Missing	1.5	2.8	

Competency: Explaining phenomena scientifically
Knowledge of: Living systems
Location in rJCSS: Biology, Section 1C
Why included? Irish females do well on this relatively easy item

This sample item from the *Mary Montagu* unit examines students' ability to *explain phenomena scientifically*, using their knowledge of *living systems*. Students need to know that vaccinations can prevent disease. The topic is covered in Section 1C (biology: animals, plants and micro-organisms) in the rJCSS. It is a fairly easy item (436 on the difficulty scale), and most students at proficiency level 2 or above should be able to answer it correctly.

To identify option B as the correct response, students must remember that vaccinations help prevent diseases caused by factors external to the body (as opposed to hereditary conditions). The item may be relatively easy to answer because of a hint offered in the question – the word "virus" appears in the introductory text and is repeated in option B – making it easier for students to identify the correct answer. Irish students' performance on this item was average, differing from the OECD average percent correct by only one point. However, there is a gender difference among Irish students; 79% of females, compared to 70% of males, answered correctly. The gender gap at the OECD level was less pronounced (4%), but also favoured females.

4 Science in PISA and the Junior Certificate

This chapter links performance on the PISA test and the Junior Certificate Science Examination. First, some background information about the cohort of Junior Certificate students who were examined in 2006 is provided. Next, the content of the PISA science test is compared with the content of the revised Junior Certificate science syllabus (rJCSS) – the syllabus experienced by most Junior Certificate 2006 students – and expected student familiarity with PISA items is linked to performance.

Junior Certificate candidates in 2006

Of all Junior Certificate 2006 candidates, 86% took a science examination. Most sat an examination based on the rJCSS, with only 10% examined on the older syllabus. Females (83%) were less likely than males (90%) to take science. Two-thirds (67%) of science students took the subject at Higher level.

In order to link performance on PISA with examination performance, science grades were placed on a 12-point scale known as the Junior Certificate Performance Scale (JCPS). This scale was developed by Martin and Hickey (1993) to allow comparison of student grades across Higher, Ordinary and (where applicable) Foundation levels. Table 4.1 shows how examination grades are converted to scores on the scale – for example, a B at Higher level converts to a JCPS score of 11. Nationally, the average JCPS score for science in 2006 was 9.2 (roughly equivalent to between a C and a D at Higher level, or an A at Ordinary level).

Table 4.1: Relationship between grade and level and JCPS score

Level	JCPS score											
	12	11	10	9	8	7	6	5	4	3	2	1
Higher	A	B	C	D	E	F						
Ordinary				A	B	C	D	E	F			
Foundation*							A	B	C	D	E	F

* While Foundation level does not apply to Junior Certificate science, it is shown for illustrative purposes.

Linking PISA and Junior Certificate performance

Using Department of Education and Science databases, Junior Certificate Examination results for science were found for most PISA participants. However, as many PISA participants completed the Junior Certificate in 2005, or were studying the older syllabus, results on the rJCSS were available for only 48% of the students who took part in PISA. We focus on these students, analysing links between the content of the rJCSS and their performance on PISA.

Of the PISA students who took the revised science syllabus, the average JCPS score was 9.3. As was the case nationally, females outperformed males, with females averaging 9.4, compared with 9.2 for males. The correlation, or statistical relationship, between Junior Certificate science grade and PISA science is reasonably strong (r= .71). In other words, students who performed well on one were also likely to perform well on the other.

Similarly, the correlations between rJCSS grade and the three competency subscales are fairly strong (.67 for *using scientific evidence*, .68 for *identifying scientific issues* and .69 for *explaining phenomena scientifically*). However, inter-correlations between the PISA domains are stronger, ranging from .80 for reading and mathematics performance to .87 for science and mathematics[9].

Unlike subjects such as English or mathematics, a significant minority of students do not take science. Thus, in Table 4.2, we show (for the entire PISA 2006 cohort) how non-science students compare with students taking science at Ordinary and Higher level. Firstly, among Higher level students, the percentages falling into proficiency levels 5 or 6 (15%) is in contrast to the less than 1% of Ordinary level students who manage to demonstrate such high scientific proficiency. Interestingly, 1% of students who did not study science managed to demonstrate sufficient scientific literacy to be classified at Level 5.

At the other end of the proficiency scales, only 3% of Higher level students fail to reach a baseline level of scientific literacy (Level 2), compared to just over one-third of Ordinary level science students and non-science students. The overall OECD average is 19%. Thus, quite a large proportion of the students who do not study science at Higher level may lack the level of scientific literacy necessary to allow them to participate fully in future life situations involving science.

Table 4.2: Percentage of students at each proficiency level by science uptake in the Junior Certificate, and mean score

	OECD	Ireland		
		Higher	Ordinary	Non-science
Level 6	1.3	1.8	0.0	–
Level 5	7.7	13.0	0.4	1.1
Level 4	20.3	31.1	4.3	8.8
Level 3	27.4	34.5	23.0	21.1
Level 2	24.0	16.5	38.9	34.0
Level 1	14.1	2.9	26.5	25.9
< Level 1	5.2	0.2	6.9	9.1
Mean score	**500**	**551**	**441**	**444**

Only students for whom information was available on Junior Certificate science uptake are shown.

The final part of Table 4.2 shows the mean scores for each group. The mean of 551 obtained by Higher level students is well above the OECD average (500). The means of Ordinary level and non-science students are not only below the OECD average, but are not significantly different from each other. While an immediately obvious explanation for this lack of difference is that Ordinary level science students are academically weaker than non-science students, comparisons of the mean scores for reading and mathematical literacy revealed no significant differences between the two groups. Therefore, we need to look elsewhere to explain the apparent lack of a difference between the two groups. One possible answer is that aspects of PISA science are covered in other subjects – such as geography and home economics.

[9] Correlations are higher again if all Irish PISA participants are considered (ranging from .82 for reading and mathematics performance to .88 for science and mathematics).

To place the results in a broader context, while Ireland's *Higher level* science students performed well above the *overall* OECD average, they still fell short of the *national* mean score of Finnish students. Ireland's Ordinary level and non-science students obtained mean scores that were similar to the national means of students in Chile, Serbia and Bulgaria.

Using the rJCSS to describe the PISA test items

The PISA test is not based on the science curriculum of any one country (unlike, say, the Junior Certificate science examination, which is clearly related to the syllabus). Nonetheless, it is likely to be more closely aligned to the science curricula in some countries than in others. In this section, we describe how the PISA science items were categorised and rated in terms of the rJCSS.

Each item was examined by three subject experts who had extensive knowledge of the revised Junior Certificate science curriculum. Two types of familiarity ratings were assigned:

- Familiarity to Irish students of the concept (the underlying scientific principle in its abstract form).
- Familiarity of the competency or process (the underlying *type of scientific understanding* needed to answer the question).

Ratings were made using a 3-point scale (1 = not familiar, 2 = somewhat familiar, 3 = very familiar). Also, the subject experts were asked to locate where each item would fit within the rJCSS. As well as sections 1A – 3C, an additional location of 'general' was used when an item did not fall into any of the main sections, but covered the general scientific skills cited in the syllabus introduction and objectives. All agreed locations and all except one of the familiarity ratings were identical for Higher and Ordinary syllabi. Hence, no further distinction is made between syllabus levels.

Where would PISA test items be covered on the rJCSS?

Twenty-eight percent of PISA items were described as falling under the biology sections of the rJCSS, 22% under physics, and 15% under chemistry (Table 4.3). A further 19% fell under general scientific skills, while only 16% of PISA items were described as not on the rJCSS. This represents a major change since PISA 2000, when Irish experts adjudged that 43% of PISA items were not on the science syllabus at that time (although some of the difference may be due to the specific inclusion of general scientific skills as a location).

Sections 1C (Animals, plants and micro-organisms) and 3A (Force and energy) were very well represented in terms of PISA items, whereas no items related to Section 1B (Human biology – the skeletal/muscular system, the senses and human reproduction). Thus, while the extent of overlap between PISA and the syllabus seems to have increased, it is also the case that PISA still does not assess some of what we would consider to be core elements of a science syllabus. In particular, the absence of any items that would be categorised under Section 1B seems to represent an important omission. It may be that item writers felt that the sort of topics covered in Section 1B (in particular, reproduction) would not be acceptable in some of the countries participating in PISA (all items are examined for possible cultural difficulties).

Table 4.3: PISA (2006) science items categorised by location within the rJCSS

Location			N	%	Overall %
Not on rJCSS		–	16	15.5	15.5
Biology	1A	Human biology – food, digestion, associated systems	12	11.7	
	1B	Human biology – skeletal/muscular, senses, reproduction	0	0.0	
	1C	Animals, plants, micro-organisms	17	16.5	28.2
Chemistry	2A	Classification of substances	4	3.9	
	2B	Air, oxygen carbon dioxide & water	3	2.9	
	2C	Atomic structure, reactions & compounds	8	7.8	14.6
Physics	3A	Force & energy	14	13.6	
	3B	Heat, light & sound	5	4.9	
	3C	Magnetism, electricity & electronics	4	3.9	22.3
General		–	20	19.4	19.4
Total		–	**103**	**100.0**	**100.0**

Are the concepts and competencies familiar?

Table 4.3 outlines where the *topics* covered in PISA items might fit on the rJCSS, while Table 4.4 shows the expected familiarity to Irish students of the scientific *concepts* and *competencies* underpinning the items. The expert group felt that all PISA science items were based on scientific competencies that should be at least somewhat familiar to Irish students who had studied the rJCSS. Over one-third (37%) of items were rated "very familiar", with all remaining items rated "somewhat familiar". Half of items were described as based on concepts that were very familiar to Irish students, 47% were described as somewhat familiar, and only 4% were perceived to be based on concepts unfamiliar to Irish students. Ratings did not vary by syllabus level.

Table 4.4: PISA 2006 science items rated on concept and competency familiarity

	Not familiar		Somewhat familiar		Very familiar	
	N	%	N	%	N	%
Competency	0.0	0.0	65	63.1	38	36.9
Concept	4	3.9	48	46.6	51	49.5

Did familiarity influence performance?

PISA 2006 used a rotated booklet design. This means that each student was given one of 13 different test booklets, each containing different combinations of items. This made it possible to calculate different competency and concept familiarity ratings for each booklet. For example, the mixture of science items in booklet X might mean that it was assigned a higher competency familiarity score for Irish students than booklet Y, which had a different mixture of items. Hence, we can examine the link between familiarity and student performance. There were weak-to-moderate correlations between the familiarity scores of the booklet a student completed and the PISA science scores of students who had completed the rJCSS (.12 for concept familiarity and .13 for competency familiarity levels). Thus, students given a booklet with an above average familiarity score tended to do slightly better than those with a lower familiarity booklet.

The correlations are weaker than might be expected, possibly because few items were rated as unfamiliar (i.e., booklet scores varied little). However, when PISA science and curriculum science were last compared (Shiel, Cosgrove, Sofroniou, & Kelly, 2001), science achievement displayed far weaker correlations with the familiarity scales than either mathematics or reading.

Thus, for science, familiarity does not seem to be as good a predictor of performance as is the case for mathematics and reading.

Using PISA to describe the rJCSS

As well as examining how PISA test items fit into the rJCSS, we can examine the rJCSS from a PISA perspective. To do this, the percentages of marks in the 2006 rJCSS (examination papers and Coursework A and B) that could be allocated to various elements of the PISA science framework were examined. Clearly, marking schemes do not capture the totality of a syllabus, but they do indicate the importance placed on its various elements.

First, each examination question/Coursework title (for both Higher and Ordinary levels) was classified using the PISA science framework. Next, because the marking schemes are quite detailed and specific, it was possible to aggregate the amount of marks allocated to the various parts of the framework – the competencies and the knowledge areas.

Like the PISA test, the rJCSS marking schemes seemed to concentrate on *explaining phenomena scientifically* (Table 4.5). Roughly two-thirds of marks allocated could be classified as assessing this competency, while remaining marks were relatively evenly divided between *using scientific evidence* and *identifying scientific issues*.

Table 4.5: The percentage of marks for the 2006 rJCSS relating to each of the PISA competency categories

	Explaining scientific phenomena	Identifying scientific issues	Using scientific evidence
Higher	62.3	17.8	19.8
Ordinary	66.8	16.8	16.3

In terms of the PISA *knowledge* areas, the *physical systems* area was disproportionately represented in marking schemes at both Higher and Ordinary levels (receiving almost half of all marks) (Table 4.6). The remaining marks were split between *scientific enquiry* (30% of marks) and *living systems* (22%), with 1% of rJCSS marks allocated to technology systems[10]. Neither *scientific explanations* nor *Earth and space systems* featured in the 2006 marking scheme. However, aspects of what PISA defines as *Earth and space systems* can be found on the Junior Certificate geography syllabus. Thus, although *Earth and space systems* do not seem to feature in science lessons for Irish students, many would be familiar with the area through their geography lessons.

Table 4.6: The percentage of 2006 rJCSS marks allocated to elements of the PISA framework

	Knowledge about		Knowledge of			
	Scientific enquiry	Scientific explanations	Earth & space systems	Living systems	Physical systems	Tech. systems
Higher	29.7	0.0	0.0	21.8	47.5	1.0
Ordinary	31.2	0.0	0.0	21.7	47.2	0.0

[10] The PISA science framework recognises technology systems as a specific knowledge area. However, the number of PISA items assessing the area was too small to allow reporting on a technology systems subscale.

Chapter Summary

Correlations between Junior Certificate science grades and PISA overall scores and subscale scores are reasonably strong. However, the inter-correlations between the PISA domains (science, reading, and mathematics) are stronger.

Students who studied Junior Certificate science at Higher level performed well above the OECD average on PISA science. However, Ordinary level students not only performed below the OECD average, but did not differ significantly from students who had not studied Junior Certificate science.

The concepts and competencies underlying most PISA items were described by Irish curriculum experts as familiar to students of the revised Junior Certificate science syllabus (rJCSS).

Most PISA items could be classified under one of the syllabus sections, or under the general scientific skills identified in the syllabus introduction. Biology was the best-represented section, although no items assessed Section 1B (human biology: skeletal/muscular, senses, reproduction). Chemistry was least well represented.

The link between the rated familiarity of items and performance on PISA was quite weak for science, and considerably weaker than links found for PISA reading and mathematics.

An examination of the rJCSS marking scheme in terms of the PISA science framework revealed an emphasis on the competency of *explaining phenomena scientifically*, on *knowledge of physical* and *knowledge of living systems* and on knowledge about *scientific enquiry*.

5 Attitudes to and Engagement with Science

In the PISA study, students were asked a number of questions about their attitudes to science and engagement in science-related activities. Themes explored comprise: students' interest and engagement in science; the value they placed on science; confidence in their own scientific skills and abilities; motivation for studying science; interest in a science-related career; and attitudes to environmental issues and sustainable development.

This chapter describes student responses to individual items and scores on *indices* (scales based on groups of related items). While the focus is on Irish students, we include some information about other countries. In particular, we highlight some examples where Irish students differ from students elsewhere. However, it should be borne in mind that attitudinal measures may be influenced by cultural factors and by the context in which a student answers the questions. For example, water shortages might have seemed a more important issue to an Australian student living in the Outback than to an Irish student in Valentia (the wettest place in Ireland in March 2006, when PISA was administered).

Interest and engagement in science

There are three indices related to students' interest in science: *general interest in science; enjoyment of science;* and *involvement in science-related activities*. Eight items asking about students' interest in specific science topics made up the index of *general interest in science*. Compared to the OECD average, fewer Irish students expressed interest in astronomy, chemistry, physics, geology, or in the way scientists design experiments, while an above average percentage expressed interest in human biology and plant biology (Table 5.1). Generally, in Ireland and across OECD countries, interest was highest for human biology and lowest for geology and for what is required for scientific explanations. Although Irish females expressed higher *general interest in science* than did Irish males, in most countries there were no gender differences.

There were no gender differences (Ireland or OECD) for *enjoyment of science*, but Irish students were slightly below the OECD average in terms of the percentages agreeing that they enjoyed various science-related activities. Smaller proportions of students in Ireland than across OECD countries indicated that they liked reading about science or were happy doing science problems (Table 5.1). The most notable difference was that while almost two-thirds of students across OECD countries agreed that they have fun learning science topics, less than half of Irish students agreed that they did so.

Across all 30 OECD countries, only Japanese students reported lower engagement in science-related activities than Irish students. For example, the percentages of students in Ireland who said that they regularly or often accessed a science website, or watched a TV programme about science are below the OECD average. In particular, far fewer Irish students reported regularly or often reading science magazines or articles (11% versus an OECD average of 20%) (Table 5.1). In Ireland, students most likely to engage in science-related activities were males, non-native students, or from a higher socioeconomic background.

Table 5.1: Percentages of students indicating an interest in various aspects of science (Ireland and OECD average)

	Students express high or medium interest in . . .	IRL	OECD
General interest in science	...human biology	77%	68%
	...the biology of plants	55%	47%
	...topics in chemistry	44%	50%
	...topics in physics	41%	49%
	Students 'agree' or 'strongly agree' . . .		
Enjoyment of science	...I like reading about science	45%	50%
	...I am happy doing science problems	39%	43%
	...I generally have fun when I am learning science topics	48%	63%
	Students 'very often' or 'regularly' . . .		
Engagement in science-related activities	...watch TV programmes about science	18%	21%
	...read science magazines or science articles in papers	11%	20%
	...visit websites about science topics	9%	13%

The value of science

Irish students were more or less average on an index of their perception of the *general value of science* (assessed by asking students to indicate their level of agreement with five statements relating to potential benefits of science). For example, in Ireland (and across OECD countries) students were highly likely to agree that advances in science and technology usually help to improve living conditions, and Irish students in particular felt such advances improve the economy (Table 5.2). In contrast, only 67% of Irish students believed that "advances in science usually bring social benefits", compared to an OECD average of 75%. It is of interest that the equivalent percentage in Northern Ireland was also 67%.

Assessment of the *personal value of science* differs from a general value of science. Students may agree that science is valuable, but may not feel it has much to do with their own lives. As in almost all countries, students in Ireland were less likely to perceive science as of personal than of general value. For example, less than two-thirds of students in Ireland and across OECD countries felt that they would use science in many ways when they were adults (Table 5.2). On this index, there was only one item on which Irish responses showed much divergence from the OECD average; proportionally fewer Irish students agreed that "some concepts in science help me see how I relate to other people".

In Ireland, males placed slightly more value than females on the general value of science, while females were more likely to see the personal value of science. Native Irish students typically had a lower score on personal value of science than non-native students.

Table 5.2: Percentages of students indicating they 'agree' or 'strongly agree' with selected statements about the value of science (Ireland and OECD average)

	Students 'agree' or 'strongly agree' that...	IRL	OECD
General value of science	...advances in science and technology usually help to improve the economy	85%	80%
	...advances in science and technology usually bring social benefits	67%	75%
Personal value of science	...some concepts in science help me see how I relate to other people	56%	61%
	...I will use science in many ways when I am an adult	61%	64%

Science confidence

Two scales examined students' confidence as scientifically literate individuals – *self-efficacy* and *self-concept in science*. *Self-efficacy* measures students' confidence in their ability to complete tasks and solve science problems, and was measured by asking students to indicate the ease with which they could perform each of eight science-related tasks. Overall, Irish students were very close to the OECD average on this index, but this was because the unusually high and unusually low percentages of positive responses on certain items cancelled each other out. Irish students differed by at least 5% from the OECD average on five of the eight items.

Compared to the OECD average, Irish students were more likely to believe that they would be able to critique explanations for acid rain, explain why earthquakes occur more frequently in some areas than in others, and identify the science question associated with disposal of waste (Table 5.3). However, fewer Irish students felt able to identify the underlying scientific question in a news article, or discuss the possibility of life on Mars. Responses of students in Northern Ireland (but not in England and Wales) displayed a similar pattern, with above average levels of efficacy for items related to waste disposal and acid rain, and below average efficacy for life on Mars. This may indicate the influence of non-school factors that are common to both sets of students – such as somewhat overlapping media.

A related index is *self-concept in science*, which assesses students' belief in their academic ability related to science. It is less task-specific than *self-efficacy*. Unlike *self-efficacy*, Irish students scored below average on *self-concept* in science. Compared to the OECD average, Irish students expressed less confidence about their ability to learn advanced science topics, or to learn science topics quickly or easily (Table 5.3).

Males scored higher than females on the *self-efficacy* and *self-concept* indices (in Ireland and in most other countries). Within many countries, there is a positive link between self-efficacy and/or self-concept and performance on the science test (i.e., the better you think you are, the better you tend to do on the test). However, readers should bear in mind two major cautions. First, we do not know if high levels of *self-efficacy in science* lead to improvement in science achievement, or if high levels of achievement increase *self-efficacy*, or if it is a reciprocal relationship. Second, comparing average levels of *self-efficacy* or *self-concept* across countries reveals some interesting cultural differences. For example, the second highest-scoring country on *self-efficacy in science* is the USA, while Finnish students are more or less average, and Japanese students have by far the lowest score of OECD countries. However, Japan and Finland are among the highest scoring countries on the science test, while the USA is below the OECD average. Thus, the extent to which students express confidence in their scientific skills is not only linked to actual achievement, but is also influenced by cultural factors.

Table 5.3: Percentages of students indicating they 'agree' or 'strongly agree' with selected statements about ability to understand science (Ireland and OECD average)

	Students could 'easily', or 'with a bit of effort' . . .	IRL	OECD
Self-efficacy	...recognise the science question that underlies a newspaper report on a health issue	68%	73%
	...discuss how new evidence can lead you to change your understanding about the possibility of life on Mars	41%	51%
	...identify the better of two explanations for the formation of acid rain	65%	58%
	...explain why earthquakes occur more frequently in some areas than in others	81%	76%
	...identify the science question associated with disposal of waste	69%	62%
	Students 'agree' or 'strongly agree' . . .		
Self-concept	...learning advanced school science topics would be very easy for me	37%	47%
	...I learn school science topics quickly	49%	56%
	...school science topics are easy for me	42%	47%

Motivation to study science

Students were asked a number of questions about their motivation to study science – relating to the relevance of science in their current lives and whether or not they wanted to study science or work in science-related careers. Irish students – females in particular – were slightly, but significantly, above average on the index of *motivation to learn science*. Specifically, Irish students were more aware than most of the potential career benefits of studying science (see Table 5.4). For example, 67% of Irish students (70% of females) agreed that "I will learn many things in my school science subjects that will help me get a job", compared to an OECD average of 56%.

Irish females also scored marginally, but significantly, higher than Irish males on *future-orientated motivation to learn science* (i.e., whether they wished to work in a science-related field or to continue studying science after school). Overall, Irish students were average in their desire to continue in a science-related field. Proportionally more Irish students indicated that they would like a career involving science or to study science after they completed school (Table 5.4). However, Irish students were less enthusiastic about working on science projects as adults or about spending their life "doing advanced science". It seems that while many Irish students were happy to have a career involving *some science*, far fewer wanted to deal with a lot of science. Similar response patterns were observed in Northern Ireland, England, and Wales.

Table 5.4: Percentages of students agreeing with various statements about their motivation for studying science (Ireland and OECD average)

	Students 'agree' or 'strongly agree' . . .	IRL	OECD
Motivation to learn science	...I study school science because it is useful to me	73%	67%
	...studying school science subjects is worthwhile because what I learn will improve my career prospects	68%	62%
	...I will learn many things in my school science subjects that will help me get a job	67%	56%
Future-orientated motivation to learn science	...I would like to work in a career involving science	41%	37%
	...I would like to study science after secondary school	36%	31%
	...I would like to work on science projects as an adult	22%	27%
	...I would like to spend my life doing advanced science	15%	21%

Interest in a science-related career

Students were asked to name the job they expected to have at age 30. Responses were divided into science-related (broadly defined as involving a considerable amount of science, as well as those involving tertiary education in a scientific field) and careers that did not involve science. Twenty-nine percent of Irish students indicated that they wanted a science-related career, compared to 25% across all OECD countries. Although roughly equivalent percentages of Irish males (28) and females (30) wanted a science-related career, there were some differences in the types of careers envisaged. For example, the most popular choice for females (5%) was to be a nurse, a career selected by only 22 males (0.1%). In contrast, the most popular choice for males was to be an architect, town planner or engineer (8% of males and 2% of females).

Examples of the top 10 categories of science-related careers selected by Irish students are shown in Inset 6.1. Careers listed include medical doctor, physiotherapist, psychologist, and computer systems analyst. Pathologist is perhaps one of the more unexpectedly popular choices, particularly with females (almost 2% selected it as their preferred career). This may reflect the fact that the current Chief State Pathologist is female, or that female pathologists feature prominently in a number of popular TV crime series.

Inset 6.1: Top 10 science-related career categories (Irish students)

Medical doctor
Physiotherapist / chiropractor / osteopath
Architect / town planner / engineer
Nurse / midwife
Veterinarian
Psychologist
Social work professional
Pharmacologist / pathologist
Computer systems designer / analyst
Biologist / botanist / zoologist

There was considerable variation across countries in the extent to which students were interested in a career involving science. For example, 39% of Portuguese students wanted a science-related career, compared to 18% of Finnish students, despite Finland obtaining by far the highest mean science score. This highlights the perhaps obvious point that not all students who are "good" at science will want to become scientists. Portuguese students also reported high levels of engagement in science-related activities, and scored highly on science *self-concept* and *self-efficacy*. This suggests that as well as scientific knowledge, interest and engagement in science may be important factors in helping to foster interest in science as a career.

Environmental awareness and sustainable development

Students were asked a number of questions about the environment and sustainable development. Some of the indices developed from the questions include *awareness of environmental issues, concern for environmental issues, optimism regarding environmental issues,* and *responsibility for sustainable development*. Irish students obtained the highest score among students in OECD countries on *awareness of environmental issues*.

Compared to students in most countries, Irish students were more likely to believe that they had an understanding of issues such as deforestation, acid rain, greenhouse gases and nuclear waste (Table 5.5). The contrast was greatest for understanding of acid rain, with 83% of Irish students reporting some familiarity with the issues involved, compared to 60% of students on average across OECD countries. Irish students were below the OECD average only on level of understanding of genetically modified organisms. As in almost all OECD countries (including Ireland), male students had a significantly higher mean score than females on the index. Of course, readers should bear in mind that the index is based on self-report, rather than actual assessment of skills and knowledge. In other words, Irish students (particularly males) believe that they have high levels of *awareness of environmental issues*, but this belief may not be matched by actual knowledge.

Table 5.5: Percentages of students indicating some awareness of various environmental issues (Ireland and OECD average)

Students are ' familiar with' or' know something about' . . .	IRL	OECD
...the consequences of clearing forests for other land use	82%	73%
...acid rain	83%	60%
...the increase of greenhouse gases in the atmosphere	75%	58%
...nuclear waste	64%	53%
...the use of genetically modified organisms	26%	35%

In contrast to their high levels of *awareness of environmental issues*, the OECD (2007b) report on PISA indicates that Irish students were well below average on *concern for environmental issues*. For example, Irish students were less likely than the OECD average to feel that water shortages, air pollution, nuclear waste, or clearing forests for other land use were serious concerns (Table 5.6). The largest gap between Irish and OECD opinion related to the extinction of plants and animals as a serious concern. Only 74% of Irish students (OECD: 84%) felt this was of serious concern, perhaps indicating that efforts are needed to make Irish students more aware of issues of biodiversity.

However, a closer examination of the index suggests that it presents an unfairly pessimistic view of Irish students' concern for the environment. Scores on the index were assigned only to students who indicated that a particular issue was a serious problem, either for them personally or for other people in their country. This is quite different from a lack of concern about the environment generally. For example, given our annual rainfall, it is not too surprising that many Irish students felt water shortages were not a concern either to them personally or to people in Ireland. Indeed, less than half of students in Iceland and Finland felt water shortages were a concern to them or to people in their country, compared to 92% of students in drought-stricken Australia. However, if scoring was extended to include students who felt an issue was of serious concern only to people in other countries, a different picture emerges – 99% of Finnish and Icelandic students were concerned about water shortages, compared to "only" 97% of Australian students.

Had students been asked about, for example, flooding caused by global warming, it is quite likely that the responses of Northern and Central European students would have demonstrated far higher levels of concern than in response to water shortages. This indicates the need for considerable caution when comparing some of the attitudinal indices used in PISA, as they can be strongly influenced by local circumstances.

A scale of *optimism regarding environmental issues* was developed by asking students if they felt six environmental issues would improve over the next 20 years. Students in all countries tended to be quite pessimistic, although Irish students were slightly more optimistic than the average. For example, although only 26% of students in Ireland felt that problems in relation to energy shortages would improve, this was still higher than the average of 21% across all OECD countries. Also, 27% of Irish students (OECD average: 18%) were optimistic that issues of water shortages would be resolved, again suggesting that Irish students do not view it as a serious issue.

Table 5.6: Percentages of students responding to various statements relating to the environment (Ireland and OECD average)

	Students report that the issue is serious concern for self or other people in their country	IRL	OECD
Concern for environmental issues	Extinction of plants and animals	74%	84%
	Clearing of forests for other land use	75%	83%
	Water shortages	67%	76%
	Students believe that the issue will improve over next 20 years		
Optimism re. environmental issues	Energy shortages	26%	21%
	Water shortages	27%	18%

Responsibility for sustainable development examined students' attitudes to strategies for such development. Irish students were average on this index. They were more likely to agree that the use of plastic packaging should be kept to a minimum (92% versus an OECD average of 82%) and that electricity should be produced from renewable resources as much as possible, even if this increased the cost (Table 5.7). However, fewer Irish students would support laws that regulate factory emissions, even if this would increase the price of products (61% versus an OECD average of 69%). Students in general seem less supportive of initiatives that would directly affect the cost to consumers, with support lowest in New Zealand (only 49% were supportive).

Of course, this may simply illustrate the fact that factory emissions are not a problem in a country such as New Zealand, with the result that students do not see any problem to be addressed. At the other extreme, 94% of Turkish students were in favour of greater regulation, even at a cost to the consumer. Presumably, Turkish responses were influenced by the problems many Turkish cities have with poor air quality. These contrasting examples again show the possible influence of contexts on students' attitudes, something that should always be borne in mind when examining the outcomes of studies such as PISA.

Table 5.7: Percentages of students responding to various statements about sustainable development (Ireland and OECD average)

Students 'agree' or 'strongly agree' . . .	IRL	OECD
...to reduce waste, the use of plastic packaging should be kept to a minimum	92%	82%
...electricity should be produced from renewable resources as much as possible, even if this increases the cost	84%	79%
...I am in favour of laws that regulate factory emissions, even if this would increase the price of products	61%	69%

Chapter Summary

Irish students were average in their perceptions of the *general value of science* and *self-efficacy in science*, but obtained the highest score among students in OECD countries on the index of *awareness of environmental issues*. In contrast, they were well below average on *concern for environmental issues* (possibly due to the specific questions asked rather than a general lack of concern on the part of Irish students).

Irish students were similar to the OECD average on the index *general interest in science*, slightly below average on *enjoyment of science*, and well below average on *engagement in science-related activities*. However, they were above average on understanding the potential career benefits of studying science.

The percentage of Irish students who wanted a science-related career was slightly higher than the average in OECD countries (29% versus 25%). However, while many Irish students wanted a career involving *some science*, less wanted to deal with a lot of science.

Irish students expressed below average levels of confidence in their ability to learn advanced science topics, or to learn science topics quickly or easily (*self-concept in science*). In Ireland, males scored higher than females on indices of science *self-efficacy* and *self-concept*, and on *engagement in science*, whereas females scored higher than males on *general interest in science* and *motivation to learn science*.

6 Factors Linked to Achievement

In this chapter, student- and school-level factors are related to performance on the PISA science test. First, the links between performance and student background and individual characteristics are examined. Next, we link school-level and system-level factors to performance. Finally, we summarise a multi-level model of science performance, which examines how a large number of factors interact to "explain" how students in Ireland perform on the test.

Student home background

Table 6.1 presents data on selected aspects of students' home environment. All of the student characteristics summarised in the table are significantly related to how students performed on the science test, although, for ease of presentation, not all response categories are shown. For example, for parental education, information on only the "extreme" categories (primary education only or third level degree) is provided.

Students from high socioeconomic status (SES) families averaged significantly higher scores on PISA science than students from middle or low SES families. The gap between the average scores of students in low and high SES families was 61 points, a very large difference. There were also very clear links between parental education levels and how students performed. For example, the 3% of students whose parents had not progressed beyond primary school had an average score of 440, over 100 points lower than the mean score of 544 obtained by students whose parents had completed a third-level degree.

Just 4% of students indicated that they were only children, while 19% had four or more siblings. The highest mean score (523) was obtained by students with one sibling, while the lowest (484) was obtained by students with four or more siblings. The mean score of the 94% of students classified as native did not differ significantly from students classified as non-native. However, the 98% of students who spoke English or Irish at home significantly outperformed students who spoke another language, by a margin of 61 points.

Table 6.1: Selected home background characteristics and performance on PISA science

		% of students	Mean score
Socioeconomic status	High	32.7	542
	Low	32.9	481
Parental education	Primary only	3.0	440
	Third level degree	24.5	544
Family size	One sibling	24.6	523
	4 or more siblings	18.5	484
Language spoken in the home	English / Irish	98.0	511
	Other	2.0	450

As well as structural and fairly unchanging aspects of the home (such as family size), information was obtained on educational and cultural resources in the home. Ireland was 21st of the 30

OECD countries in terms of availability of educational resources (e.g., study desk or calculator) in the home, and 26th of 30 countries in terms of cultural resources (e.g., classic literature or poetry). In contrast, Ireland was well above the OECD average on availability of "affluence indicators" such as TVs, dishwashers and cars.

The extent of cultural and educational resources in the home was clearly linked to performance on the science test. For example, in Ireland, students who were rated as very high on the scale of cultural resources outperformed students rated as very low by a margin of 69 points (Table 6.2). The number of books in Irish students' homes was quite similar to the OECD average, with roughly one in ten students having 10 books or fewer at home. The mean science score of 434 obtained by such students was 117 points lower than the mean obtained by students with over 500 books in the home, a very large difference.

There were also clear links between the frequency with which students and parents interacted (e.g., eating dinner together, just chatting) and how well students did on the science test. For example, the mean score of students who hardly ever or never discussed politics or social issues with their parents is 63 points lower than that of students who did so regularly.

As mentioned, Irish homes were above the OECD average on affluence indicators, and most of these indicators were positively linked with achievement (the more "things" students had, the better they tended to do). The exception was television. Irish students were far more likely than the OECD average to have at least three TVs in the home (78% versus 52%, respectively), but such students averaged 32 points lower on the science test than students with only one TV.

Table 6.2: Selected home "atmosphere" characteristics and performance on PISA science

		% of students	Mean score
Score on 'cultural resources' in the home	Very high	25.3	551
	Very low	23.4	482
Number of books in the home	10 or fewer	10.3	434
	Over 500	8.5	551
Frequency of discussing political or social issues with parents	Never/hardly ever	34.0	484
	Several times a week	11.3	547
Number of TVs in the home	One	3.8	536
	Three or more	78.3	504

Student behaviour, experiences and attitudes

As noted in Chapter 4, students who took Junior Certificate science at Higher level scored significantly higher on the PISA science test than those who took science at Ordinary level or did not study the subject for Junior Certificate. However, somewhat surprisingly, students who took Ordinary level science did not perform any better on the PISA science test than students who had not studied science (Table 6.3). Taking Third year (the modal year) as an example, over one-quarter of students were participating in some form of extra science lessons or science grinds. Contrary to what might be expected, these students were outperformed on PISA science (a mean of 486 versus 516) by those *not* taking extra science lessons.

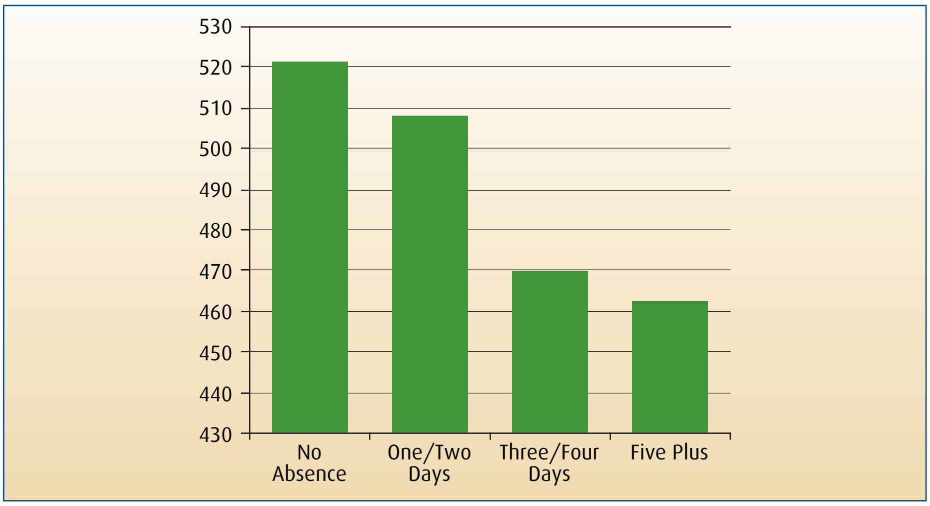
Close to half of students indicated that they had experienced some form of bullying by a student in their school, either inside or outside of school hours, in the school term during which PISA was administered[11]. Those who had not experienced bullying in any form obtained the highest mean score (522) on the science test, while students who had experienced four or more forms obtained the lowest score (480).

Table 6.3: Selected student characteristics and performance on PISA science

		% of students	Mean score
Studied Junior Certificate science	Ordinary level	27.6	441
	Did not study	8.4	444
Third years taking extra science lessons	Yes	26.5	486
	No	73.5	516
Forms of bullying	None	56.6	522
	Four or more forms	7.2	480

Students who had not been absent for any day in the fortnight preceding PISA (about half of participants) outperformed all other students, with the gap largest (59 points) when compared with the 5% of students who had missed five or more days. Figure 6.1 shows the relationship between test scores and absenteeism.

Figure 6.1: Mean scores on the overall science scale by number of days absent in the two weeks preceding the assessment



Almost two-thirds (63%) of Irish students had engaged in some paid work during school term. There was a weak-to-moderate negative correlation (– .15) between the number of hours worked and science test scores, with the link slightly stronger for males than females (i.e., as hours worked increased, test scores tended to decrease slightly).

Almost all of the attitudinal and engagement measures outlined in Chapter 5 were linked to test performance. The strongest correlations with science test performance are for *self-efficacy in science* (.45), *enjoyment of science* (.40), *self-concept in science* (.39) and *general interest in science* and *personal value of science* (both .34). Thus, students who, for example, reported a high level of enjoyment of science tended to do quite well on the PISA science test.

One index, *optimism regarding environmental issues,* was negatively correlated with achievement (– .18), meaning that weaker students tended to be more optimistic about the environment.

[11] Many studies explicitly define bullying for students as *repeated and intentional* behaviour. This study simply asked which, if any, of a list of six behaviours (e.g., being physically hurt) had been used to bully them.

Concern for environmental issues was the only index that was unrelated to science test scores, perhaps due to the problematic nature of the index, as outlined in Chapter 5.

School characteristics

School characteristics can be divided into ones that relate to intake and ones that relate to school policies and resources. The latter are more amenable to change and are therefore more useful to teachers than, say, knowing that high SES schools tend to do better than low SES schools.

Intake characteristics

Students in schools where most students were from above average SES families did best on the science test (a mean of 512), while those in low SES schools did poorest (475) (Table 6.4). Similarly, students in designated disadvantaged schools were outperformed by students in non-designated schools. There were also differences between sectors. Secondary school students had the highest mean score and vocational school students the lowest. Students in same-sex schools obtained higher mean scores than students in mixed-sex schools. However, readers should be aware that both school gender composition and sector are closely linked to SES.

Table 6.4: Selected school intake characteristics and performance on PISA science

		% of students	Mean score
School-level SES	Low	33.6	475
	High	33.5	512
Designated as disadvantaged	Yes	25.2	480
	No	74.8	518
Sector	Comm./comp.	16.8	501
	Secondary	59.6	521
	Vocational	23.6	481
Gender composition	All-male	18.7	522
	All-female	23.2	522
	Mixed	58.1	498

Only 2% of Irish students were in schools where Third year students were not ability grouped for any subjects, compared to an OECD average of 33%. Indeed, only in the UK was the percentage of students in ability groups higher than in Ireland. Part of the difference can be explained by the fact that Ireland does not separate schools by "academic track". This contrasts with a country such as Germany (where *gymnasien* cater for university-bound students, and *hauptschulen* provide a vocational education).

On average across OECD countries, 86% of students were in public schools, compared to only 42% of Irish students[12]. Generally, students in schools classified as private outperformed students in schools classified as public. Complex statistical analyses carried out by the OECD revealed that once differences in student background were taken into account, the "private advantage" disappeared (or was reversed in a number of countries). This means that the achievement gaps probably existed before the students enrolled in their post-primary school, and do not derive from any "added value" of attendance at a particular type of school.

[12] All secondary schools in Ireland are classified by the OECD as private due to their management structure and ownership.

Policies and staffing

Principals were asked a series of questions about policies to promote science in their school. Responses were used to develop an index of *science promotion*, on which Ireland was slightly, but not significantly, above the OECD average. For example, Irish students were more likely than the average to attend science fairs and to engage in extracurricular science projects, but less likely to attend science clubs. Students attending schools with a high score on *science promotion* outperformed students in schools that scored poorly on the scale. Two elements of the scale were particularly important in Irish schools: science clubs and science competitions (Table 6.5).

Table 6.5: Selected school policies and staffing and performance on PISA science (Ireland)

		% of students	Mean score
Availability of science clubs for Third years	Yes	20.9	522
	No	79.1	504
School engagement in science competitions for Third years	Yes	54.1	519
	No	45.9	494
Percent of teaching staff qualified (***Difference not significant**)	All qualified	67.6	504*
	Not all qualified	32.4	514
Science teacher shortage (***Difference not significant**)	None / a little	90.9	507*
	Some extent / a lot	9.1	518

Based on principals' responses, almost all teachers (across all subjects) in Irish schools were qualified to teach (97% of teachers versus an OECD average of 87%). Overall, 68% of schools had a fully qualified teaching staff. In comparisons between schools where all teachers were qualified with ones where at least some were unqualified, no significant differences were found in how students performed on PISA (Table 6.5). In a related vein, only 9% of Irish students were in schools where the principal believed that a lack of qualified science teachers was hindering instruction (OECD average: 17%), and such students did not differ significantly from students in schools unaffected by a science teacher shortage. Of course, this does not mean that shortages of qualified teachers do not influence student performance. It simply means that it is a relatively minor problem in Ireland, compared to other countries, where major shortages may well affect performance.

System characteristics

In this section, two system-level factors (structure and spending) are related to students' test performance. Countries vary in the models they adopt for their education systems. This can affect overall national performance, as well as variation within a country. When describing variation in test performance within a country, we examine two types of difference: differences between schools and differences between students in the same school. In Ireland, 17% of variance in science test scores was found to be attributable to differences between schools, much lower than the OECD average of 33%[13]. This means that despite what is popularly assumed, schools in Ireland tend to be reasonably similar to each other in terms of average achievement, with considerable diversity in each student body.

Contrasting examples are Hungary and The Netherlands (where roughly 60% of variation is between schools) and Finland (where only 6% of variation is between schools). Finland is the

[13] The percentages shown differ slightly from those reported by the OECD, as the latter only refers to students for whom information on SES was available.

highest-performing country in terms of PISA science scores, yet espouses a very egalitarian model of schooling, where knowing what school a student attends and his or her SES is not a good predictor of performance on PISA. The Netherlands also attains quite high scores in PISA, yet does so via a much more "segregated" system, whereby a student's SES and choice of study programme can predict PISA performance quite accurately. Ireland tends to be slightly closer to the Finnish model than to the Dutch.

Broadly speaking, richer countries tend to do better on PISA. However, wealth does not directly translate into spending on education, and the relationship between PISA performance and how much a country spends on education is not particularly strong. For example, OECD (2007b) data reveal that Finland invests roughly the same amount per student as Australia and the UK, yet has a much higher level of achievement[14]. Norway and the US are among the highest spenders, yet their mean levels of achievement are similar to that in the Slovak Republic, which is among the lowest spenders. Ireland's performance is more or less what might be predicted, given the level of education spending.

Of course, state investment in education is not the only form of investment. Parents may invest in private schooling or in shadow education (grinds). Further, richer countries often differ from poorer countries not only in terms of investment in education, but on other relevant factors, such as parental education levels and the extent of educational resources available in homes. Nonetheless, the evidence suggests that the relationship between what governments spend on education and how students perform on PISA is not a straightforward one.

Multi-level model of science achievement

Many of the factors described in this chapter are interrelated. For example, school SES and school designated disadvantaged status are closely linked, as are factors such as student *enjoyment of science* and *general interest in science*. Multi-level models of achievement simultaneously examine the effects of a number of variables. This means that the relationship between a variable and science achievement can be described, while holding the effects of other variables constant. The use of multi-level models also allows us to identify an optimal set of factors to "explain" achievement differences.

Cosgrove and Cunningham (in prep.) examined 23 student-level variables and 17 school-level variables in a multi-level study of Irish performance on PISA 2006 science. However, most variables were removed from the model as they explained little once other variables were also considered. For example, the explanatory value of parental education is no longer significant if parental SES is taken into account. School-level variables dropped included sector, gender composition, size, shortage of resources (science equipment and personnel) and academic selectivity (whether academic ability was considered in admitting students). Their final model, summarised in Table 6.6, "explains" 79.6% of variation in achievement between schools, and 44.0% of variation in achievement within schools.

Students from smaller families, who spoke either English or Gaeilge at home, who had a large number of books, and whose parents had high SES occupations tended to perform well on the PISA science assessment. In terms of student characteristics, those in higher grades (e.g., Fifth Year) not studying the Leaving Certificate Applied programme, who reported enjoying science

[14] Comparisons are based on *purchasing power parities*, a measure that takes into account factors such as national differences in cost of living and services.

and reading science articles for fun, and who studied science at Higher level for the Junior Certificate were the highest-achieving students. Female students who had not studied Junior Certificate science outperformed male students who had not done so.

At the school-level, students did best in schools where proportionally few students were in receipt of a Junior Certificate Examination fee waiver and where at least some students in the school participated in science competitions.

Table 6.6: Summary of factors included in the final multi-level model of science achievement

	Factor	Higher scores obtained by students...
Family and home	Siblings	with fewer than three siblings
	Language spoken at home	who spoke English or Gaeilge at home
	No. of books in the home	with large number of books in their home
	SES	whose parents had high SES occupations
Student	Grade and programme	in Fifth year, taking Leaving Certificate Established or Vocational Programme
	Attitudinal variables	who scored above average on indices of *enjoyment of science* and *self-efficacy in science*
	Behaviour	who report reading science articles or magazines
	Science uptake	taking Higher level JC science
	Science uptake X gender	who did not study JC science and are female, compared with male students who did not study JC science
School	JCE fee waiver	in schools where proportionally few students were in receipt of JC examination fee waiver
	Science competitions	in schools involved in science competitions

Chapter Summary

Many aspects of students' home background were related to achievement (e.g., parental socioeconomic status and education levels, family size, and language spoken in the home). In Ireland, home variables positively related to science scores included availability of educational and cultural resources, number of books in the home, and frequency of parent-child interaction. There was a negative relationship between science scores and number of TVs in the home.

Ireland ranked 21st of the 30 OECD countries on availability of educational resources in the home, and 26th for cultural resources. However, Ireland was well above the OECD average on most affluence indicators.

In Ireland, higher scores on the science test were associated with a variety of student characteristics: study of science at Higher level, good attendance rates, *not* taking out-of-school science lessons, and *not* being bullied. Scores on the *enjoyment of science* scale showed a strong link with achievement test scores.

SES underpinned almost all school-level characteristics linked to good science test performance (e.g., designated disadvantaged status, sector).

The percentage of variation in science test scores that could be accounted for by differences *between* schools is much lower in Ireland than the OECD average. This means that schools in Ireland tend to be reasonably similar to each other, with considerable diversity within each student body.

A multi-level model of performance on PISA science in Ireland (Cosgrove & Cunningham, in prep.) revealed that family size, home language and SES were important factors in explaining achievement. Student grade and programme, engagement with science outside of school, and study of Junior Certificate science at Higher level were also predictive of higher science scores. However, only two school-level variables – Junior Certificate fee waiver and school-level engagement in science competitions – predicted science achievement.

7 What Does it Mean for Teachers?

In this chapter, we summarise some of the main findings of PISA 2006, and identify their relevance for science teachers.

Irish students' scientific literacy

The performance of Irish students on the overall science scale is above the OECD average, if only by a small margin. Their ranking in 2006 is reasonably similar to their ranking in 2000 and 2003, suggesting a fairly consistent, average-to-good level of scientific literacy. Performance across the science subscales is also consistent, as scores on all subscales were at least as high as the OECD average. Thus, there is no area in which Ireland's performance can be classified as weak. Irish students showed a relative strength in *identifying scientific issues*, scoring 17 points above the OECD mean. This may perhaps reflect success in achieving one of the central objectives of the rJCSS (understanding the scientific method and the concept of a valid experiment).

Generally, the introduction of the rJCSS has led to a closer match between PISA science and science as experienced in Irish schools. When PISA and Junior Certificate science were last compared – in PISA 2000 – 43% of science items were considered to deal with topics that were not included in the syllabus (Shiel et al., 2001). This time, only 16% of items could not be located somewhere within the revised syllabus. Thus, it is a little surprising that Irish performance on PISA did not improve.

Unlike the other two PISA domains of reading and mathematics, the link between familiarity of the topic and test performance is fairly weak for science, even if only students who studied the rJCSS are considered. The reasons for this are unclear, but it may be that students are picking up scientific knowledge from other subjects and sources. For example, some of the PISA *Earth and space systems* items are covered in Junior Certificate geography. From a science teacher's perspective, it highlights the importance of external sources in what their students may and may not know. Unlike, say, mathematics, other school subjects and life outside of school may represent significant sources of the scientific information (and sometimes misinformation) held by students.

Perhaps the most surprising finding in PISA 2006 was that students who took Junior Certificate science at Ordinary level did not do any better on the PISA science test than students who had not studied science. This is not because Ordinary level science students are generally academically weaker – both sets of students are reasonably similar on overall academic performance. However, males who do not take science seem to be a significantly weaker group than their female counterparts. Whatever the explanation, the skills and knowledge students acquire in Ordinary level science seem to have little effect on how they perform on the PISA science assessment.

High-performing students

Only 9% of Irish students attain the top proficiency levels of 5 or 6, compared to 21% in Finland and 18% in New Zealand. This indicates that there is considerable room for improvement amongst higher-achieving students. One obvious suggestion that arises from PISA is that Irish students would benefit from more "science time" outside the classroom. Irish students rarely read science articles or magazines, visit science-related websites, or engage with science outside a classroom setting. They were also slightly below average on the scale measuring *enjoyment of science*.

Teachers are limited in how much they can teach in the time allocated to science lessons. However, student engagement in science activities outside the classroom is not time-constrained. Encouraging student engagement in science for enjoyment may give a necessary "stretch" to some of the higher-achieving students. It may improve performance on PISA scientific literacy, and indeed the Junior Certificate examination. It may also create more positive attitudes towards science.

Weaker students

Using the OECD interpretation of "baseline" scientific literacy (proficiency level 2 or above), almost 16% of Irish students will not have sufficient scientific literacy to engage with science or technology in real-life situations and in future education. Since PISA science requires a certain amount of language skills and the ability to apply science in real-life settings, it may be that the unfamiliar contexts (and sometimes unfamiliar language) used in PISA made it difficult for many Ordinary level students to apply what they learned in class. Nonetheless, it is worrying that roughly one-third of students who studied Junior Certificate science at Ordinary level fail to demonstrate even baseline scientific literacy.

There may be a tendency for weaker students to reduce the curriculum to the minimum, and to focus on the basic facts, without context. However, doing so means that such students may not understand the meaning or the relevance of what they are being taught. We suggest that where possible, teachers make greater use of real-life settings and language to explain scientific concepts to students.

Attitudes to and engagement with science

Amongst OECD countries, Irish students recorded the highest mean score on *awareness of environmental issues*. They also reported a positive general attitude to science, and average levels of interest. However, their interest levels in chemistry and physics were below average, something previously noted by the Task Force on the Physical Sciences (2002). In particular, the Task Force concluded that females' experiences of Junior Certificate science were likely to discourage them from taking chemistry and physics for Leaving Certificate, a view supported by the evidence from PISA.

The revised Junior Certificate science syllabus (introduced subsequent to the Task Force report) might be expected to improve interest in chemistry and physics. However, our data show that students taking the rJCSS are no more interested in physics and chemistry than are students taking the older syllabus. Further, the Chief Examiner's report on the 2006 science examination indicated that students did best on the biology section of the Ordinary and Higher level papers, followed by the physics section, with performance on chemistry lagging well behind (State

Examinations Commission, 2006). Although clearly not the only factor involved, lower levels of student interest may account for some of the poorer performance reported for physics and chemistry. Another factor may be that science at Junior Certificate is not always taught by subject specialists. As the Task Force on the Physical Sciences noted, most science teachers (particularly in all-girls schools) have a background in the biological, not the physical sciences.

We suggest that major efforts need to be made to make physics and chemistry more interesting and appealing to students. Such efforts should not be restricted to teachers alone. The extent to which teachers can stimulate interest in the classroom is somewhat constrained by external factors, such as the quality of textbooks and the types of Coursework investigations which must be completed. Further, an increase in the proportion of science teachers whose speciality is physics or chemistry may be helpful in stimulating greater student interest (through their more in-depth knowledge of the subject areas and wider availability of physics and chemistry as Leaving Certificate subjects).

As noted, Irish students had very low levels of engagement in science-related activities outside the classroom (e.g., watching TV programmes about science or accessing a science website). While science lessons will no doubt remain the main source of science education for students, accessing good quality scientific information in non-school settings can only benefit students' scientific education. Creative methods will be required to increase student engagement with science, including the incorporation of science websites and other media into student assignments.

Gender differences

Overall science scores for Irish males and females were identical, but there were notable gender differences on aspects of their performance. Broadly speaking, females in Ireland are good at understanding the nature of science and understanding scientific enquiry and explanations, while males seem to be better at understanding scientific facts and topics, particularly in relation to *knowledge of physical systems*.

Irish females exhibited a notable weakness (relative to Irish males) on their *knowledge of physical systems*. This is roughly similar to topics covered in physics and chemistry, and suggests two areas on which teachers of females need to focus. As noted earlier, this may be related to the relative dearth of physics and chemistry teachers in all-girls schools. Irish males were not below the corresponding OECD average on any element of scientific literacy, although their lowest score was for *using scientific evidence*.

There were also notable gender differences in perceptions of science among Irish students. Females were more likely to see the long-term value of studying science (career prospects) while males were more likely to engage in science-related activities and to have confidence in their scientific skills. Females also expressed much lower levels of interest than males in topics related to physics. From a teacher's perspective, this might mean a greater focus on emphasizing the broad career value of science for males and on encouraging females to increase their engagement with science outside the classroom. Targeting females' relative lack of interest in physics may also help improve their poor performance on *knowledge of physical systems*.

Of course, the gender differences reported are averages, and there is considerable variation among males and females on both aptitudes and attitudes. We are not suggesting that teachers adopt a heavily gendered approach to teaching. However, information about student strengths and weaknesses is always useful when targeting teaching to student needs.

Policies for improving scientific literacy

One of the recommendations of the Task Force on the Physical Sciences was to make science compulsory at Junior Certificate level. However, non-science students did as well on the PISA science test as students who had studied Junior Certificate science at Ordinary level. This suggests that, for example, increasing the cohort taking Ordinary level science may not automatically improve "national" scientific literacy, at least as measured by PISA. A more appropriate strategy might be to increase the number of students who take science because they *want to*, while also ensuring that all students can select physics and chemistry as Leaving Certificate subjects. Further, there is a need to improve the scientific literacy of students who take science at Ordinary level. Since studying Junior Certificate science at Ordinary level does not seem to provide any significant advantage on the PISA science assessment, an examination of what it *does* provide might be appropriate.

Many of the schools involved in PISA had a number of strategies to promote science uptake and to stimulate interest in the subject. While all such strategies are welcome, some are more effective than others. Schools where students were involved in science competitions (such as the BT Young Scientist competition) tended to have above average scores on PISA science, even after controlling for other variables. Transition Year would also seem to provide an ideal opportunity to give students the chance to engage with real-life, PISA-style science.

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Explanation of technical terms used

Correlation: A correlation is a measure of the relationship between two variables, and can range from –1.00 to +1.00. A negative correlation (e.g., –.4) means that as one variable increases, the other decreases; a positive correlation (e.g., .4) means that both either increase or decrease together. The closer a value is to ±1, the stronger the relationship. A strong correlation does not necessarily mean that one variable "causes" the other.

Domain: The three areas, or subjects, PISA assesses are called domains. In 2006, the focus was on science (the major domain). This means that a larger number of test items were used to assess science than reading and mathematics combined (the minor domains in 2006).

Proficiency Level: As well as scores, we can describe performance on PISA scales and subscales using proficiency levels. These describe the skills that students falling within certain score ranges can demonstrate. There are six proficiency levels, with Level 6 representing the highest (i.e., the most complex scientific skills) and Level 1 the lowest. There is also a 'Below Level 1' category for students who did not demonstrate the competencies required for the simplest PISA science tasks. Level 2 is defined as the baseline proficiency level – the level at which students begin to demonstrate the science competencies that will enable them to participate effectively and productively in life situations related to science and technology and in future education. Each student is assigned to the highest level at which he or she would be expected to answer correctly the majority of assessment questions.

Rotated Booklet Design: PISA used a rotated booklet design, meaning that each student was randomly assigned one of 13 test booklets. Each booklet contained four half-hour "blocks" of items, and no two booklets contained all the same blocks. The position of the blocks was rotated in different booklets. By linking items that are common across booklets, equivalent achievement scores are assigned to each student regardless of the particular booklet attempted. A rotated design is used to obtain broad coverage of the assessment domains (it would not be reasonable to give every student the total number of PISA assessment items).

Significant difference: A significant difference between groups is one that a statistical test has established as unlikely to be due to chance. As well as whether a difference is significant or not, the reader should pay attention to the size of the difference.

Standard Deviation: The standard deviation is a measure of how widely spread the values are in a set of data. For example, if student scores are bunched around the mean, the standard deviation is small; if many students' scores are far from the mean, it is large. In a "normal" distribution of scores, 68% of students have an achievement score that is within one standard deviation of the mean (± 1 sd), and 95% of the population have a score that is within two standard deviations of the mean (± 2 sd).

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