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Her Majesty's Inspectorate for Education and Training in Wales

Science in key stages 2 and 3

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Contents Page

Introduction

This report has been produced in response to a request for advice from the Welsh Government in the Minister's annual remit letter to Estyn for 2012-2013. It has a context in the Welsh Government's vision for scientific research, science teaching and the commercialisation of research set out in the Welsh Government document 'Science for Wales – A strategic agenda for science and innovation in Wales'.[1]

This report also provides evidence for the Welsh Government in relation to a recommendation from the Enterprise and Learning Committee's report on science, technology, engineering and mathematics[2]: **'We recommend that the Welsh Assembly Government should carry out a study of why science in primary schools may be experiencing a decline and should explore with Estyn how best to assess science performance in the future.'**

The intended audience for this report is the Welsh Government, headteachers and practitioners in schools, and officers and advisers in local authorities and regional consortia.

Background

Since the publication of the first National Curriculum orders for science in 1988, several reviews have reduced the number of attainment targets over time from four (broadly corresponding to biology, chemistry, physics and scientific investigation) to one on scientific enquiry. The two aspects of the current scientific enquiry attainment target emphasise the development of skills, but do not define a body of knowledge that pupils should learn: 'Skills' explain how the skills of thinking, communication, information and communication technology, and number can be developed within science; and 'Range' outlines the opportunities and contexts in which those skills can be developed through different kinds of investigation.

Until 2003, standardised assessment tests, as well as teacher assessment, measured pupils' attainment in science at the end of key stages 1, 2 and 3. Key stage 1 tests ended in 2000 and key stages 2 and 3 tests ended in 2004. The tests were superseded by end-of-key-stage teacher assessment up to key stage 3. In 2010, Estyn reported concerns about the reliability of teacher assessment in the core subjects in key stages 2 and 3.

[1] This document was published by the Welsh Government in March 2012 and sets out a vision for science along with key initiatives to be launched and indicators for measuring progress

[2] The National Assembly for Wales Enterprise and Learning Committee; the science, technology, engineering and mathematics (STEM) agenda – published January 2011

Main findings

1 In the majority of lessons observed as part of this survey, standards in science were good or better in key stages 2 and 3. Pupils achieved excellent standards in only a few lessons. In a minority of lessons, pupils are making too little progress in their knowledge and understanding of science or in their writing and numeracy skills.

2 Teaching is good or better in the majority of lessons in key stages 2 and 3. In the few excellent lessons, teachers have high expectations of their pupils including the more able. These teachers plan a wide range of stimulating activities that capture pupils' imagination and promote a sense of excitement about learning science. In a minority of lessons, over-direction by the teacher limits opportunities for pupils to explore their own ideas and pupils are given tasks that are too easy, such copying information from websites, which limit the development of their scientific understanding. In the majority of lessons, more able pupils are not stretched enough. Only in a very few cases do pupils get the opportunity to pursue their own scientific interests. In a few lessons in key stage 2, teachers do not have a secure understanding of science and pass on their misunderstandings to pupils.

3 There are shortcomings in the assessment of science in nearly all the primary schools and in half of the secondary schools visited. In most of the schools, teachers set pupils tasks in science to provide evidence for teacher assessment at the end of key stages 2 and 3. Teachers undertake moderation procedures, including working across primary and secondary schools. Even so, the reliability and validity of teacher assessment in science are doubtful because of the lack of external verification and of clear assessment criteria.

4 Since 2005, the proportion of key stage 2 pupils attaining the expected level (level 4) or above in teacher assessments has been higher in science than in the other core subjects, but there has been a decline in the proportion of pupils achieving the higher levels (level 5 or above). Since 2005, the proportion of key stage 3 pupils attaining the expected level (level 5) or above has improved. Since 2007, science has performed above English and mathematics, but below Welsh first language. The performance of boys is below that of girls at both key stages.

5 Curriculum planning in science lacks challenge and structure in a minority of primary and secondary schools. The emphasis on investigative skills in the current science National Curriculum orders introduced in 2008 does not help schools to plan progression in scientific knowledge and understanding. Most schools have not developed new schemes of work in line with the changes made to the National Curriculum in 2008. The few secondary schools that have developed such schemes of work do not prepare pupils well enough for GCSE science syllabuses. Many schools have retained a focus on content in the curriculum that is helpful in providing progression in understanding even though the content is not specified in the current National Curriculum subject orders for science.

6 In key stage 2, the time devoted to teaching science varies between one and three hours a week. In primary schools that only provide an hour of science a week, there is not enough time to cover all aspects of the science National Curriculum effectively. The time allocated to science at key stage 3 is sufficient in all schools.

7 A majority of primary and secondary schools have suitable plans to develop pupils' science investigation skills within interesting contexts. However, a minority of schools do not plan or provide opportunities for pupils to apply their scientific knowledge or understanding well enough.

8 In key stage 3, the range of numeracy techniques developed through science investigations is too narrow and many departments limit the development of pupils' understanding of mathematical techniques by offering shortcuts to solving problems. Only a few schools provide suitable opportunities for pupils to answer PISA-type questions that develop pupils' thinking skills and ability to apply subject knowledge.

9 The majority of secondary science departments visited are led effectively by teachers who are enthusiastic about science. However, only about half the primary leaders have a clear vision for developing science in their schools. Only a minority of secondary schools support their partner primary schools to develop science.

10 A majority of schools have suitable arrangements for gathering first-hand evidence for the self-evaluation of science and produce suitably self-critical reviews of performance. A minority of schools do not assess the impact of teaching on standards in science thoroughly enough.

11 Most schools have suitable opportunities to share good science teaching and learning within the school. In a few schools, teachers observe other teachers and science department meetings focus on the impact of teaching methods on standards. However, very few secondary schools and no primary schools in this survey have made links with other schools to share ideas for teaching science. Only a very few teachers attend courses to widen or develop their understanding of how to teach science. There is too little support for science teaching from local authorities or regional consortia.

Recommendations

Primary and secondary schools should:

R1 provide challenging science opportunities to stretch all pupils, particularly the more able, and eliminate tasks that are too easy;

R2 provide more opportunities for pupils to pursue their own scientific interests;

R3 ensure that assessment and marking practices provide pupils with meaningful advice on how to improve their scientific understanding and skills; and

R4 work with other schools to share effective approaches to teaching and assessing science.

In addition, primary schools should:

R5 make sure that pupils are taught science for at least two hours a week; and

R6 provide training for teachers with weak science subject knowledge.

In addition, secondary schools should:

R7 plan to use a wider range of numeracy skills in science lessons.

Local authorities should:

R8 provide more professional development, support and advice to schools on science teaching and learning; and

R9 support schools to share best practice in science education.

The Welsh Government should:

R10 improve the reliability and validity of teacher assessment by reviewing assessment criteria and introducing an element of external moderation; and

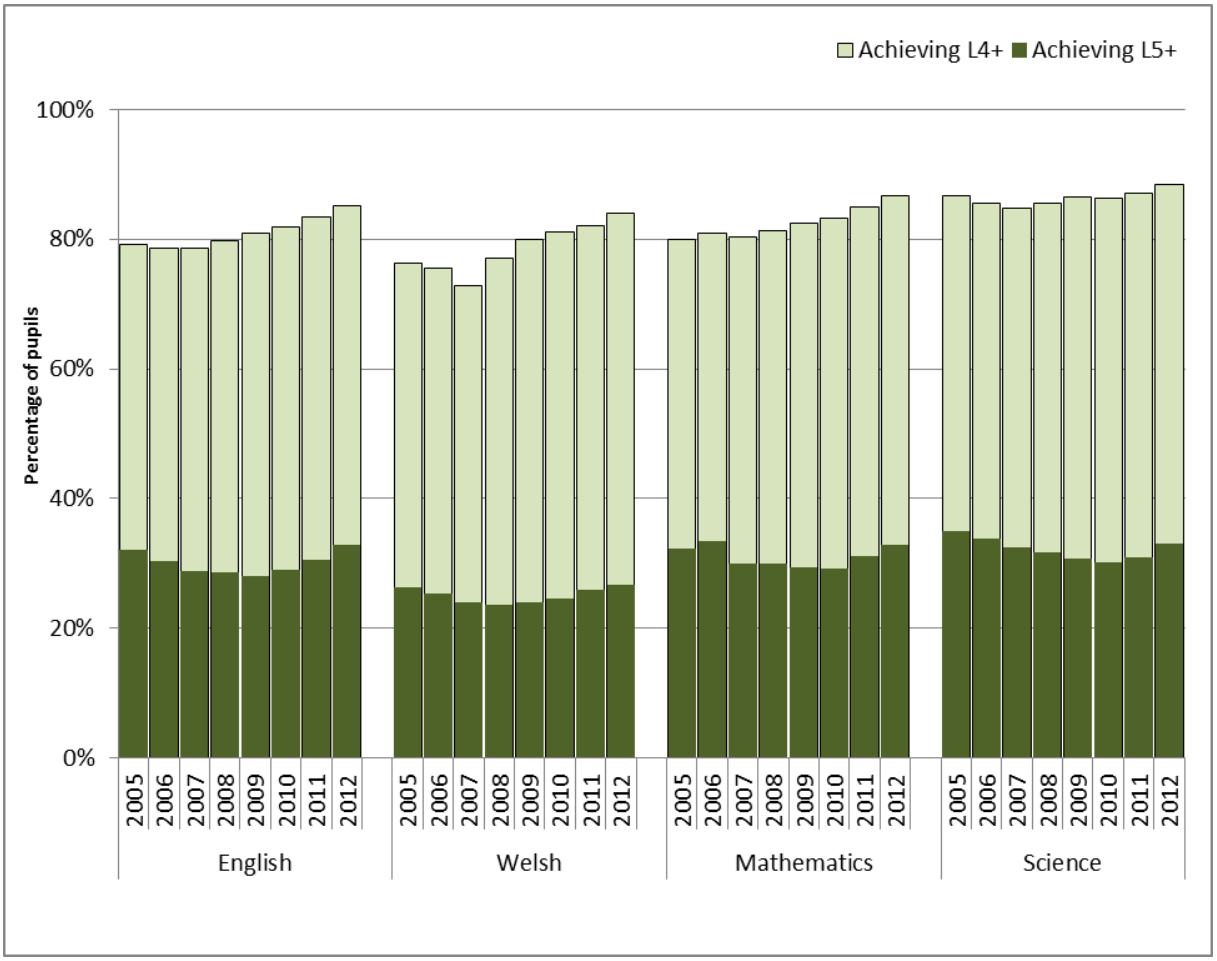
R11 review the National Curriculum subject orders for science to include essential content.

Standards

Teacher assessment at key stages 2 and 3

12 Since 2005, the proportion of pupils gaining the expected level (level 4) or above in science has been consistently higher than in the other core subjects. This proportion declined in 2006 and 2007, but from 2008 to 2012 performance has shown improvement. Due to steady improvements in the other core subjects, the gap in performance between science and the other core subjects was smaller in 2012 than in preceding years.

Percentages of pupils achieving the expected level (level 4) and above in teacher assessment at the end of key stage 2 (2005-2012)

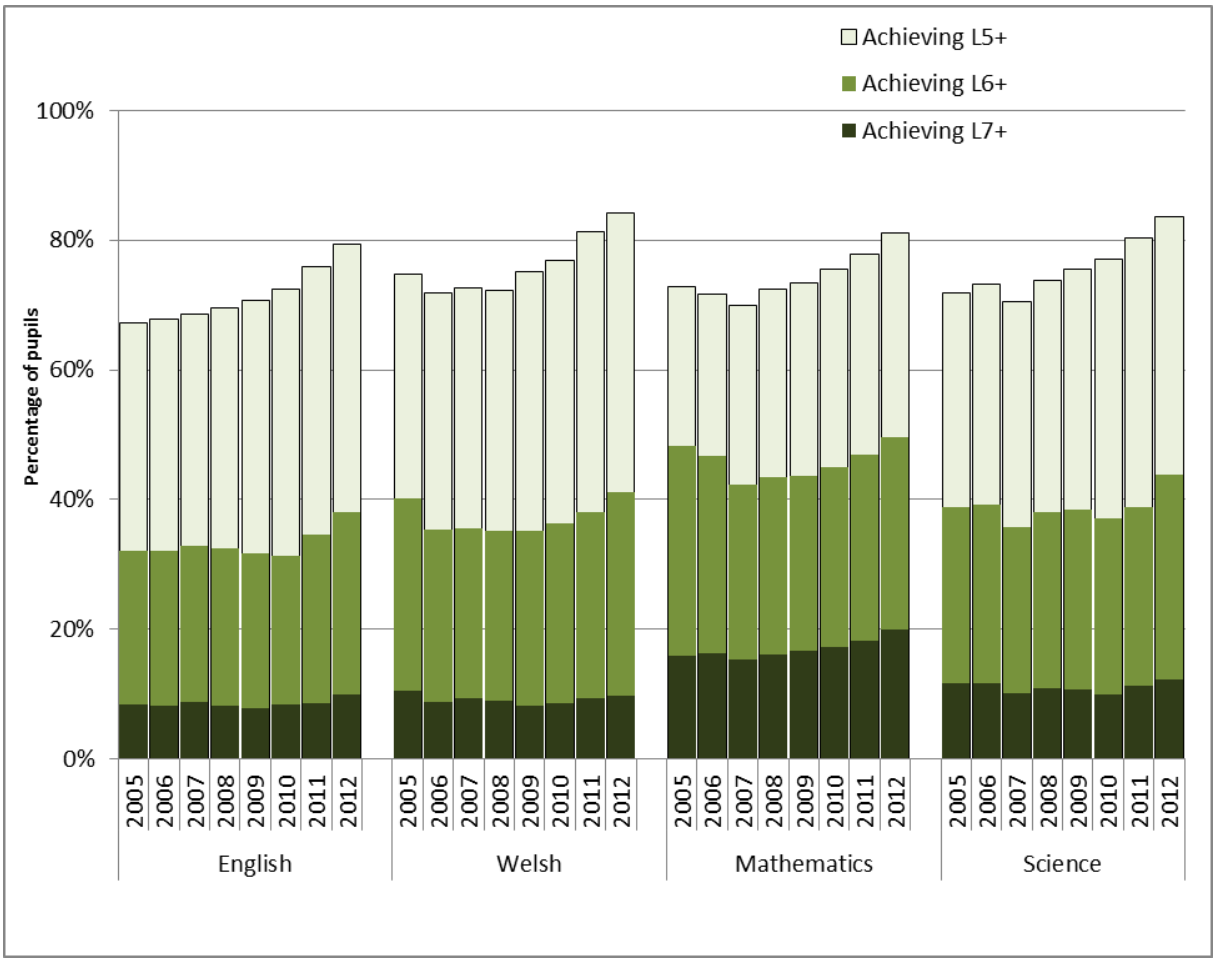


13 Until 2010, the proportion of pupils achieving level 5 and above in science was higher than in other core subjects. In 2011, mathematics overtook science as the highest performing subject and the gap in performance between science and English reduced. In 2012, there were no differences in performance in science, English and mathematics. Performance in science at level 5 and above declined steadily between 2005 and 2010. There were improvements in 2011 and 2012, but performance was below that of 2005.

14 In each year since 2005, at key stage 3 girls have performed consistently better than boys in science at level 4 and above and at level 5 and above.

15 Following a dip in 2007, there has been a year-on-year increase in the proportion of pupils attaining the expected level (level 5 and above) in science at key stage 3. During the last two years, science has performed below Welsh first language, but has been above English and mathematics since 2006.

Percentages of pupils achieving the expected level (level 5) and above in teacher assessment at the end of key stage 3 (2005-2012)



16 The proportion of pupils gaining level 6 and above in science has fluctuated over the last seven years. Although performance in science at level 5 and above is consistently better than that in mathematics, the proportion of pupils attaining level 6 and above in science is consistently lower than that in mathematics.

17 Performance in science at level 7 and above has fluctuated since 2005. It declined in 2010, but there were improvements in 2011 and 2012. This trend contrasts with that in mathematics, where there has been a consistent improvement over the past six years. Science performs worse than mathematics at level 7 or above, but better than English and Welsh first language.

18 The performance of boys has been lower than that of girls at level 5, level 6 and level 7 in each year since 2005. The pattern in key stage 3 is similar to that in key stage 2.

Performance in international surveys

19 Wales took part in the Programme for International Student Assessment (PISA) in 2006 and 2009. The questions in science are designed to assess pupils' ability in three broad aspects:

- 'explaining phenomena scientifically', which tests pupils' ability to apply scientific knowledge, describe or interpret phenomena scientifically and predict changes;
- 'identifying scientific issues', which tests pupils' skills in recognising matters that can be investigated scientifically, and in their understanding of key features of a scientific investigation; and
- 'using scientific evidence', which assesses skills such as interpreting scientific evidence, making and communicating conclusions, identifying assumptions, evidence and reasoning behind conclusions, and reflecting on the societal implications of science and technological developments.

20 In 2006, Wales performed around the average for the Organisation for Economic Co-operation and Development (OECD) countries. The proportion of pupils attaining different levels of performance was also similar to the OECD average. However, performance in science was lower in Wales than in England, Northern Ireland or Scotland, particularly at the higher levels of achievement. There were no significant differences between Wales, England, Northern Ireland or Scotland in the 'explaining phenomena scientifically' aspect. However, both England and Scotland scored significantly higher than Wales on the 'identifying scientific issues' aspect and Scotland also scored significantly higher than Wales on the 'using scientific evidence' scale. In Wales, boys performed significantly better than girls, mainly as a result of their better performance in the 'explaining phenomena scientifically' aspect. This performance contrasts with performance in GCSE science, where girls perform slightly better overall than boys.

21 As reading was the main focus in 2009, the same level of analysis of pupil performance in science is not available. However, as in 2006, the performance of pupils in science in Wales was not significantly different from the OECD average, placing Wales in the middle ranks of achievement. Again in 2009, overall performance was significantly lower than in England, Northern Ireland or Scotland, especially at the higher levels. In 2006 and 2009, performance in science in Wales, was relatively better than that in reading or mathematics. The overall performance of boys, as in 2006, was significantly higher than that of girls.

Standards in lessons

22 In the survey, standards are good in a majority of lessons at key stages 2 and 3. Standards are excellent in only a few lessons. Standards have important shortcomings in a minority of lessons.

Common strengths

23 In both key stages 2 and 3 in the schools visited, nearly all pupils enjoy science. There is no obvious difference between boys or girls in terms of motivation or achievement during lessons, but boys generally do not produce as much high-quality written work as girls.

24 In the few lessons at both key stages 2 and 3 where there is outstanding work, pupils are motivated and maintain a high level of concentration. They demonstrate a high degree of independence and enjoy the challenge of testing and evaluating their own predictions and ideas. As a result of these activities, pupils make very good progress in their understanding of the scientific method. In these lessons, pupils develop their thinking skills very well through explaining results that do not fit their expectations. They also make good progress in their ability to communicate sophisticated ideas orally and through extended writing.

25 In the few cases where there is outstanding progress at key stage 3, pupils of all abilities have excellent recall and understanding of the scientific principles that they have studied. They are able to search for information skilfully from text books or the internet and build on their learning effectively. More able pupils develop their ability to recognise bias in such sources and identify information that is not fully supported by evidence. During these lessons, pupils refine their understanding of science through purposeful and challenging discussions. In addition to the development of their scientific understanding, pupils in these lessons make very good progress in their reading, writing and numeracy.

Cefn Saeson Comprehensive School

Year 7 – Reproduction and gestation

In a Year 7 science lesson, pupils discussed in small groups, how to present data about gestation periods in different animals. All pupils responded very positively to an interesting and relevant video presentation about different animals' reproductive cycles. They showed a great deal of interest in the topic on an emotional and intellectual level. All pupils worked well with each other with more able pupils providing effective support to others in the group. As a result, nearly all pupils made very good progress in their ability to:

- select the most appropriate method of presenting data;
- produce graphs with sensible scales; and
- plot lines of best fit, taking into account points that did not fit the expected pattern.

Pupils drew on their prior knowledge effectively to provide explanations for any unusual results. They also developed their ability to interpret data, link variables and write clear explanations using scientific language and conventions.

26 In key stages 2 and 3, pupils carry out purposeful experimental work in a majority of lessons. Nearly all pupils enjoy the practical aspect of science lessons. In these lessons, they develop their ability to manipulate scientific equipment, make accurate measurements and record data methodically. They often write at length using a wide range of scientific vocabulary and make effective use of their numeracy skills, for example to calculate averages or plot bar charts. In key stage 2, more able pupils plot scatter graphs and calculate percentages. Towards the end of key stage 3, about half of pupils across the ability range make appropriate scales, plot scatter graphs and calculate percentages accurately. A few more able pupils select and apply the most suitable lines of best fit to scatter graphs.

27 In many lessons in key stages 2 and 3, pupils are involved in investigative work to explore scientific phenomena and solve problems. In key stage 2, many pupils in these lessons make satisfactory progress in their understanding of how to control different variables to carry out a fair test. Towards the end of key stage 2, a few more able pupils are beginning to develop their ability to describe relationships between variables using appropriate scientific vocabulary.

28 In key stage 3, a majority of pupils design their own investigations based on contexts set by the teacher. Pupils make the greatest progress when they have a firm understanding of the scientific principles underlying the topic they are investigating. A majority of pupils in these lessons make suitable predictions, drawing effectively on prior learning and make good progress in their ability to:

- plan and organise their own work;
- record, analyse and interpret data;
- make connections between different areas of learning;
- manipulate scientific equipment;
- evaluate how well the evidence gathered supports scientific theory; and
- produce coherent and clear extended writing, often for a wide range of different audiences and purposes.

29 Towards the end of key stage 3, a majority of pupils can identify different types of variable and describe relationships between them. During investigations, many pupils make appropriate use of their numeracy skills in activities such as calculating percentages and averages, or plotting graphs.

30 During key stage 2, a majority of pupils learn about insulation, separation and food chains. During key stage 3, a majority of pupils make good progress in their knowledge and understanding of a wide range of concepts, such as the pH, forces, cells, electrical current and energy.

31 In a few lessons in key stages 2 and 3, pupils make suitable use of ICT to word process, produce slide presentations, log data from experiments and construct graphs using spread sheets. In a minority of investigations, pupils search the internet for relevant scientific knowledge. Where this work is well structured, pupils gain useful information. In Welsh-medium or bilingual schools, the lack of websites in Welsh reduces pupils' opportunities to read about science in Welsh. However, in these schools, many pupils use opportunities to search the internet well to improve their English vocabulary and extend their Welsh vocabulary through translating information into Welsh.

32 Only in a very few cases in key stage 2 or key stage 3 do pupils pursue their own scientific interests. When given these opportunities, pupils are highly motivated and plan experimental work creatively. Where they are closely supported and guided by their teachers, pupils involved in this kind of work make good progress in their understanding of the scientific method.

33 In key stages 2 and 3, most pupils take part in activities outside the classroom that complement the work carried out in lessons. These include:

- field trips to local habitats, such as beaches or woodland areas and industry;
- visits from theatre companies dramatising science;
- science shows;
- visits to Techniquest in Cardiff or Wrexham; and
- in a very few schools, a science club.

34 Pupils enjoy all of these activities and are motivated by them. In general, pupils learn the most from field trips and science clubs. Specifically, pupils learn most about the Welsh dimension from field trips or visits to local industry. Where pupils receive many of these opportunities, a high proportion of pupils show an interest in pursuing a career in science.

Pontarddulais Primary School

Science club

The science club runs for a series of six-week blocks that ensure that all pupils have the opportunity to take part. Pupils are involved in exciting activities that allow them to explore aspects of science such as changing states of matter, heat transfer, the properties of light and sound, and rocket science.

The science club gives pupils valuable opportunities to make comparisons, take measurements, control variables and draw conclusions. The children plan experiments and develop a good understanding of scientific principles.

Pupils do not formally record or write up their experiments; instead the focus is on pupils learning through having fun.

Pupils really enjoy the activities, and gain motivation and enthusiasm for exploration in science.

Common shortcomings

35 Boys often produced written work of a lower standard than that of girls. The other important shortcomings in a minority of lessons in both key stages 2 and 3 have the effect that pupils:

- develop misconceptions during a lesson;
- do not gain an understanding of important scientific principles or concepts;
- do not use subject-specific vocabulary to express scientific ideas effectively;
- do not apply their scientific knowledge to making predictions, particularly when this knowledge is gained from internet searches;

- do not understand the difference between controlling variables in a fair test and improving reliability;
- cannot not describe or explain the relationships between variables; and
- use practical activities as opportunities to disrupt learning.

36 In addition at key stage 3, the shortcomings in a minority of lessons mean that pupils:

- cannot recognise bias or identify errors in information drawn from internet searches; and
- use too narrow a range of numeracy skills, usually only calculating averages or plotting graphs.

37 These shortcomings were commonly seen in lessons where standards were judged adequate, but they were also seen to a lesser degree in a majority of lessons where standards were good overall.

Teaching and assessment

Teaching

38 Teaching was good or better in the majority of lessons observed during this survey. There were only a few lessons where teaching was excellent. The teaching in about a half the lessons was good and in a minority adequate. In a very few lessons teaching was unsatisfactory.

39 In most lessons in key stage 2 and all lessons in key stage 3, teachers have a secure subject knowledge. In a few lessons in key stage 2, teachers do not have a secure enough grasp of important scientific principles and concepts. In these lessons, teachers pass on misunderstandings to their pupils and do not spot or correct pupils' misunderstandings.

40 In the few lessons in key stages 2 and 3 where there is excellent teaching, teachers devote considerable thought and creativity to planning. Teachers in these lessons possess very good subject knowledge and have a thorough understanding of how to capture and sustain pupils' interest. Teaching in these lessons is characterised by:

- very high expectations of what pupils can achieve;
- skilful use of questioning to develop pupils' understanding of scientific enquiry;
- sensitive correction of misconceptions;
- carefully structured opportunities to develop scientific understanding alongside the development of literacy or numeracy;
- a wide range of stimulating activities that maintain pupils' interests and keep the pace of the lesson high;
- the provision of work that is carefully adapted to support pupils of different abilities, including work to challenge and interest the more able;
- valuable exploration of results that do not fit the expected pattern; and
- skilful use of demonstrations, computer simulations or video clips.

Ysgol Gynradd Gymraeg Garth Olwg

Year 3 – Solving a crime

Pupils entered the class, accompanied by music, which helped to set a calm learning environment. The teacher captured pupils' interest effectively through announcing that there had been a theft. The teacher had used a digital camera to provide simulated security camera footage of a theft from the classroom. Pupils were given the exciting challenge of solving the crime. First of all, they collected each other's fingerprints and categorised them according to shape. The teacher then asked the pupils to plan how to use their knowledge of fingerprints to catch the thief. As a result, pupils engaged in animated discussions and developed their skills of planning, data collection and classifying. Because of the teacher's careful planning, all pupils remained focused on their work throughout the lesson and developed valuable scientific skills.

41 In key stage 3, outstanding teaching is further characterised by:

- the high levels of responsibility given to pupils to plan and carry out their work;
- stimulating whole-class and group discussions; and
- careful planning to extend pupils' mathematical skills, for example in re-arranging formulae, using statistical techniques or selecting different lines of best fit for graphs.

Cefn Saeson Comprehensive School

Year 9 – Ethics of cloning

The teacher began the lesson by questioning pupils extensively about previous work on cloning organisms. She made very effective use of interactive software to explain and reinforce pupils' understanding of the principles of cloning.

She then set pupils the following question: "If you could clone yourself, what would you do with the clone?" All pupils engaged enthusiastically with the task, developing ideas that ranged from using the clone to do household chores to using its organs as 'spare parts'. Following this discussion, the teacher asked the pupils to consider the ethics of the plans for their clones. In the debate that followed, pupils came to the conclusion that they had misconceptions about cloning and had considered clones to be less than human.

During the lesson, all pupils made very good progress in their understanding of scientific principles and ethics, and in their ability to argue from a basis of scientific understanding.

42 The majority of investigations set by teachers require pupils to develop their understanding of how to carry out a fair test. The contexts to be investigated were set by the teacher in all the lessons and work scrutinised for this survey in key stage 2 and most of the lessons and work in key stage 3. In a majority of lessons, in key

stages 2 and 3, teachers give pupils the freedom to choose how they wish to use science equipment. However, in a minority of lessons, over-direction by the teacher restricts pupils' independence and the development of their ability to plan creatively.

43 In key stage 3, many teachers give pupils significant freedom to explore open-ended questions such as "What types of sunglasses are most effective? " or "Are expensive heartburn tablets better than cheaper versions? " These kinds of questions provide pupils with rich investigative opportunities to develop their scientific knowledge, understanding and skills as well as their skills in writing, numeracy and thinking. Pupils make the greatest progress in their subject knowledge when investigations build systematically on work previously studied.

44 In a few lessons, teachers encourage pupils to search the internet for relevant information to use in their investigations. In most of the investigations that follow, pupils do not apply the scientific knowledge they gathered successfully. This is because:

- sifting through the vast number of results is difficult to synthesise;
- the language on scientific websites is often inaccessible to pupils at key stage 3; and
- some websites contain misleading, clumsily expressed or incorrect information.

45 Where teachers use internet searches to good effect, they provide pupils with carefully-selected website addresses relevant to the task that are written in accessible language such as the National Grid for Learning website, which contains scientific news articles written specifically for pupils of this age. These teachers also ensure that pupils have a sound understanding of the underlying scientific principles before they embark on planning their investigations.

46 In key stages 2 and 3, a majority of schools set an appropriate range of homework to build on pupils' subject knowledge and skills. In most of these schools, teachers set useful tasks such as:

- plotting graphs from data gathered in lessons;
- using scientific knowledge to produce creative writing;
- searching for scientific information from the internet; and
- building models or mock-ups to re-emphasise the principles encountered in lessons or as preparatory work for fair-testing investigations.

Ysgol Gynradd Gymraeg Gartholwg

Year 5 and Year 6 – Making a tea cosy

Following a series of lessons on insulation, a class of Year 5 and Year 6 pupils were set homework to design the most effective tea cosy. Pupils sought additional information about this topic on the internet and made their own tea cosies at home. Pupils brought these into school and had to explain to their peers in small groups why they had chosen their materials for their design. During well-organised group discussions, the pupils made predictions about which models would be the most and least effective, using success criteria based on their scientific knowledge.

The teachers, working as a pair, effectively circulated around these groups, challenging the groups' ideas and carefully supporting their scientific thinking. During this lesson, nearly all pupils made very good progress in their knowledge of the process of heat transfer and in their ability to make predictions using scientific knowledge.

47 In the majority of lessons at both key stages, pupils of all abilities are given the same work. In a minority of lessons, teachers adapt work so that pupils of all abilities make suitable progress. In these lessons, learning support assistants are often involved in planning work to suit individual pupils' needs and teachers give more able pupils appropriate additional work such as using textbooks or searching the internet for extra information. In the few cases, where these pupils make very good progress, teachers customise pupils' work to match their abilities and ensure a high level of challenge. These teachers often give more able pupils greater freedom to adapt their investigation predictions or refine their conclusions in the light of detailed scientific information.

48 A majority of teachers use ICT to enhance lessons and promote better understanding of scientific concepts. Often, teachers make effective use of computer simulations to explain scientific processes. These are at their most effective when pupils interact with the software, adjust variables and observe resulting changes. However, too often teachers do not provide pupils with opportunities to use software in a sophisticated way, for example by giving pupils opportunities to develop and investigate their own scientific models.

49 In the majority of lessons, teachers have clear aims and objectives for developing pupils' skills and scientific understanding. However, a significant amount of time is wasted when teachers require pupils to copy these objectives into their books. When teachers refer briefly to objectives during the lesson, this helps pupils track their own progress. In the majority of lessons, teachers refer helpfully to lesson objectives when summarising main points at the end of a lesson. During these summaries, a minority of teachers focus only on literacy or numeracy at the expense of scientific understanding. As a result, summaries do not always reinforce pupils' knowledge or understanding of specific scientific principles.

50 In a majority of lessons, teachers have suitably high expectations of pupils but, in a minority, pupils are given tasks such as copying, gap filling, or cutting and pasting information from the internet. These activities do little to develop pupils' scientific understanding, or their reading, writing or numeracy skills.

Assessment

51 There are shortcomings in the assessment of work in science in nearly all primary schools and in half of secondary schools.

52 In the majority of lessons, teachers make effective use of questioning to assess informally pupils' understanding and develop their thinking. However, in a minority of lessons, teachers give overly-long explanations and mainly ask closed questions. In addition, these teachers often provide answers to questions themselves and do not

guide pupils' learning through follow-up questions. These shortcomings mean that pupils are too passive and they make little progress in their ability to think independently or in their understanding of science.

53 In nearly all schools visited during this survey, marking is up-to-date. Teachers provide supportive comments such as "very good work" or "well done! " In key stage 2, many teachers focus appropriately on aspects of pupils' spelling, punctuation and grammar, and the quality of pupils' presentation. In key stage 3, useful advice to pupils on how to improve aspects of their writing is found only in about half of pupils' books. In a few instances, at both key stages, marking is superficial and does not identify errors in pupils' literacy skills or understanding of science.

54 In a majority of pupils' books in key stage 3, teachers' marking focuses suitably on pupils' understanding of the scientific method. Where this is done most effectively, teachers comment on how aspects of pupils' scientific skills can be improved and give pupils an opportunity to respond. For example:

- "To ensure that your test is fair, you need to keep certain variables the same. Which do you think you should keep the same?";
- "In your next investigation, make sure you get reliable results through repeating your measurements. Why do you think this helps?";and
- "Please re-draw this graph, making sure that your scale is sensibly set out on both axes. What scales will you use?"

55 Only a very few teachers in key stage 2 provide pupils with such guidance on how to make progress in their understanding of scientific method.

56 At both key stages, only a few teachers give pupils useful advice on how to apply scientific knowledge in investigations. Most teachers write comments such as "use more scientific knowledge next time" or "use more detailed scientific knowledge". Because of the vagueness of these comments, pupils do not find them easy to act on, and as a result a minority do not make suitable improvements.

57 A few schools plan their curriculum carefully so that they systematically re-visit specific aspects of scientific knowledge and understanding. In these schools, teachers keep notes of pupils' progress in understanding scientific concepts and principles. These teachers then use these notes to give pupils general and specific targets before beginning their investigations. Examples of these include:

- general targets such as "make sure you describe which variable is independent (the one you decide to change) and which is dependent (the one that changes as a result)"; and
- more specific targets such as "in your planning, try to use your knowledge about plants and light to predict how different colours of light will affect the rate of photosynthesis".

58 As a result, pupils make consistent progress in their ability to apply general scientific principles and specific aspects of scientific knowledge.

59 In a majority of secondary schools and a few primary schools, teachers give pupils appropriate assessment grids, adapted from the National Curriculum progression framework. These include descriptions of progress and are intended to be used by pupils to assess their own and each other's work. In many schools, teachers adapt assessment criteria to use language that pupils can understand.

60 However, the majority of targets that pupils develop from using assessment grids in self-assessment or peer-assessment activities are too general to promote any improvement. Most pupils do not to refer to these targets when planning their own work and a majority of teachers do not encourage them to do this. In the few effective examples, teachers adapt criteria from the National Curriculum progression framework to suit individual tasks. This good practice helps pupils to apply specific aspects of scientific knowledge in their predictions and conclusions.

61 In a few lessons, teachers give pupils the opportunity to assess each other's work. In most of these activities, pupils carry out useful evaluations of other pupils' progress in aspects of literacy. Only in a very few lessons do pupils use their understanding of science to set criteria to judge their own work or that of others. Where teachers skilfully guide and support pupils in making their choice of criteria, most pupils develop their understanding and knowledge of science well.

Teacher assessment at the end of key stages 2 and 3

62 In most schools, teachers set specific tasks to gather evidence for teacher assessment. All schools in the survey carry out suitable internal standardisation exercises for these tasks. Most secondary schools work closely with their partner primary schools to reach agreement in their interpretation of different levels of attainment.

63 The Welsh Government has issued useful guidance to support teachers in assessing pupils' science work. Even so, there are a number of factors that undermine the reliability and validity of teacher assessment. These include the lack of:

- an external verification process to moderate teacher assessment across schools;
- clear guidance about the conditions under which work that is to be assessed should take place; and
- clarity in the level descriptions for science assessment criteria.

64 Anecdotal evidence suggests that, in a very few cases, teachers are unsure whether pupils' work has been produced with help from peers or parents.

65 As a result of the above shortcomings, it is difficult to judge whether the outcomes of teacher assessment represent a true indication of pupil performance in science in key stages 2 and 3.

Curriculum planning

66 Planning for learning experiences in science are good or better in a majority of the primary and secondary schools visited. The revision of the science National Curriculum orders in 2008 and the resulting reduction in science content provided considerable freedom for schools to plan their science curriculum. Guidance provided by the Welsh Government emphasises the importance of investigative work, but provides little guidance on progression in knowledge and understanding. A positive impact of the National Curriculum revision and guidance is that all schools have increased the range and number of investigations that they plan. However, the lack of detail about progression in scientific knowledge and understanding does not help schools to plan progression in scientific knowledge and understanding and has led to a minority of schools to plan work that lacks challenge and structure.

67 Most of the primary schools visited have placed a low priority on science and have planned few new developments in science over the past few years. This has been mainly because of the greater focus on developing pupils' literacy and numeracy skills. In general, primary schools have been slow to develop new schemes of work or practices that align with the 2008 changes to the National Curriculum for science. A minority of the primary schools in the survey are still in the process of producing new schemes of work for science that fully meet the new National Curriculum requirements. These schools have made few changes to the schemes of work that they had already developed for the 2002 version of the National Curriculum for science.

68 Most secondary school science departments have also taken a conservative approach to changing schemes of work in light of the 2008 changes to the National Curriculum orders for science. Their schemes of work continue to cover the same scientific content as they did for the 2002 National Curriculum orders. In general, they have adapted previous schemes of work through expanding the variety and increasing the frequency of investigative work. As a result, many departments' schemes of work contain suitable opportunities for pupils to explore scientific ideas in increasingly demanding contexts. In a majority of these departments, this approach provides pupils with a firm foundation in basic scientific principles, knowledge and skills and provides a suitable basis for GCSE courses. A minority of schemes of work contain too many low-level activities, such as word-searches, gap-filling exercises or practical work that only requires pupils to follow instructions.

69 In key stage 2, the amount of curriculum time devoted to science varies between one and three hours a week. In a few primary schools, the topic-based approach to planning means that there is no set time for science. All the science schemes of work include broadly suitable opportunities to develop pupils' literacy and numeracy skills. A majority of primary schools make suitable use of the whole range of investigation types[3] suggested in Welsh Government guidance to plan for

[3]
- Pattern-seeking;
- Exploring;
- Classifying and identifying;
- Making things (or developing systems);
- Fair testing; and
- Using and applying models.

progression in pupils' understanding of basic scientific concepts and thinking. In a minority of primary schools, teachers plan systematically to revisit specific sections of the assessment grid in increasingly challenging contexts. This provides pupils with effective progression in specific skills. However, in primary schools that only provide one hour of science a week, there is not enough time to carry out these plans effectively.

70 In key stage 3, all the schools surveyed teach science for three hours a week. Many schools teach biology, chemistry and physics as 'integrated science' across key stage 3. In most schools, units of work cover aspects of biology, chemistry or physics separately. In Year 9, a few schools do not teach integrated science. In these schools, biology, chemistry and physics are taught as separate subjects by specialist teachers. In these schools, there is a greater emphasis on developing pupils' numeracy within physics. However, teaching biology, chemistry and physics separately means that pupils receive one lesson a week in these subjects. This presents schools with difficulty in planning continuity, especially where investigations span more than one lesson. Nearly all schools begin to teach GCSE science in Year 9.

71 A majority of primary and secondary schools in the survey have suitable plans to develop pupils' science investigation skills in interesting contexts. These investigations or enquiries are intended to develop pupils' understanding of fair testing, and most are appropriately designed to reinforce and extend pupils' understanding of the science studied in a particular unit. Nearly all science departments in secondary schools plan such investigations once a half-term. In primary schools, most science lessons are planned to develop pupils' investigative skills. A minority of primary and secondary schools do not plan opportunities for pupils to apply scientific knowledge or principles in unfamiliar situations well enough. In addition, only a few schools plan effectively to give pupils opportunities to pursue their own ideas in science.

72 Many enquiry-based activities provide pupils with rich opportunities to develop their writing skills. However, in key stage 3, the range of numeracy techniques developed within science investigations is too narrow, being mainly restricted to measuring, calculating averages and plotting graphs. Opportunities to develop a wider range of numeracy skills are often found in topics related to physics. In key stage 3, many departments limit the development of pupils' understanding of mathematical techniques by offering shortcuts rather than developing the key mathematical principles such as re-arranging formulae.

73 The radical changes made by a few schools in response to the guidance issued with the 2008 National Curriculum orders has resulted in schemes of work that are solely concerned with investigative work. The aim was to develop pupils' skills through planning and carrying out investigations in response to open-ended questions, but this approach has not led to better knowledge or understanding of science and it does not prepare pupils well enough for studying GCSE science at key stage 4. These schools are now re-introducing activities that are designed to develop pupils' scientific knowledge and understanding.

74 Most primary and secondary schools develop pupils' understanding of the Welsh dimension in their planning in science. Where this is done most effectively, teachers

make good use of the natural environment of Wales and local industrial links. Only a few schools pay enough attention to the contribution made by Welsh people to scientific and technological developments.

Transition from key stage 2 to key stage 3

75 A minority of primary and secondary schools plan science activities together. For example, pupils might begin an investigation in primary school (Year 6) and analyse and extend this work when they arrive in secondary school (Year 7). Most schools plan for pupils in Year 6 to experience a secondary science lesson. These activities allow younger pupils to use unfamiliar scientific equipment, such as Bunsen burners, that they would not encounter in primary schools. These events increase pupils' enthusiasm for science and start to train them to work safely in the laboratory.

PISA-type activities

76 A few schools provide suitable opportunities for pupils to answer PISA-type questions that are taken from past tests or designed by the school. These activities are usually given to pupils as a homework task at the end of a unit of work or as extension work for more able pupils. In these questions, pupils are given reading materials that contain detailed information about an aspect of science. These are followed by questions that test pupils' understanding and ability to apply subject knowledge. PISA-type questions present pupils with challenges that they normally do not encounter in science lessons in key stage 3 such as:

- a high volume of reading for understanding, which is generally greater than pupils would encounter in GCSE science questions;
- the need for pupils to apply their scientific knowledge in answering questions that explore unfamiliar situations; and
- questions with multiple-choice answers.

77 These kinds of activities are effective in developing pupils' reading, knowledge and understanding of science, thinking and examination skills and provide useful preparation for GCSE science questions.

Leadership and improving quality

78 In about half of the primary schools, leaders have a clear vision of how they would like to develop science in their schools. In these schools, leaders recognise the impact that science can have on pupils' everyday lives and future employment. They also understand how studying science can contribute to the development of pupils' thinking, literacy and numeracy skills. They appreciate that studying science can be motivating and exciting and enhance pupils' ability to answer questions and solve problems. In the other schools, science is not a priority. These schools often do not allocate enough curriculum time to science and do not discuss science in enough depth in teacher meetings.

79 A majority of leaders of science in secondary schools set high expectations for the quality of teaching in their department. These leaders ensure that they match specific responsibilities to individual teachers' expertise. In these departments, teachers work well together to produce well-considered schemes of work and stimulating learning resources. A minority of schools do not evaluate the impact of teaching on standards in science. Leaders in these departments do not use self-evaluation outcomes to challenge and support individual teachers. As a result, there is too much variation in the quality of teaching within these departments.

80 Leaders of science in nearly all the primary and secondary schools visited have suitable arrangements for gathering first-hand evidence, such as lesson observations and scrutiny of pupils' work, to inform the self-evaluation of science in their schools. A majority use this information together with evidence from scrutiny of pupils' work and analysis of assessment data to provide suitably self-critical reviews of their school's performance in science.

81 In the few instances where quality assurance is particularly effective:

- the school collects data from its tracking system regularly and uses this to evaluate the performance of different groups of pupils and provide targeted support;
- leaders of science have received training in how to conduct lesson observations; and
- there is a culture of openness and honesty;

Darland High School

Departmental self-evaluation

Teachers in the science faculty are enthusiastic about trying new ideas and sharing experiences. The faculty evaluates the impact of new initiatives on pupils' learning rigorously.

The head of faculty meets a line manager from the leadership team to discuss the faculty's performance each fortnight. In these meetings, there is an agenda that focuses on evaluating the impact of teaching initiatives and interventions on different groups of pupils. The whole faculty is involved in self-evaluation and all members take part in scrutinising pupils' work in meetings.

Individual teachers' performance management objectives link appropriately with departmental and whole-school priorities. However, priorities for improvement can be adjusted and development plans amended throughout the year according changes identified through careful monitoring of pupils' progress.

The effect of this strategy is that the faculty is flexible and responds rapidly to changing circumstances

82 Most schools have arranged suitable opportunities for sharing good practice within the school. In a few schools, teachers regularly observe other teachers and departmental meetings focus on the impact of different approaches and teaching methods on standards. However, very few secondary schools and no primary schools in this survey have made links with other schools to share ideas for teaching science. Only a very few teachers attend courses to widen or develop their understanding of how to teach science.

83 A few schools were well supported by their local authority in implementing the 2008 National Curriculum subject orders for science. Effective local authority support for science has diminished since then, with only a few local authorities or regional consortia currently providing specialist support for science.

Annex: Teacher recruitment

There are differential incentives to improve recruitment of trainee teachers in shortage subjects, including physics and chemistry. In spite of these, the majority of trainee science teachers are biology specialists.

The number of trainee science teachers in Wales (2010-2011)

Speciality	Total number	Number of trainees able to teach through Welsh	% of trainees able to teach through Welsh
Biology	83	10	12
Chemistry	36	*	+
Physics	36	6	17

Due to data protection, figures of less than 5 have been replaced by *. Any figure that allows the * value to be identified both within an individual table and from all institution totals has been replaced by +.

The low proportion of trainee science teachers able to teach in Welsh makes recruitment challenging for Welsh-medium and bilingual schools.

Evidence base

The findings and recommendations in this report draw on visits to a representative sample of nine primary schools and 10 secondary schools. This sample takes account of geographical locations, socio-economic backgrounds, size of school and linguistic contexts. In these visits, inspectors:

- observed lessons in key stages 2 and 3;
- scrutinised pupils' work in key stages 2 and 3
- met with representative groups of pupils; and
- held discussions with teachers, senior managers, local authority officers and representatives from the association for science education.

Additional evidence is drawn from teacher assessment outcomes at the end of key stages 2 and 3.

List of schools visited

- Afon Taf Comprehensive School, Merthyr Tydfil
- Alun School Mold, Flintshire
- Bishop Gore Comprehensive School Swansea
- Cefn Saeson Comprehensive School, Neath and Port Talbot
- Darland High School, Wrexham
- Hafod Primary School, Rhondda Cynon Taf
- Llandogo Primary School, Monmouthshire
- Llandrindod Wells County Primary School
- Machen primary School, Caerphilly
- Newport High School, Newport
- Pontarddulais Primary School, Swansea
- Porth County Community School, Rhondda Cynon Taf
- Porthcawl Primary School, Bridgend
- Sandfields Primary School, Neath and Port Talbot
- Ysgol Bodhyfryd, Wrexham
- Ysgol Gyfun Aberaeron, Ceredigion
- Ysgol Gyfun Gymraeg, Bro Morgannwg, The Vale of Glamorgan
- Ysgol Gyfun Maes yr Yrfa, Carmarthenshire
- Ysgol Gynradd Gymraeg Gartholwg

Glossary

PISA	The programme for international student assessment. PISA is an international study that was launched by the OECD in 1997. It aims to evaluate education systems worldwide every three years by assessing 15-year-olds' competencies in the key subjects of reading, mathematics and science.
STEM networks	A national organisation that promotes the understanding of and participation in science, technology, engineering and mathematics
OECD	Organisation for Economic Co-operation and Development

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