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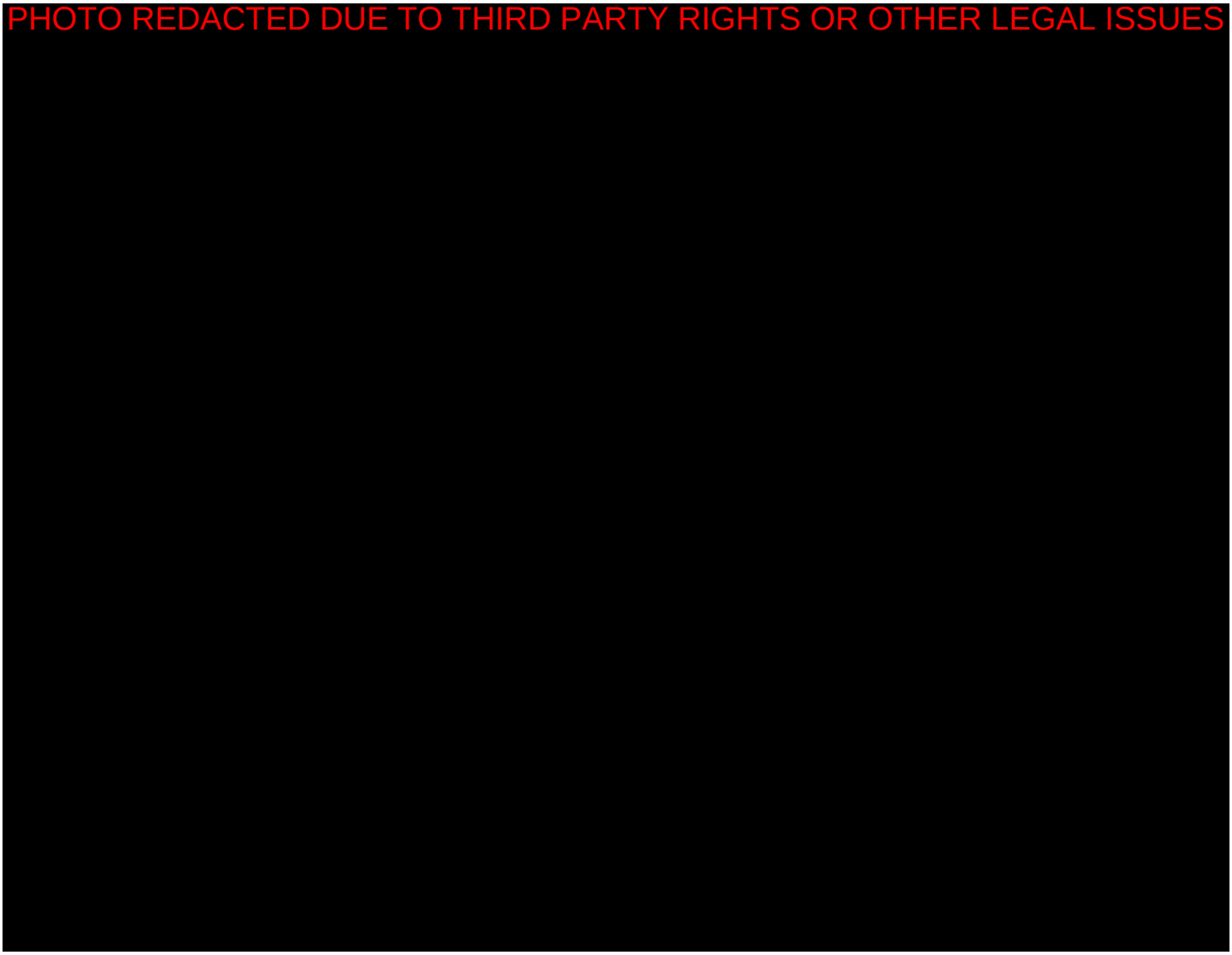
Science at key stage 3 and key stage 4

September 2017



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Introduction

This report is in response to a request in the Minister's annual remit letter to Estyn for 2016-2017. It reports on standards, provision and leadership in science at key stage 3 and key stage 4. It considers a range of factors, such as the quality of teaching and assessment, curriculum planning, staff development, and curricular and extra-curricular learning experiences, that contribute to improving standards in science. It considers general and vocational examination routes at key stage 4. It also reports on the progress made in key stage 3 against the recommendations made in Science in key stages 2 and 3 (Estyn, 2013).

The intended audience for this report is the Welsh Government, headteachers and science teachers in schools, and officers in local authorities and regional consortia. The report findings will also help to inform work on the new curriculum for Wales. The majority of schools visited during this survey have been judged good or excellent for standards in a core inspection since 2010 – for further details on the evidence base for this report, see appendix 3.

Background

The revised National Curriculum for science from key stage 2 to key stage 4 was published in 2008 (Welsh Assembly Government, 2008). The requirements of the curriculum were:

> *At key stage 3, pupils should build on the skills, knowledge and understanding acquired at Key Stage 2. They should develop their skills through the range of interdependence of organisms, the sustainable earth and how things work. Pupils should be taught to apply their scientific skills, knowledge and understanding to design strategies, solve problems and offer explanations, relating scientific ideas to the information about them, including current issues. They should be given opportunities to study the work of scientists and to recognise the role of experimental data, creative thinking and values in their work and in developing scientific ideas.*
>
> *At key stage 4, students should learn about the way that science and scientists work within society. They consider the relationship between data, evidence, theories and explanations and develop their practical, problem-solving and enquiry skills, working individually and in groups. They evaluate enquiry methods and conclusions both qualitatively and quantitatively, and communicate their ideas with clarity and precision. Pupils develop their ability to relate their understanding of science to their own and others, decisions about lifestyles, and to scientific and technological developments in society.*

Assessment at the end of key stage 3 measures performance against level descriptions. Level descriptions describe the types and range of performance that pupils working at a particular level should characteristically demonstrate. In deciding on a pupil's level of attainment at the end of a key stage, teachers should judge which description "best fits" the pupil's performance.

Until recently, a wide range of science qualifications was available in Wales at the end of key stage 4 from several examination boards. In 2016, a new suite of reformed science qualifications for GCSE in Wales was introduced by the WJEC for examination in 2018. The new suite of science qualifications comprises:

- Applied Science (Double award) GCSE
- Applied Science (Single award) GCSE
- Biology GCSE
- Chemistry GCSE
- Physics GCSE
- Science (Double award) GCSE
- Entry Level Certificate in science

In 2013, Estyn published a report on science in key stage 2 and key stage 3 that included the following recommendations:

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

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

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

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

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

In 2015, Professor Graham Donaldson published a review of curriculum and assessment arrangements in Wales (Donaldson, 2015). He proposed that science and technology be drawn together to form one of six areas of learning and experience in the new curriculum for Wales. This area of learning would include physics, chemistry, biology, engineering, design technology, craft, graphic design and computer science. In October 2015, the Welsh Government accepted all recommendations from 'Successful futures' and set out a plan to take forward the recommendations in a document titled 'A Curriculum for Wales: A Curriculum for Life'. (Welsh Government, 2015). This includes developing a new curriculum that is evidence-led, manageable, ambitious and inclusive.

Main findings

Standards

1 Pupils make good progress in their knowledge and understanding of science in many of the science lessons observed in key stage 4, but in only about half of the science lessons in key stage 3. The quality of teaching is better in key stage 4 lessons than in key stage 3. In key stage 3, teacher expectations of what pupils can achieve are often too low.

2 In the lessons where good progress is made, pupils recall previous science work well. They are engaged and are enthusiastic about their work. They undertake practical and investigative work competently. They use scientific terms with understanding and can provide reasoned explanations in their written and oral responses. Many write about science topics in a variety of styles and for a range of audiences. They develop their numeracy skills appropriately.

3 In a minority of lessons, progress is too slow. In these lessons, many pupils are too reliant on the teacher. In a very few lessons, a few pupils disrupt the learning of others. This disruption is more common in key stage 3 and in lessons taught by teachers who are not science specialists.

4 In key stage 4, performance at level 2 in science has shown an upward trend from 2012 to 2015. Despite declining in 2016, science remains the highest attaining core subject in Wales. Girls consistently perform better than boys in science. Pupils eligible for free school meals still do not perform as well as other pupils. The proportion of pupils who achieve the highest grades in science GCSE has not improved over time.

5 In key stage 3, according to teacher assessment, there has been a year-on-year increase in the proportion of pupils attaining the expected level (level 5 and above) in science since 2012. The proportion of pupils gaining the higher levels in science has also improved, although more able pupils eligible for free school meals do not do as well in science as their peers. Performance of boys has been lower than that of girls at each level every year since 2012.

6 The GCSE and teacher assessment outcomes contrast with the findings in PISA tests in 2015. The average PISA scores for science in Wales have declined every three years since 2006. A key factor in this decline has been the deterioration in the performance of the highest achieving pupils. In PISA, there is no significant difference in the performance of boys and girls in science.

Provision

7 In the schools visited, the quality of teaching has many strengths in many lessons in key stage 4 and in around a half of lessons in key stage 3. Many teachers, particularly in key stage 4, have strong subject knowledge and develop pupils' scientific knowledge and understanding well by planning a range of interesting

activities. These teachers provide well-planned practical work, make good use of information and communication technology (ICT) to enhance their teaching, and provide opportunities for pupils to develop their literacy and numeracy. Teachers' exposition is clear and concise. In a few lessons, teachers have exceptionally high expectations and help pupils to achieve them.

8 In a minority of lessons, particularly in key stage 3, expectations are low, and teachers do not plan well enough to meet the needs of all pupils and do not plan enough opportunities for pupils to develop their ICT skills.

9 Many teachers use assessment information from tests and examinations well to gain a clear picture of the strengths and weaknesses of individual pupils. Only a minority of teachers provide pupils with useful subject-specific comments to improve their work. Pupils respond positively to such feedback.

10 In many lessons, teachers question pupils well, allowing appropriate time for response and encouraging more expansive answers. A few teachers offer useful opportunities for pupils to assess their own work and the work of others, but more often the purpose of this type of assessment is unclear as pupils do not use suitable criteria that help them improve their work.

11 In general, enough teaching time is allocated for teaching science currently, but time is being reduced for GCSE science in many schools to accommodate other curriculum areas such as the Welsh Baccalaureate at key stage 4. Most schools have reduced the number of pupils entered for vocational science courses significantly since 2015. Very few schools have reviewed their science curriculum in response to the 'Successful futures' report (Donaldson, G. (2015)).

12 Most schools offer worthwhile extra-curricular science activities, but planning for extending more able pupils is underdeveloped in science. There is also a lack of opportunity for pupils to contribute to what and how they want to learn.

Leadership and management

13 In the schools visited, senior leaders generally have a broad vision for the school curriculum and what they want to achieve for their pupils. In science departments, leaders are less clear about the specific aims of the science curriculum. The recent changes to qualifications may have contributed to this lack of clarity, since science leaders are not familiar enough with the content or assessment requirements.

14 Lines of accountability for science departments are generally clear. However, because all qualifications are included in the level 2 measure for science, performance data is not specific enough to allow a department to compare itself effectively with similar schools. This has led to a lack of rigour in the performance management and evaluation of science departments in recent years, especially when leaders are not using a range of evidence to evaluate the quality of teaching and leaders of science departments and are too dependent on using data.

15 Most science department self-evaluations are based on information gathered from suitable sources, such as lesson observations and scrutiny of pupils' work. However, lesson observations tend to focus too much on whole-school priorities, and as a

result they do not evaluate standards and progress in science knowledge and understanding well enough. When looking at pupils' work, most departments consider pupils' literacy and numeracy skills, but only a few focus clearly on the standard of science.

16 In most schools, the science department improvement plan is suitably linked to their self-evaluation report. The plan includes appropriate actions to address priorities and the success criteria are linked properly to the department's targets. In a majority of cases, the actions are not specific enough to improve the quality of teaching.

17 A minority of the schools visited have taken part in the latest round of PISA tests. Only a few schools have analysed their school's own report on the test outcomes in detail so as to identify any weaknesses and plan to address them. Similarly, of the schools that did not take part in the PISA tests in 2015, very few have considered the content of the report for Wales or how it would impact on their work.

18 Most science teachers benefit from sound internal support from their school leaders and colleagues. However, regional consortia subject officers target their support on science departments that need to improve significantly and there is not enough subject-specific support for science in schools that are not underperforming.

19 Most lessons are taught by specialist science teachers. Generally, there is a lack of applicants for science posts and recruiting to Welsh-medium science departments is a particular problem. When science staff are absent, many schools have to employ non-specialist supply teachers to cover their lessons, especially in key stage 3. The number of post-graduate science teachers being trained has fallen short of national targets over several years.

20 Most science departments are well equipped. They have a suitable number of laboratories and an appropriate number of technicians to support the teaching. Science support staff receive appropriate training on health and safety issues. There is very little training or support available for technicians.

Recommendations

Schools should:

R1 Provide stimulating and challenging learning opportunities in science involving effective practical work to meet the needs of all pupils, including the more able

R2 Evaluate their curriculum for science in preparation for the new area of learning and experience for science and technology

R3 Ensure that departmental self-evaluation is robust and based on a range of evidence to evaluate subject-specific standards and the quality of teaching

R4 Use feedback from the latest PISA report to inform planning for improvement

R5 Ensure that assessment helps pupils to know what they need to do to improve

Local authorities and regional consortia should:

R6 Provide more subject-specific support for science teachers on improving teaching and assessment, and facilitate the sharing of good practice

R7 Provide more support for schools to evaluate their curriculum, and plan for the development of the science and technology area of learning and experience, as well as the changes to qualifications in science

The Welsh Government should:

R8 Campaign to attract more science graduates into the teaching profession in Wales

Standards

Science skills, knowledge and understanding

21 In the schools visited, pupils make good progress in their scientific understanding and knowledge in only about half of the lessons observed in key stage 3. In key stage 4, pupils make good progress in many lessons. There are important shortcomings in a minority of lessons in key stage 4 and around a half of lessons in key stage 3.

22 Many pupils recall their previous scientific knowledge well. They have a suitable understanding of scientific ideas such as the kinetic theory that they apply well to contexts that are new to them.

23 In around a half of lessons in key stage 3, progress is too slow. Pupils are not clear about what is expected of them and are unable to complete the tasks and activities to a standard appropriate to their age and ability. Similarly in key stage 4, in a minority of lessons, pupils do not make enough progress due to the teachers' lack of challenge and low expectations. Often, boys do not perform as well as girls, are more easily distracted from their work, and tend to engage more frequently in activities that cause low-level disruption.

24 In the majority of cases, pupils' books are well presented. In key stage 4, they often contain strong examples of extended writing, practical work and progression in science knowledge and understanding.

25 Many pupils in key stage 4 undertake practical and investigative work independently and competently. Most of these pupils are willing to take risks and are not afraid of being wrong. They challenge themselves appropriately and learn from their mistakes. This helps them to improve and deepen their understanding.

26 In whole-class investigations, many pupils often make predictions that are not soundly based on scientific knowledge and understanding. They do not explain their predictions well because of their misunderstanding of scientific ideas such as particle theory. In addition, they do not always draw the correct conclusion from data and information gathered. The conclusion often restates the prediction or does not pay attention to data that might not support the prediction. In key stage 3, where the practical activities are poorly thought out and planned, many pupils do not make appropriate progress in developing their science understanding.

27 Many pupils work well on their own and are diligent when answering to open-ended tasks, writing at length and reading to gather information. They work well in groups and pairs when given the opportunity and consider thoughtfully the opinions of others during discussions.

28 Many pupils follow written instructions well. During practical work, pupils show due regard to health and safety and set up and carry out practical work competently. In a majority of lessons, they develop aspects of their thinking well through completing challenging investigations and solving problems. In these lessons, pupils gather new

information through experimenting and trialling. They use the information effectively to reach a logical conclusion and solve the problem. In the few best examples, pupils structure investigations very well. They are clear about concepts such as reliability, fair testing, and control of variables. A few pupils are able to identify shortcomings in their work and suggest how to improve.

29 A few pupils develop their critical thinking skills through science. When given the opportunity, pupils form opinions based on their knowledge and understanding or on the information available, for example when weighing up the advantages and disadvantages of nuclear energy.

30 Pupils develop their numeracy skills appropriately in many science lessons. They are able to draw relevant graphs and charts to display data collected through experiments. Many pupils use their numerical skills well to solve problems involving the rearranging of formulae and conversion of units. In one school, pupils working independently worked out how many atoms that molecules contain by applying rules introduced in their mathematics lessons.

31 When presenting data collected from their own experiments, many pupils are unable to choose the correct method for displaying the data. They are too dependent on tables provided by the teacher. When required to produce their own tables, too often they include the wrong units or omit them altogether, or have inappropriate ranges or insufficient data to draw a sensible conclusion. Many pupils are too reliant on the teacher to choose the correct and most appropriate graph to draw for their data. A few pupils do not possess the numeracy skills required to set the correct scales for their axes or construct basic bar charts.

32 Most pupils display strong listening skills and act on instructions from the teacher. Many pupils speak well using scientific terms appropriately and offer reasoned verbal explanations to justify their answers. Their mature discussions are based on prior knowledge and they ask pertinent questions of each other and of the teacher.

33 The majority of pupils write for a wide range of purposes and audiences about science topics. They write with technical accuracy without help from the teacher. These pupils write at length when answering examination questions, reporting on experiments, and compiling information from their own research.

34 Most pupils read aloud with confidence and meaning. They are able to extract information by skimming and scanning. They use this information appropriately to answer short questions.

35 Pupils' ICT skills are underdeveloped in science. In general, pupils' use of ICT is basic and confined to word processing, presenting information or displaying data in spreadsheets. The development of more advanced ICT skills, such as modelling and use of data logging, is very limited due to lack of opportunities provided.

36 Most pupils engage well and are enthusiastic about the work. They show interest in nearly all aspects of lessons, in particular when carrying out practical work that is stimulating and challenging. For example, key stage 4 pupils at Radyr Comprehensive School, Cardiff, were fully engaged in a lesson from the start with the

teacher demonstrating inertia using a raw egg and a boiled egg. Pupils were actively engaged in the demonstration and were very eager to respond to the teachers' questions, offering explanations based on their previous learning. The lesson progressed into a whole-class practical activity on inertia using swinging bottles containing sand or water. All pupils took an active part in setting up the equipment and in gathering evidence and recording. They were enthusiastic in their approach to follow up written and numerical tasks. A key feature of the lesson was that pupils showed interest in all aspects, the work was challenging for most pupils, and the lesson well paced, with a range of activities.

37 In a very few lessons, a few pupils disrupt the learning of others. This is more common in key stage 3 or where lessons are taught by teachers who are not science specialists, or who are supply teachers or cover supervisors. This disruption is often due to a lack of interest by pupils in the topic or subject. In a very few cases, pupils lose interest in the work when they do not understand the language of instruction well enough. In addition, a few pupils are inactive for parts of lessons when the work is either too easy or too hard for them.

38 Since 2012, there has been a year-on-year increase in the proportion of pupils attaining the expected level (level 5 and above) and the higher levels in science at key stage 3. The performance of boys has been lower than that of girls at level 5 or above, level 6 or above, and level 7 or above in science each year since 2012 (Welsh Government, 2017a). Over the same period, the performance of pupils eligible for free school meals has improved at all levels, although their performance remains lower than that for other pupils. At level 7 or above, the difference between the attainment of pupils eligible for free school meals and those who are not has widened. (Welsh Government, 2017b & 2017c) This suggests that more able pupils eligible for free school meals do not do as well in science as their peers. Appendix 1 sets out teacher assessment outcomes at key stage 3 in more detail.

Ysgol Gyfun Cymer Rhondda, Porth

A Year 7 lesson on 'familiarising with specialised cells', developing understanding of cell structure and adaptation

Pupils came into the laboratory in an orderly fashion and took their places in groups pre-determined by the teacher. From the start, pupils showed a positive attitude towards the work and were eager to learn. The objective of the lesson was for pupils to familiarise themselves with specialised cells and to learn about one type of cell of their choice in detail. They used this information to teach others within the group. This lesson followed work on plant and animal cells. The teacher assessed prior learning successfully through a true or false exercise. Almost all pupils recalled the parts of the cells and their function. They identified the difference between plant and animal cells accurately. An introduction to specialised cells referred to a familiar context of members of a rugby team, where most pupils could see that each player had their function and are of different sizes and proportions suited to that function. They made the link to a cell displayed by the teacher. As a result, nearly all pupils instantly showed interest in the topic.

The main activity was a 'marketplace', where pupils were given access to text and pictures of about five different cells including root hair cells, sperm cells and cilia. One pupil from each group gathered around each work station, then read and discussed the information. Most pupils read well and were well understood by other pupils. They were not allowed to take notes other than to note key words. After a set time, the pupils returned to their original group and each one in turn informed the rest of the group about their cell. Nearly all pupils worked well in their groups and transferred the information effectively to the other members. Pupils composed a written paragraph about their chosen cell. Nearly all wrote well, with due care to spelling and grammar and using the new scientific terms. Throughout the lesson, nearly all pupils were fully engaged in their learning and devoted to the tasks. They made strong progress in their scientific understanding and communication skills (writing, listening and reading).

Performance in examinations at key stage 4

39 In key stage 4, performance in science at level 2 has shown an upward trend from 2012 to 2015, as seen in figure 1. Despite declining almost two percentage points in 2016, science remains the highest attaining core subject in Wales and markedly above mathematics and English (Welsh Government, 2016a).

Figure 1: Percentage of pupils achieving level 2 (A*-C GCSE or equivalent) in the core subjects

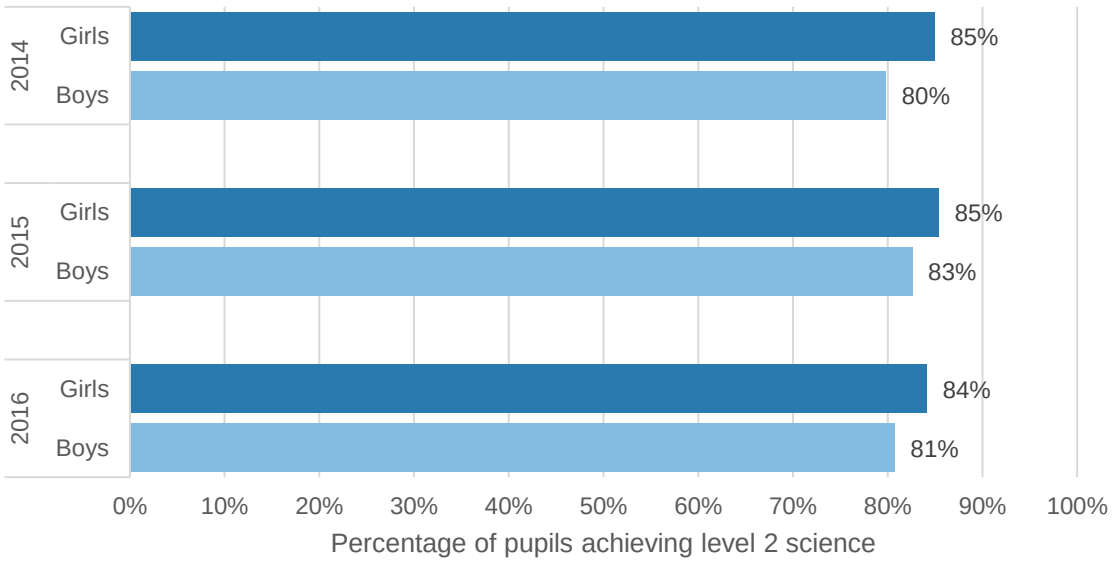
	Percentage of pupils[1]					Percentage of entrants[2]	
	Cohort	Science	Mathematics	English	English or Welsh	Entries	Welsh first language
2012	35,404	71%	58%	62%	64%	5,207	74%
2013	36,617	75%	60%	63%	64%	5,591	74%
2014	35,168	82%	62%	66%	67%	5,548	74%
2015	34,004	84%	64%	69%	70%	5,452	75%
2016	32,248	82%	67%	69%	70%	5,285	75%

[1] From 2012 to 2015, this includes all 15-year-olds in Wales. In 2016, this includes all Year 11 pupils in maintained schools (excluding independent schools).
[2] Only based on those entering Welsh first language, not all pupils as in other subjects

Source: Welsh Government (2016a)

40 Girls consistently perform better than boys in science at the end of key stage 4 (an average of three percentage points over five years), although the gap is decreasing slightly; see figure 2.

Figure 2: Percentage of pupils[1] achieving level 2 science in key stage 4 by gender, Wales, 2014 to 2016

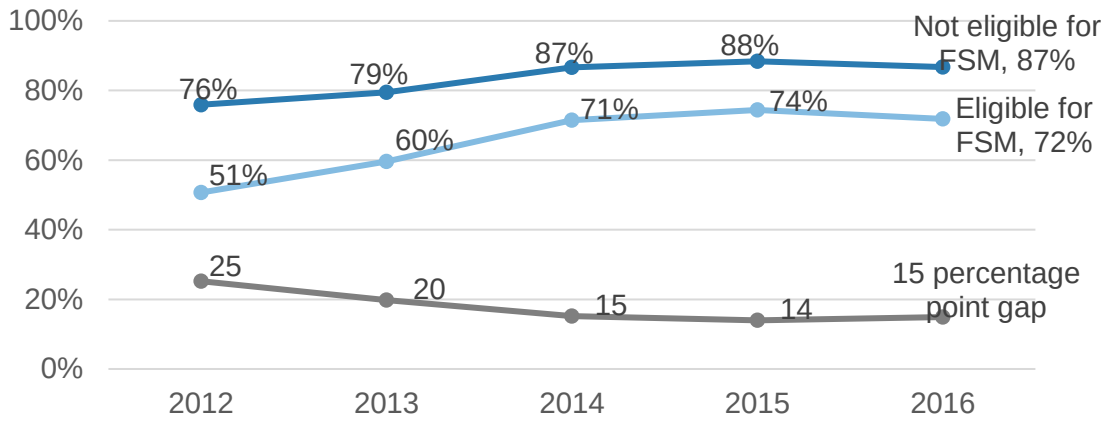


[1] Pupils aged 15 from 2014 to 2015; all pupils in Year 11(excluding independent schools) in 2016. For more information: http://gov.wales/docs/statistics/2016/160721-key-stage-4-performance-measures-changes-comparability-en.pdf

Source: Welsh Government (2016a)

41 Pupils eligible for free school meals do not perform as well as other pupils in achieving at least a level 1 or level 2 qualification in science. Although the gap in performance at level 2 closed significantly in 2014, it has remained at a similar level for the last three years (Welsh Government, 2017c & 2017d).

Figure 3: Percentage of pupils[1] achieving level 2 science, 2012 to 2016, by free-school-meal (FSM) eligibility



Source: Welsh Government (2017c and 2017d)

[1] Pupils aged 15 from 2014 to 2015; all pupils in Year 11 (excluding independent schools) in 2016. For more information: http://gov.wales/docs/statistics/2016/160721-key-stage-4-performance-measures-changes-comparability-en.pdf

42 Performance of pupils in Welsh-medium schools in science at levels 1 and 2 is better than that for pupils in English-medium schools for the last five years (Welsh Government, 2017c & 2017d). This is due in part to Welsh medium schools having lower levels of pupils eligible for free school meals.

Figure 4: Percentage of pupils achieving each level in science, 2012 to 2016, by school medium

Year	School medium[1]	Number of pupils[2]	Percentage achieving level 1	Percentage achieving level 2
	English medium	27,025	94%	71%
	Welsh medium	6,659	96%	77%
	English medium	28,224	94%	76%
	Welsh medium	6,650	96%	80%
	English medium	26,937	94%	84%
	Welsh medium	6,480	97%	87%
	English medium	25,899	95%	86%
	Welsh medium	6,328	98%	90%
	English medium	25,023	96%	85%
	Welsh medium	6,008	97%	88%

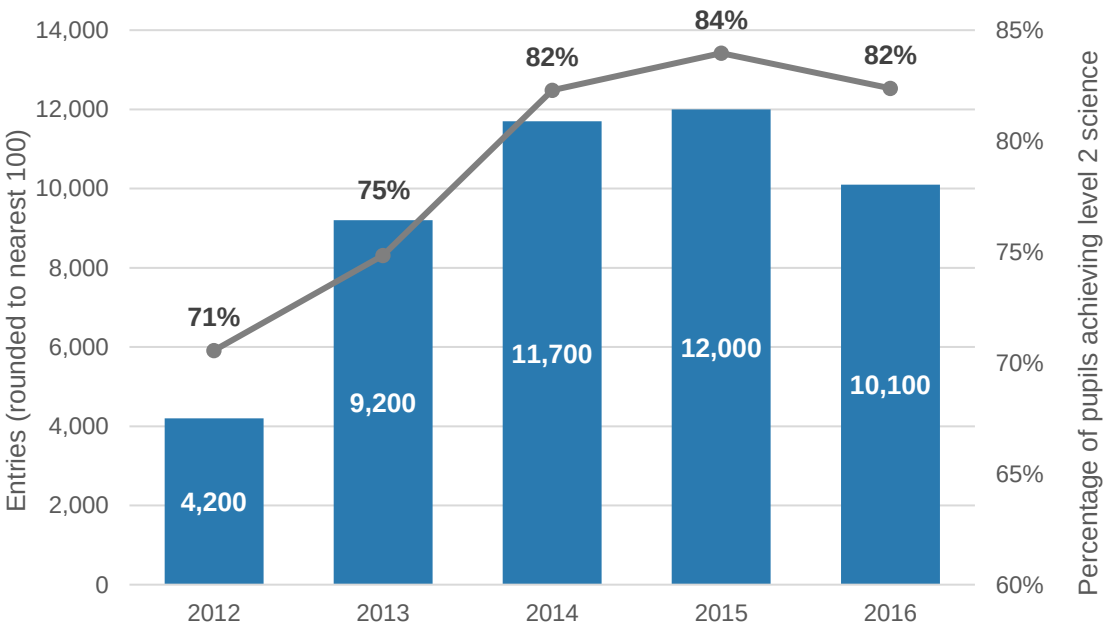
[1] Welsh medium includes bilingual schools.
[2] From 2012 to 2015, this includes all 15-year-olds in Wales. In 2016, this includes all Year 11 pupils in maintained schools (excluding independent schools).

Sources: Welsh Government (2017c)

Vocational courses

43 The number of pupils entered for the BTEC applied science level 2 qualification has declined from a peak of around 12,000 in 2015 to around 10,100 in 2016 (see figure 5). This decline is attributed to the qualification not being accepted as a level 2 science qualification for new whole-school performance measures from 2018. This decline also correlates with the overall performance at level 2 for science. Level 2 performance increased as the number of entries for BTEC increased. In 2016, both declined (Welsh Government, 2017c & 2017d).

Figure 5: Relationship between BTEC entries and performance in level 2 science from 2012 to 2016



Source: Welsh Government (2017c)

44 Year-on-year, most pupils entered for BTEC achieve at least a level 1 qualification, with at least 94% achieving a level 2 qualification every year.

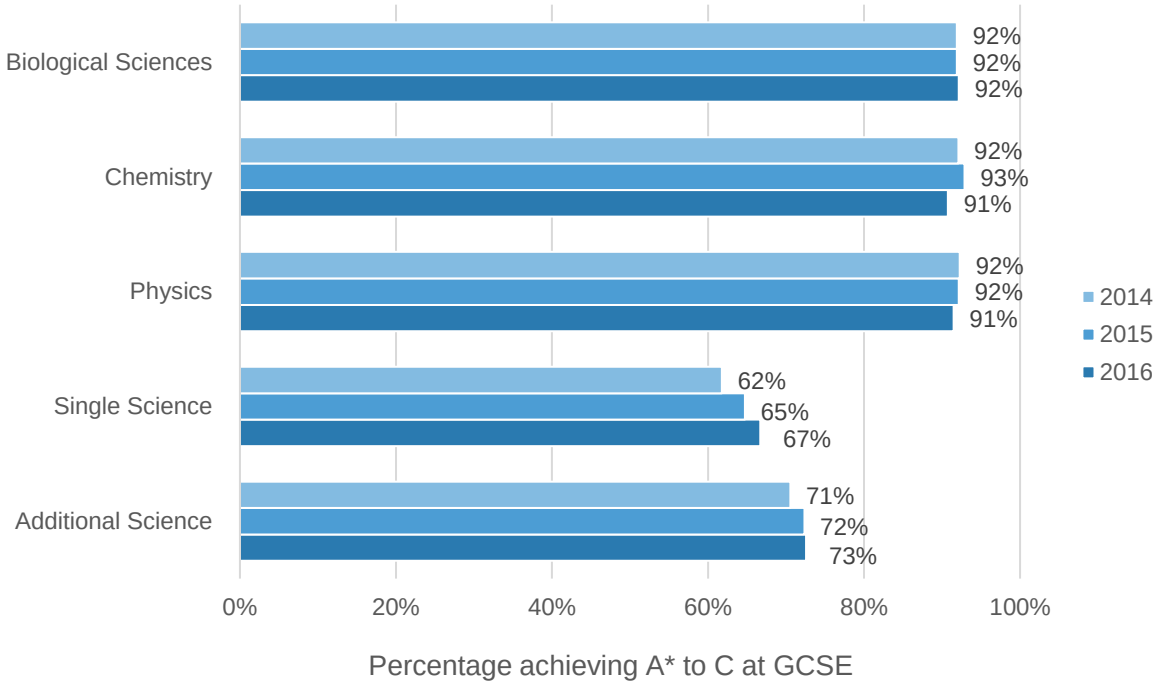
GCSE

45 The proportion of pupils achieving grades A*-C in the separate sciences at GCSE has varied over the last five years but remains very high at over 90%. The number of pupils entered for each course in Wales has remained fairly consistent between 5,000 and 6,000 pupils over this period (Welsh Government, 2016a). In England, the number of pupils entered for separate science courses has also remained fairly consistent (Ofqual, 2016). (

46 Performance in additional science GCSE has gradually improved over the last four years. In 2016, nearly 73% of pupils entered achieved a grade A*-C compared to 69% in 2012. However, the number of pupils entered for the course has declined by 4,300 over the same period from 16,200 to 11,900. Performance at the higher

grades of A*-A has fallen by an average of five percentage points since 2012. In the separate sciences, around 40% of pupils achieve grades A*-A in all subjects, although chemistry is consistently higher by one or two percentage points over the past five years (Welsh Government, 2016a).

Figure 6: Percentage of entrants achieving a grade A* or C in science GCSEs, Wales, 2012 to 2016



Source: Welsh Government (2016a)

47 In additional science, the proportion of pupils gaining the highest grades has remained the same, at around 14%, despite a declining number of entries. The proportion of pupils who achieve the highest grades in science has not improved over time, while the proportion achieving level 2 has improved. This suggests that expectations are not high enough and that schools have been concentrating on pupils achieving a grade C or level 2 qualification (Welsh Government, 2016a).

48 This report does not include comparisons of performance in science in Wales with that of other countries at key stage 4. This is because there are different examination collection and reporting methods. Comparisons can therefore be misleading, since there are a number of limitations to the data, particularly around different early entry patterns in England and Wales. England no longer publishes teacher assessments data at the end of key stage 3.

Performance in international surveys

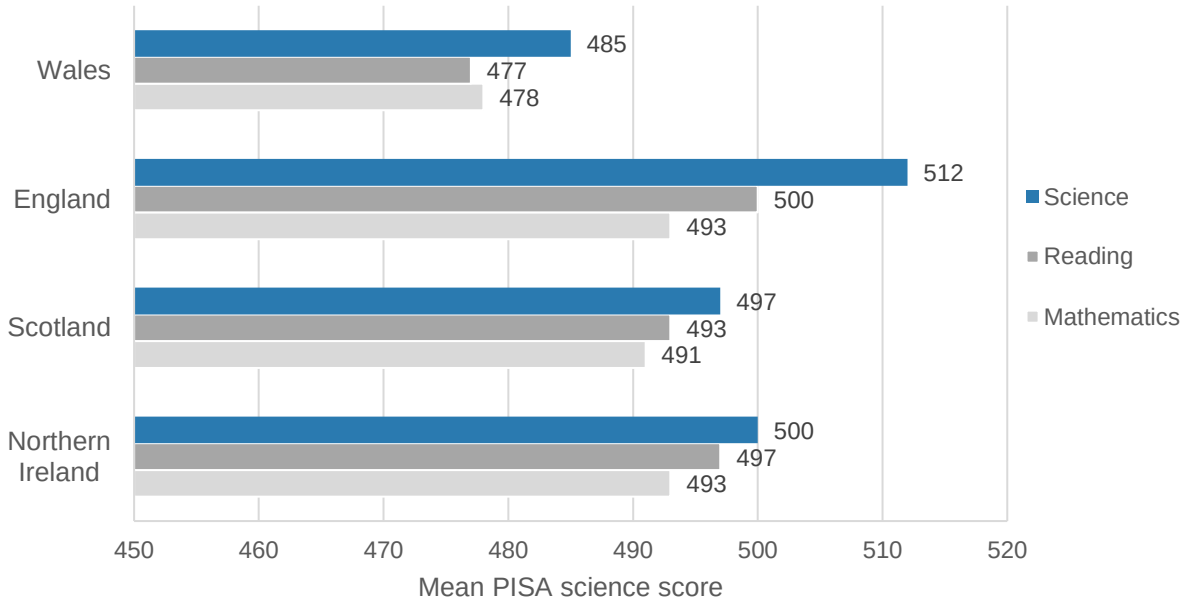
49 PISA is the programme for international student assessment survey undertaken by the Organisation for Economic Cooperation and Development (OECD).

50 Every three years, students from countries around the world take tests in reading, mathematics and science. In each cycle of PISA, a focus is given to one of these three domains. The focus for PISA 2015 was science, with reading and mathematics being the minor domains. All of the pupils that took part sat assessments in science and around two-fifths of pupils took assessments in reading and mathematics. The last occasion science was the main domain was in 2006.

51 Seventy-one countries participated in this round of PISA (OECD, 2016). In Wales, 3,451 pupils from 140 secondary schools took the PISA tests (Jerrim & Shure, 2016). This is around 10% of 15-year-old pupils. The proportion of pupils entered for the test in participating countries ranges from 0.1% to over 50% (OECD, 2015). Around 10% of pupils took the tests through the medium of Welsh (Jerrim & Shure, 2016).

52 As can be seen in figure 7, for PISA 2015, scores for Wales were well below those of the other countries of the United Kingdom in science, reading and mathematics. Around one-third of pupils in Wales lacked basic skills in at least one of the three PISA domains, compared to 29% in England and Scotland, and 25% in Northern Ireland (Jerrim & Shure, 2016).

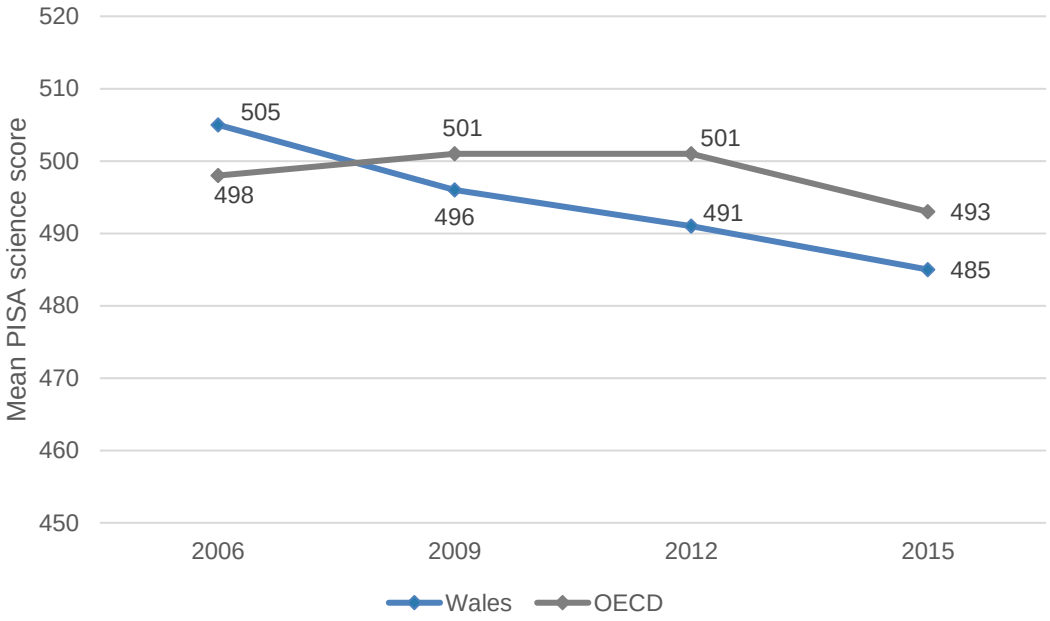
Figure 7: PISA scores 2015 for science, reading and mathematics, comparing the home nations



Source: Jerrim & Shure (2016)

53 In science in 2015, 31 countries significantly outperformed Wales compared to 25 in PISA 2012.

Figure 8: Mean PISA scores in science for Wales



Source: Jerrim & Shure (2016)

54 The PISA results (see figure 8) show that there has been a significant decline in the average scores for science in Wales since 2006. A key factor in this decrease has been the decline in the performance of the highest achieving pupils. The proportion of pupils attaining the lower levels has broadly remained at a similar level between 2006 and 2015. The proportion of pupils attaining the higher levels has steadily declined since 2006 with a difference of 36 test points between 2006 and 2015. In 2015, only 5% of Welsh pupils are defined as top performers compared to 8% across participating countries and 12% in England, (Jerrim &Shure, 2016). As there is no breakdown of PISA results by school type available, we cannot be sure that the proportion of pupils in comprehensive, state-maintained schools or independent schools is similar across countries.

55 There is no statistically significant difference in the performance between boys and girls in science. However, boys are slightly stronger than girls in aspects such as the physical scientific system and explaining phenomena scientifically. It is also reasonably similar to the results for PISA 2006, 2009 and 2012 in favour of boys. This is different from the pattern observed for science GCSEs, where a slightly higher proportion of girls achieves the higher grades than boys (Jerrim & Shure, 2016).

56 Pupils who took the Welsh language version of the PISA 2015 science test achieved lower scores than their peers who completed the test in English. However, pupils from Welsh-medium schools who took English language papers did better than pupils in English-medium schools. This could be due to the small sample size as it is contrary to the trend seen at GCSE level 2. The schools visited identified that the Welsh language questions in the PISA tests are difficult to read and include unfamiliar translations of terms, and that the general language used is too complicated (Jerrim & Shure, 2016).

57 Overall, pupils in Wales achieved similar scores across the three PISA scientific systems of 'living', 'physical' and 'earth and space'. This is common for many countries, including the high achieving countries. Pupils in Wales also scored similarly in each type of scientific knowledge that is 'content' and 'procedural and epistemic'. This is common for many countries, but pupils in some high performing countries show better procedural and epistemic knowledge. For scientific competencies, pupils in Wales are stronger at explaining phenomena scientifically than they are at evaluating and designing scientific enquiry (Jerrim & Shure, 2016). Since the current science curriculum in Wales is based on scientific enquiry, this is a surprising outcome and is not a pattern found in many of the highest performing countries.

58 Most pupils in Wales view school science as relevant to their future, irrespective of their gender, socio-economic status, or proficiency in this area. Pupils in Wales are more likely to aspire to a science career than pupils in the average OECD or average top performing country (Jerrim & Shure, 2016).

59 Pupils indicated that they spend 90 minutes more studying science in school a week than pupils across the OECD countries on average. Pupils in Wales also report spending more time studying science outside of school than the average across OECD members and the average across high-performing countries (Jerrim & Shure, 2016).

60 Pupils in Wales report low-level disruption occurring more frequently in science classrooms than do pupils in many other OECD and high-performing countries.

61 Headteachers in Wales are generally positive about the resources available to support science learning within their schools. Headteachers in Wales are more likely to report staff absence as a barrier to pupils learning than headteachers in the average OECD or high-performing country. How much time students spend learning and how science is taught are more strongly associated with performance than the quality and availability of resources.

62 Outcomes from PISA 2015 suggest that there is a weaker association between socio-economic status and PISA science scores in Wales than in the rest of the UK. This is mainly due to the most advantaged Welsh pupils not achieving as highly as similar pupils in England, Scotland and Northern Ireland (Jerrim & Shure, 2016)..

Provision for science

Curriculum planning, enrichment and learning experiences

63 In general, schools allocate suitable time for teaching science. In nearly all schools, lessons are 50 minutes or 60 minutes in length. Many schools timetable 'double' science lessons of up to two hours. In a very few schools a 'triple' science period is timetabled. Multiple sessions provide pupils with an opportunity to carry out longer practical or investigative work. If not planned carefully enough, pupils have difficulty in maintaining concentration for a long period and become disengaged. In addition, if a pupil is absent for a day, this arrangement results in a large proportion of science lessons being missed. In key stage 3, the time allocated for teaching science varies between 2.5 hours and six hours a week. This wide variation is sometimes explained by the need to balance time allocation with other subjects across the three years. For the Science (Double award) GCSE course, the time allocated varies between 4.5 hours and six hours a week.

64 Curriculum time is increasingly being reduced for teaching GCSE science in many schools to accommodate other courses at key stage 4, for example the Welsh Baccalaureate. The time allocated for teaching the separate sciences is a concern in the few schools where it is not timetabled as an option. In these schools, it is expected that the three separate sciences are taught in the same time allocation for the double award. This results in teachers struggling to complete the course content in the required time. Pupils, in particular the more able who tend to opt for separate sciences, have to work at an unsuitable pace that can restrict their learning and understanding.

65 Most schools prioritise the allocation of science staff to key stage 4 over that in key stage 3. This sometimes results in classes at key stage 3 being split between different members of staff, which leads to a lack of continuity and consistency in teaching and assessment. When science staff are absent, schools often adapt their timetable to ensure that key stage 4 classes are taught by science specialists. However, non-specialist supply staff, who do not have the experience or knowledge to make science interesting, are often used to teach key stage 3 classes.

66 The existence of numerous courses and qualifications for science at key stage 4 is a challenge for science departments. For pupils currently in Year 11, 'legacy' courses still run alongside the new suite of qualifications and vocational courses, such as the BTEC level 2 applied science and international vocational qualifications at level 1 and 2 for science. Therefore, science departments are dealing with several different assessment requirements that include tracking each pupil for each qualification. The wide range of courses has implications for planning and assessment. For example, courses have different guided learning hours, different subject content and a choice of units that may be assessed through examination or coursework.

67 Nearly all schools are adapting to the change in the requirements for whole-school performance measures at the end of key stage 4. The new science GCSEs that are

examined from 2018 will be required for the main school performance measures. This means that, from 2018, schools will be able to compare themselves against other schools, something that is not currently possible because both GCSE and BTEC science qualifications are fairly included in an undifferentiated way in performance indicators at key stage 4. Most schools have reduced the number of pupils entered for vocational courses in readiness for 2018 because they will not contribute to school performance measures in future.

68 Very few schools have opted to offer the Applied Science (Double award) course, preferring to offer the Science (Double award) GCSE and separate sciences. A very few schools are considering entering a few less able pupils for the single Applied Science qualification. Although this qualification only contributes half of the science requirements towards school performance measures, they believe that this is in the best interests of these pupils and helps to provide them with a broad and balanced curriculum that meets their needs.

69 While there are sufficient resources to deliver existing qualifications through the medium of Welsh, there is a lack of Welsh-medium resources to support the new qualifications. Many schools that offer science through the medium of Welsh work well with other schools to prepare resources and to share materials.

70 In key stage 3, schemes of work include the required elements of the national curriculum for science. In most schools, schemes of work set out clearly what subject content needs to be taught in the three science aspects. However, it is not always clear in schemes of work how and what the teacher needs to do to best deliver activities. A few, good examples outline clearly the opportunities to develop pupils' literacy and numeracy skills. They also note where activities contribute well to developing pupils' thinking skills and to introducing aspects of Cwricwlwm Cymreig, such as the contribution of Welsh scientists and local environmental issues.

71 In key stage 3, planning to challenge more able pupils is underdeveloped in most schools. Teachers tend to plan the same type of activities, including practical work for whole classes that use the same resources and equipment. Schemes of work do not include specific strategies for extending the more able and most science departments do not plan opportunities for pupils to achieve the highest levels at the end of the key stage. As a result, no pupils in any of the schools visited attained level 8 or exceptional performance by the end of key stage 3.

72 Most schools have adapted their schemes of work or lesson plans at key stage 3 and key stage 4 to include questions and activities that are similar to those found in PISA tests. These activities place science in context and are more demanding of pupils' reading and thinking skills. Examination boards have also adapted their examinations to be more similar to PISA. As a result, pupils have more appropriate opportunities to practise their reading and comprehension skills. The PISA report for Wales suggests that more emphasis should be placed on developing pupils' skills in evaluating and designing scientific enquiry. Currently, most opportunities for pupils to plan, design and evaluate scientific investigations are too structured and do not allow pupils enough scope to offer their own analysis and evaluation.

73 For most pupils, practical work is a very enjoyable aspect of science lessons. However, not enough practical work is completed and actual experiments and demonstrations are being increasingly replaced by worksheets, videos and internet media clips. When used well, media clips can stimulate and enthuse pupils while keeping a safe environment. However, pupils are deprived of opportunities to develop and practise their practical skills when the teacher does not provide enough hands-on experiences in the laboratory.

74 Most schools visited offer worthwhile extra-curricular activities that relate to science, for example through science or STEM clubs. These activities are popular and well attended, especially by pupils in key stage 3. These clubs enable the pupils who attend to pursue their interest in science. Many schools are also involved in science competitions and facilitate visits to local industries. In most of these schools, pupils benefit from interesting workshops provided by 'Techniquest', either at the school or through visiting their facilities at Wrexham or Cardiff. A few also offer more customised opportunities, for example a zoo club, projects that extend for a whole year, residential courses, and visits abroad.

75 Many schools generally do not have strong links for science with the wider community. They say that this is due to increasing demands on curriculum time, competition with other subject areas, cost and lack of relevant local businesses and industries. There is a lack of opportunity for all pupils to decide how they learn and what they want to study. Generally, little progress has been made since our 2013 thematic review on science in key stages 2 and 3 recommended that schools provide more opportunities for pupils to pursue their own scientific interests (Estyn, 2013).

Teaching

76 The overall quality of teaching is better in key stage 4 than in key stage 3. In key stage 4, many of the lessons observed had strengths in teaching that allowed pupils to make strong progress. In key stage 3, only around a half of the lessons had strengths in teaching and no important areas that require significant improvement.

77 In the better lessons across both key stages, teachers have strong subject knowledge that enables them to teach across the key stages and to all abilities. There is a productive relationship between the teacher and pupils. In these lessons, the teacher manages each activity well and ensures the smooth transition from one activity to another.

78 In a few lessons, teachers have exceptionally high expectations of pupils. They encourage pupils to ask questions and plan carefully to deepen their understanding. Activities are focused on pupils, who are skilfully encouraged by the teacher to achieve their objectives and make excellent progress.

79 In many lessons, teachers interact skilfully with pupils, achieving a fine balance between support and challenge. In the best examples, teachers support the development of pupils' understanding and provide opportunities for them to solve challenging problems. In these lessons, sophisticated planning gives pupils the opportunity to use more complex reasoning.

80 Many lessons, mostly in key stage 4, are well paced and give enough time for pupils to complete tasks. Enough time also enables teachers to work effectively with the pupils to develop according to their ability. In these lessons, suitable and relevant homework is set to complement the work and to extend pupils' understanding.

81 Many teachers' exposition is clear and concise. They use a blend of approaches to ensure that pupils make good progress. This includes direct instruction and opportunities for pupils to work things out for themselves. Clear explanations to the whole class are especially important and effective after questioning pupils and ensure that each pupil develops their understanding and ideas.

82 Many teachers in key stage 4, plan well for the development of pupils' scientific knowledge and understanding. They provide a wide range of interesting and purposeful activities. These activities make the learning fun and interesting. For example, 'give us a clue', 'market place' (see case study on page 10), 'hot seating' and quizzes are methods that help engage every pupil in the class and provide them with useful strategies to remember facts and gain deeper knowledge.

83 In a minority of lessons, teaching does not deepen scientific knowledge and understanding. The tasks and activities are superficial and teachers do not explain ideas and concepts clearly. When activities are not planned skilfully enough, they do not develop pupils' scientific knowledge and understanding and concentrate too much on developing communication skills only.

84 Around a half of teachers in key stage 3 and a minority of teachers in key stage 4 do not plan well enough to meet the needs of all pupils. Very few teachers plan well enough to cater for less able pupils or to stretch the more able. Even when teachers have planned to meet the needs of pupils of different abilities, the plans are not always delivered effectively enough. An example of this includes teachers providing answers for pupils without allowing them enough time to think or to work things out for themselves. Another strategy for meeting the needs of pupils is to provide tasks with different levels of challenge. This can be appropriate if the teacher ensures that specific pupils receive the tasks relevant to them. Where pupils are free to choose their own level of challenge, this strategy is largely unsuccessful as pupils often opt for the easier tasks.

85 Expectations are often too low in key stage 3, where only a very few teachers plan well enough to ensure that more able pupils gain level 8 or exceptional performance. Most teachers tend to focus on the same type of activities for all. Much of the time is spent on low level, simple tasks, for example solving anagrams, irrelevant numeracy tasks, cutting and pasting, sticking and copying. In a few lessons, learning objectives are not useful. Often this is because they refer simply to activities to be carried out rather that defining precisely the subject knowledge or skills to be developed. These include examples such as 'to carry out a card sorting activity' or 'to burn food'.

86 A majority of teachers are adept at developing pupils as independent and flexible learners. A few teachers have developed useful strategies that allow pupils to work from home, in their own time, through using interactive software that allows for instant assessment and feedback.

Bryngwyn Comprehensive School, Carmarthenshire

A key stage 4 lesson on the Haber process for producing ammonia

The teacher offered pupils a stimulating challenge that involved complex reasoning around a counterintuitive result. The lesson was planned in a sophisticated manner, offering pupils snippets of relevant information to inform discussions around the initial challenge.

The teacher opened the lesson by questioning pupils thoroughly on their understanding of rates of reactions and the characteristics of reversible reactions. She then gave pupils a laminated sheet with three unlabelled axes. She then presented them with two statements:

- The percentage yield of ammonia increases when the pressure is increased
- When temperature increases, the percentage yield of ammonia decreases

She then gave pupils the task of labelling the axes and drawing two curves for the reaction at high and low temperatures. This stimulated a great deal of debate among the pupils. The teacher constantly walked around the class, listening to pupils' debate and challenging their thinking.

The teacher conducted a whole-class debate on the impact of pressure and temperature, getting them to apply their knowledge and understanding of reversible reactions.

She then set them the task of explaining in writing what happens in the Haber process. Key words were shared with pupils to support this activity.

Ysgol John Bright, Llandudno: Developing independent learning

Information about the school

Ysgol John Bright is an 11-18 mixed comprehensive school with around 1,250 pupils, with about 220 of these in the sixth form. Pupils are drawn from the town of Llandudno as well as from other areas within a 15 mile radius. Around 15% of pupils are eligible for free school meals. The proportion of pupils with special educational needs is around 20%, with just over 1% of pupils having a statement of special educational needs.

Context and background to the practice

Developing independent learning has been a key focus for the school, to enable pupils to take responsibility for their own learning, particularly outside the school environment.

Description of activity/strategy

In September 2016, Ysgol John Bright adopted a suite of computer hardware and software applications that provide pupils and staff with a new and flexible way of teaching and learning. The science department is pioneering its use in the school.

Pupils do not need to take their class books home with them to complete homework and this has led to a significant improvement in pupils not losing books. The department has developed electronic homework tasks that include links to internet resources. The tracking of homework is automatic, leading to improved communication between home and school as parents are able to see what homework has been set and can also request to see their own child's records.

The software allows pupils to work collaboratively without having to be in the same physical space. This can happen simultaneously, allowing for the free flow of ideas between pupils as they work together on their homework tasks. This strategy has proven particularly useful when students are working on presentations and scientific reports. The software also gives the opportunity for pupils to resubmit work and track modifications, and for pupils to redraft with ease.

Impact on provision and standards

There is clear evidence that more homework is being completed than previously recorded and the turn-around time for feedback has significantly decreased. As a result, pupils have shown much greater engagement with their learning in science.

Specific feedback and follow-up dialogue with pupils have proven especially useful in the run-up to examinations. Reducing learning-associated stress for students in this way has helped to improve both behaviour and engagement in lessons in school.

87 In a minority of cases, the teaching is too dependent on worksheets and booklets. These are too formulaic and restrict pupils' independent thinking. In these instances, there is not enough scope for the development of pupils' thinking skills or extended writing, or for work to be varied within the class or group.

88 Teachers provide many opportunities for pupils to develop their literacy and numeracy skills. Well-planned literacy tasks give pupils the opportunity to use their skills in a different context and enhance their subject vocabulary, for example in responding to longer examination questions on respiration in key stage 4 or researching into climate change in key stage 3. Numeracy tasks are generally appropriate and correspond to the expectations for the science and mathematics curriculum. In key stage 4, nearly all the numeracy tasks provide the appropriate challenge and complexity specified for examination courses. However, very few science departments plan to develop pupils' numeracy skills beyond those required for the qualification. In key stage 3, most tasks are planned in accordance with the numeracy expectations within the national literacy and numeracy framework.

89 Many teachers make good use of ICT to enhance their teaching. Almost all have access to an interactive white board and projector. They produce high-quality presentations, and use video and images to stimulate discussions and for exemplification. The most successful use of ICT is seen when the pupils interact with the resources, for example in using software to change variables and modelling the impact.

90 A very few teachers use data loggers to gather information and display the output in other software applications for analysis or to gather data that would otherwise be difficult or take too much time to collect and show the results directly in graphs and tables.

91 Although many teachers use ICT well to enhance the learning experiences, they do not plan well enough to develop pupils' ICT skills in science lessons. In general, pupils use ICT for a few research tasks, basic word processing and power point presentations. Data loggers and sensors are rarely used by pupils, and data processing and graph work are on the whole done by hand.

92 In a majority of lessons, teachers provide well-planned practical opportunities. Pupils are given worthwhile opportunities to plan and carry out investigative work. The investigations are placed in a familiar context that appeals to pupils and is relevant to them, for example investigating the shapes of fishing weights, 'magic tricks' and fairground forces. Pupils gain the most out of the investigations:

- when they fully understand the science principles under consideration beforehand and can therefore make sensible predictions
- when the teacher makes efficient use of pupils' time by asking different groups to use different values of the variables under consideration
- when practical activities do not take up too much time
- when pupils have sufficient opportunities to evaluate their findings

Assessment

93 In key stage 3, when marking pupils' work, many science teachers focus on specific tasks used to assess against national curriculum level descriptors. The majority of these are accurate and are well supported by evidence in books and portfolios. A minority of teachers provide useful subject specific comments and, in a few cases, pupils respond positively to these, improving their work as a result. However, the quality of feedback by teachers varies too much. A majority of teachers provide very superficial feedback that does not help pupils to understand how to improve their scientific skills and knowledge.

94 A minority of assessments by teachers in key stage 3 do not correspond to the correct level. In general, teacher assessment is too generous, which could lead to setting incorrect targets and misinforming parents. However, there is a lack of clarity in level descriptions for science at the end of key stage 3. They do not focus well enough on science knowledge and understanding. A majority of teachers provide feedback to pupils on spelling and grammar that follows school policy. This feedback is often given instead of an assessment of scientific skills, knowledge and understanding.

95 In key stage 4, many teachers mark work comprehensively but concentrate more on tests and past paper examination questions using criteria set by examination boards. In many cases, teachers offer diagnostic feedback that helps pupils understand how to demonstrate their skills, knowledge and understanding in external examinations. In a few schools, pupils use a separate book for assessment tasks and respond well to feedback on their work. This helps teachers to track pupils' progress effectively so that they can support pupils on specific aspects of their work, for example to plan and provide further questions and activities to develop their understanding of a scientific concept.

96 Many schools use assessment information from tests and examinations well to gain a clear view of the strengths and weaknesses of individual pupils. A few schools use this information exceptionally well and plan work for individuals based on their analysis. This has led to improved and sustained outcomes at the end of key stage 4.

Whitchurch High School, Cardiff: Using assessment objectives to improve learning experiences for pupils

Information about the school

Whitchurch High School is a large comprehensive secondary school in the suburb of Whitchurch, North Cardiff. Currently Year 11 pupils are able to study from a variety of level 2 courses. These include BTEC (applications and principles of science), GCSE science A, GCSE additional and GCSE separate sciences. Year 10 pupils can opt for either GCSE double award or triple award science. In Year 10 there are five groups studying separate sciences and 12 groups studying double award science.

Context and background to the practice

GCSE science specifications published by WJEC/CBAC have different

assessment objectives (AO) criteria. In order to prepare pupils for their GCSE science examinations, the school carefully maps the distribution of AOs and openly shares them with pupils. End of topic assessments, with their mark schemes, have been constructed to reflect the different assessment objectives covered.

Description of activity/strategy

New schemes of work have been developed to give as many opportunities to pupils, during the course, to visit the AOs. The type of questioning in class has changed significantly. As a result, teachers frequently provide opportunities for pupils to apply their scientific knowledge, to evaluate, to conclude and to interpret in science lessons at each key stage.

Impact on provision and standards

Although the work carried out is in its early stages, there have been positive outcomes. Science staff have become more aware of the different AOs, and adapted their teaching strategies to suit the needs of the learners. As a result, pupils' learning experience at GCSE has improved. Their preparation for GCSE science examination papers is in line with the published AOs, which raises pupil confidence and their examination results. The strategy has improved the quality of assessment data and final predicted outcomes.

97 In many lessons, teachers question pupils well, allowing enough time for responses and encouraging more expansive answers. Where expectations are very high, teachers' questions are more challenging and deepen pupils' understanding and knowledge. For example, in a Year 7 lesson, when discussing differentiation of cells, the teacher is determined to receive a detailed response and explanation that includes reference to the cell components, how they are different to other cells, and how they support the specific function of the cell.

98 In many lessons, teachers regularly check progress and verbally provide sound advice about how pupils can improve. This is done well during lessons and not kept until the end of the lesson. Several successful techniques have been observed during this survey, including whole-class feedback, pupils writing answers on white boards, and interactive quizzes with instant feedback. The most successful teachers adapt their teaching expertly during the lesson in response to this continuous assessment.

99 A few teachers allow pupils to assess their own work and the work of others using criteria that are suitable for use by pupils and help them improve their work. They can be useful, especially if they do not take up too much time and include purposeful activities such as pupils reading their work aloud to each other.

100 In many cases, when pupils assess their own work and the work of others they do not use criteria that are suitable to help them improve the work. More often the purpose or relevance of this type of assessment is unclear.

Successful Futures – A Curriculum for Wales

101 While most schools are aware of recent curriculum developments arising from the 'Successful Futures' report (Donaldson, 2015), very few have responded to the report's recommendations or considered the possible benefit of closer links between science and technology departments. This is mainly because science departments are prioritising their efforts on developments in examinations at key stage 4 and post-16 changes and think they should wait for guidance on the new curriculum. A few schools have recently adapted the curriculum for Year 7 to be a more thematic approach to teaching science. Schools who have pioneer status have considered how they meet the four purposes and a few have adapted their schemes of work (see following case study).

Adaptations to curriculum planning and learning experiences

A minority of schools visited for this report have reconsidered carefully the content and purpose of their science schemes of work, in particular at key stage 3. They made some adaptations that give clearer guidance to teachers and enhance the learning experience for pupils, including:

- arranging enrichment opportunities to widen the scope of the curriculum, for example visits to local sites of environmental interest, links with science based industries and regular science clubs
- matching the key content from the new GCSE science syllabus with the knowledge included in the national curriculum for key stage 3; this avoids too much repetition when pupils are prepared for GCSE and raises expectations at key stage 3
- providing pupils with access to online resources that cover all curriculum content at key stage 3; an increased level of challenge is incorporated within the scheme of work, which provides support and prepares pupils well for the increased levels of demand in science at key stage 4
- purposeful planning to provide dedicated time for pupils to improve their work and respond to teachers' comments
- mapping different skills across the curriculum, identifying useful opportunities to develop literacy, numeracy and ICT; this is followed by careful planning of written, spoken and practical tasks with clear purpose and progression

A few schools deliver a skills-based curriculum for Year 7 pupils. They work on projects that have a common theme with other subjects and contribute well to developing many aspects of literacy such as extended writing and reading for research. A few schools combine science and technology into one area of learning experience that involves co-ordinating schemes of work and teaching.

Leadership and management

Leadership – structure and organisation

102 Senior leaders, in general, have a broad vision for the school curriculum and what they want to achieve for their pupils. In science departments, leaders are less clear about the aims of the science curriculum. The recent changes to qualifications may have contributed to this lack of clarity. Many leaders and science teachers are of the opinion that the status of science in the curriculum was diminished when it was omitted from the main performance indicator in 2006-2007.

103 There are various models of leadership for science within schools. The most common model consists of a head of department or faculty, with a head of biology, head of chemistry and head of physics in addition. It is usual, but not always explicit, that the head of science is also head of one of separate sciences. In larger schools, an additional post of a key stage 3 or key stage 4 co-ordinator is common. In smaller schools, the structure can consist of a single head of department with no other teaching and learning responsibilities for science within the department.

104 Lines of accountability are clear in nearly all schools, with a senior leader denoted as link and line manager to the science department. There are regular meetings with fixed agendas that include items such as standards, evaluation of teaching and progress against an improvement plan.

105 Science departments have not been held to account effectively by school leaders during the past four years, including some that may have been judged too harshly. This is because leaders are over-reliant on data for evaluation, although there are challenges to using benchmarking data to evaluate a science department's relative success. The All-Wales Core Data Sets include information about pupils' performance in science at level 1 and level 2. The data sets do not identify the differences in performance between different courses, such as the separate sciences, additional science or BTEC applied science. Instead, outcomes from all of these courses are combined to provide a single figure. In the near future, these problems may decrease as a result of the changes to key stage 4 school performance reporting measures (Changes to Key Stage 4 school performance measures 2016-2018, Welsh Government). This should increase the effectiveness of the scrutiny that science performance data will receive from leaders in schools.

106 Nearly all performance management procedures follow whole-school policy with worthwhile opportunities to set subject-specific targets linked to standards. In most schools, performance management of members of the science department is usually delegated to the head of science. In larger departments, this is often further delegated to the heads of the separate sciences. In general, leaders use information gathered from lesson observations well to hold science teachers to account. However, many schools do not use more specific data such as value added and performance in different courses to hold science staff to account well enough. In addition, weakness in the quality of lesson observations and scrutiny of work means that leaders often fail to identify specific weaknesses in teaching.

107 A few senior leaders have been slow to realise the increased importance of science in forthcoming performance measures. A minority of schools include heads of science in meetings with other core subject leaders. In general, the focus of these meetings is on pupils gaining the level 2 threshold including English or Welsh and mathematics. The perceived importance of science has diminished because many schools take for granted that pupils will achieve a level 2 qualification in science, especially when they offered BTEC, and it is not seen as a limiting factor to gaining performance measures at the end of key stage 4.

108 The range of responsibilities that heads of science hold is normally broader than for heads of other core subjects. All middle leaders will have responsibilities for staff management, tracking pupils' progress, monitoring of performance, self-evaluation and improvement planning. A head of science will normally have additional responsibilities that include:

- health and safety
- three subject areas
- several examination courses
- greater resource management with more staff, including laboratory technicians
- more equipment, rooms and laboratories

109 These are substantial and important responsibilities that require significant investment of time and specific management skills. However, very few heads of department are given additional time or support to carry out these tasks effectively.

110 A few schools plan well for succession in leadership within the science department. These schools identify potential in their staff, develop them to be role models for other teachers, and provide them with a specific support and training programme to develop their leadership skills. This approach has contributed towards overcoming difficulties in recruiting leaders within these schools.

Self-evaluation and improvement planning

111 In general, departmental self-evaluations are informed by a suitable range of data, including the All Wales Core Data Sets, examination board information and internal data. Generally, leaders suitably consider and evaluate performance against that of similar schools, although simple comparisons with similar schools have not always been useful for the reasons set out in paragraph 105. The majority of self-evaluation reports include additional useful analysis of within-school data, comparing groups of pupils, and performance of different classes and sets. Many departmental self-evaluation reports include details about separate courses and performance at the higher grades or levels. However, only a very few departmental evaluations consider progress against previous attainment or value-added data.

112 In many schools, lesson observations focus mainly on the quality of teaching, but they do not evaluate standards or the progress that pupils make in science sufficiently. As a result, schools are unable to identify areas of weakness or plan for improvement well enough. In a minority of schools, the information gained from lesson observations is not used well enough in their self-evaluation of standards or teaching.

113 Nearly all departments monitor the work of pupils regularly as part of an evaluation or improvement calendar. In general, the reports on pupils' work tend to focus on whole-school initiatives such as compliance with the school's marking policy, literacy and numeracy. Only a few focus well enough on the quality of the science in pupils' work.

114 In most schools, the department improvement plan is linked suitably to the self-evaluation report. The most common priorities found in improvement plans are improving standards at key stage 3 and key stage 4, improving the quality of teaching, and responding to changes in qualifications. In a few departments, the improvement plans list too many administrative tasks for the year and lack detailed quantifiable targets. The success criteria for these actions are mainly completion of a task, which are not necessarily measures of improvement.

115 A minority of schools visited had taken part in the latest round of PISA tests. These schools have received a full evaluation of their performance in the tests. However, the use of this information by the schools varies too much. Only a few schools have analysed the report in detail to identify any weaknesses in their results and plan to address them. A few departments were unaware of the existence of a school-specific report on PISA outcomes at the time of the visit. Of the schools not part of the PISA tests in 2015, very few had considered the content of the report for Wales and how it could impact their work.

Professional development

116 The majority of science staff develop their general teaching skills well and keep up to date with developments in their subject. However, in general across Wales, there is not enough subject-specific support and training in science.

117 Most science teachers benefit from sound internal support from leaders and colleagues. Nearly all science teachers benefit from whole-school opportunities for professional development. They are given development opportunities such as the outstanding teacher programme, developing leaders programme, internal professional learning communities and specific support for performance management targets. They also participate in useful cross-curricular developments, for example teaming up with other departments to develop pedagogy.

118 Senior leaders and heads of science provide a suitable programme of induction for teachers new to the school with regular support sessions. Other science staff provide valuable informal support, such as demonstrating practical work, sharing resources and observing the teaching.

119 Professional associations such as the Association for Science Education and the Institute of Physics offer very valuable opportunities for teachers to develop professionally. For example, science teachers have benefited from visits to science education conferences and to renowned international institutions.

120 Nearly all heads of department attend examination board courses and schools prioritise attendance at these events as they are viewed as being essential to maintain standards at end of key stage 4.

ERW regional consortium – science-specific support

The consortium has been proactive in providing science departments with useful targeted support. For example, science subject officers have:

- set up heads of science meetings in all of their six local authorities
- given useful presentations to science teachers on changes to GCSEs and performance measures and on the implications of these
- close contact with departments, especially those in schools that require improvement; much of the time is used for discussing and giving advice on the new suite of qualifications at key stage 4
- invited identified teachers to a day of discussion around science teaching in several localities; the turnout was high and feedback from delegates very positive
- supported specific schools to improve aspects of their teaching, such as conducting science investigations
- organised a course on PISA and encouraged science departments to embed PISA-style questions into key stage 3 schemes of work

121 Most heads of science benefit from network meetings with other heads of science that are facilitated by the regional consortia. Regional consortia subject officers offer sound support to departments in need of improvement. In general, there is a lack of subject-specific support through regional consortia for science teachers in departments that are not underperforming.

122 Most science support staff receive appropriate training on health and safety issues from external providers. There is very little training or support for developing existing or new technicians.

Resources

123 Most science departments are well equipped. They receive appropriate funding on an annual basis, which is mostly spent on consumables that support teaching and learning. Most departments can submit extra bids, for example to purchase additional ICT equipment or resources for laboratories. However, where schools expect departments to bid for finance for the year, heads of science may not know the full requirements of a new curriculum or qualifications at the time of bidding. As a result, departments can end up with insufficient funds.

124 Most lessons are taught by specialist science teachers and there is generally an appropriate number of technicians to support teaching. Most schools have a suitable number of laboratories and a majority of departments have a programme of refurbishment or are new builds.

125 In general, most schools provide enough ICT facilities for use by science departments. However, there are often restrictions on booking and timetabling these facilities. Many departments own sets of laptops or tablets for use in the classroom. Nearly all rooms have an interactive whiteboard and projector. Only a very few teachers provide useful opportunities for pupils to use these and develop their ICT skills in lessons.

Recruitment

126 Generally, there are not enough applicants for science teaching posts across Wales. This is especially the case in the rural and western part of Wales. Even where schools are more successful in recruiting staff, the number of high-quality applicants is low. There are fewer applicants for physics posts than for biology or chemistry. Recruiting to Welsh-medium science departments is particularly challenging. There are very few suitable applicants for advertised posts and schools in more remote parts of Wales experience the greatest difficulty in recruiting and retaining staff.

127 Departments are employing non-specialists and rearranging the timetable to prioritise for a specialist teacher to teach key stage 4 groups when they experience difficulty in recruiting. As a consequence, in a majority of schools, key stage 3 classes have been taught by either a non-specialist teacher or a cover supervisor.

128 A minority of departments visited in this survey have experienced difficulties with long-term absenteeism of staff. Supply teachers for science who can teach through the medium of Welsh, especially in rural parts of the country, are in very short supply. As a consequence, schools will often employ a non-specialist supply teacher to cover science lessons. Pupils consulted during this survey expressed their concern that supply teachers are unable to help them with their work, carry out practical work or assess their work meaningfully. This impacted on their progression and enjoyment of the lessons.

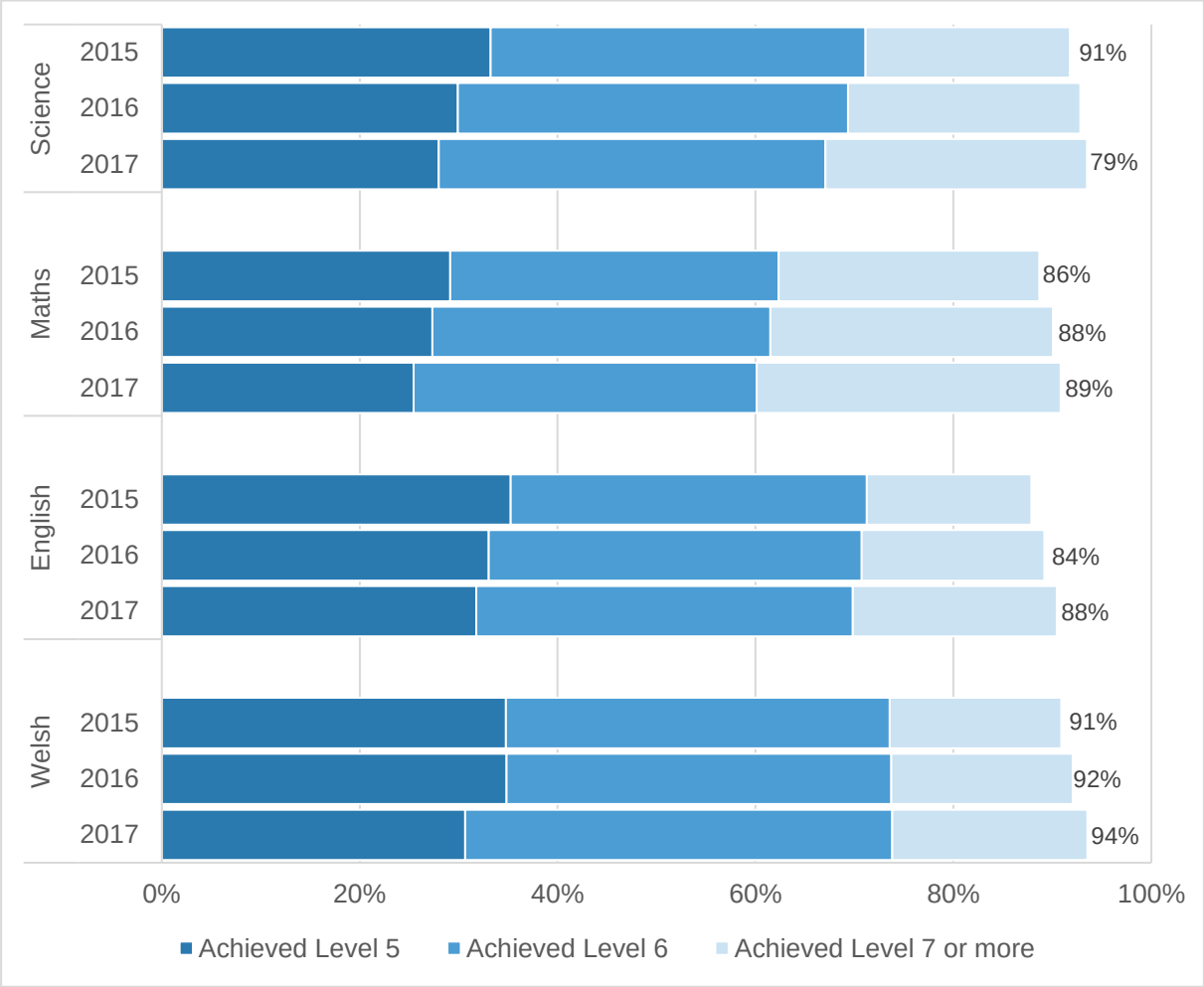
129 Schools also have difficulty recruiting technicians. Since there is very little training for technicians, schools have to adapt to ensure progression and continuity of support. A very few schools have responded creatively to this problem, for example through employing and training an apprentice alongside the technician who is due to retire.

130 There is a shortfall in the number of post-graduate science teachers being trained. In 2016-2017, of the targeted 142 places in science, only 86 trainees were recruited (35 biology, 31 chemistry and 20 physics: Higher Education Funding Council for Wales, 2017). A few trainees have a first class degree and a minority have the opportunity to train through the medium of Welsh. This is in contrast to England, where the number of physics trainees is proportionately higher at 851 in 2016-2017. This is 81% of targeted places, compared to 65% of targeted places in Wales. (Department for Education & National College for Teaching and Leadership, 2016.)

Appendix 1: Teacher assessment at key stage 3

131 Since 2012, 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 same period, performance in science has been above that of mathematics and English but similar to that of Welsh first language (Welsh Government, 2017a). This is illustrated in figure 9 below.

Figure 9: Percentages of pupils achieving the expected level (level 5) and above in teacher assessment at the end of key stage 3 (2015-2017)



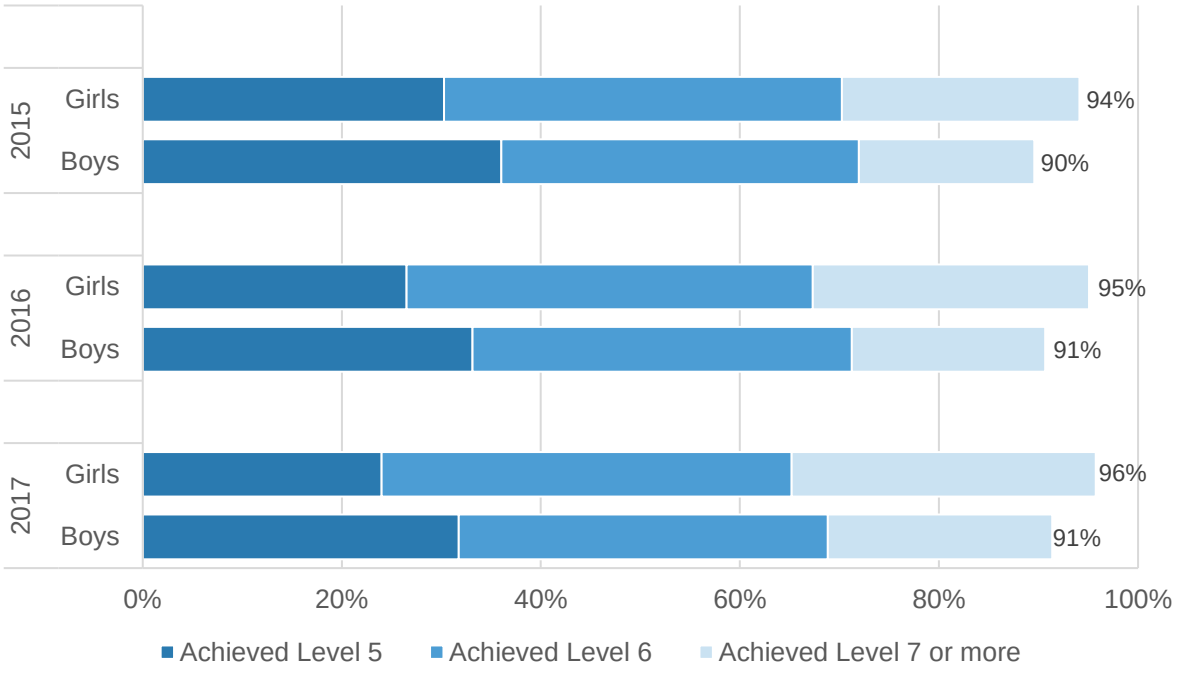
Source: Welsh Government (2017a)

132 Over the last five years, the proportion of pupils gaining level 6 and above in science has also increased year-on-year. The proportion of pupils attaining level 6 and above was higher than that for mathematics in 2016 for the first time in five years and continues to be slightly higher in 2017. Science performance at level 6 or above has been higher than for English and Welsh first language for the last five years (Welsh Government, 2017a).

133 Performance in science at level 7 and above has also improved year-on-year since 2012. This trend is similar to that in mathematics. Science performs worse than mathematics at level 7 or above, but better than English and Welsh first language. The proportion of pupils gaining a level 8 or above in 2017 is 1.5%. Performance has been at a similar level for the past three years. This level is similar to English and Welsh but represents less than half the proportion that gain a level 8 or above in mathematics. The proportion of pupils assessed as exceptional for performance in science has been extremely low at around 0.1% for the last three years (Welsh Government, 2017a).

134 The performance of boys has been lower than that of girls at level 5 or above, level 6 or above and level 7 or above in science each year since 2012 (figure 10 below). In our report on science in key stage 2 and key stage 3, a similar pattern was identified for the five years prior to 2012 (Estyn, 2013). This pattern raises questions about the reliability of assessments and whether teachers' expectations of boys are high enough. In addition, the level descriptors at the end of key stage 3 are based on pupils' skills and do not necessarily provide an useful measure of the body of scientific knowledge and understanding expected of pupils prior to transition into GCSE.

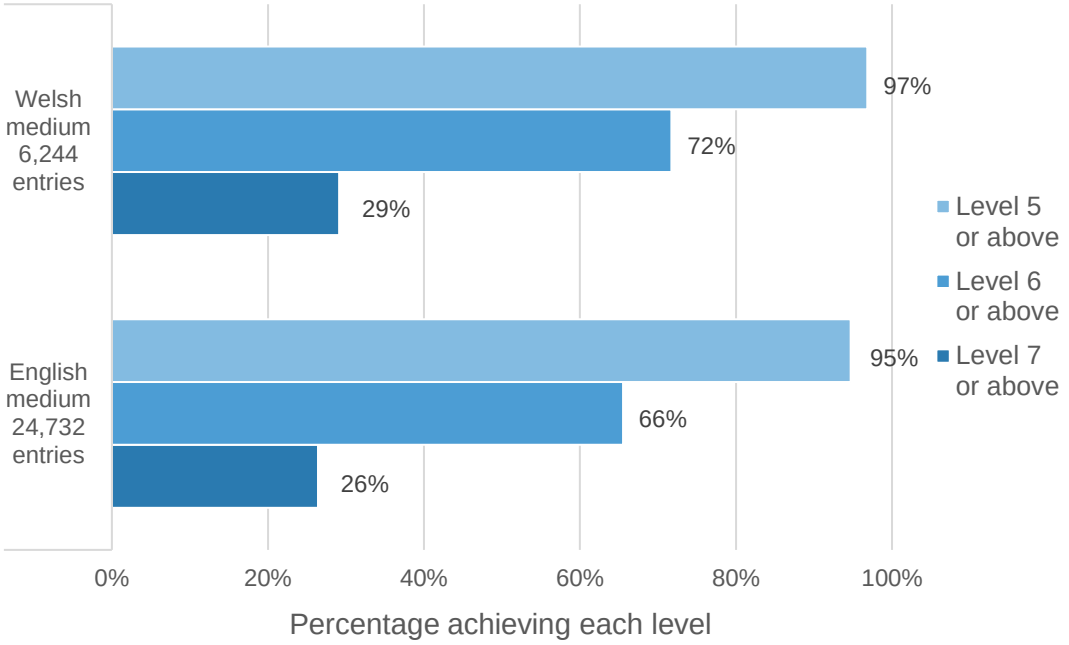
Figure 10: Percentage of pupils achieving different levels in science teacher assessments by gender, Wales, 2015 to 2017



Source: Welsh Government (2017a)

135 Performance at level 5 or above, level 6 or above and level 7 or above in science has been better in Welsh-medium schools than in English-medium schools since 2012 (Welsh Government, 2017b & 2017c). Figure 11 shows that the performance in Welsh medium schools continues to be above that in English medium schools in 2017.

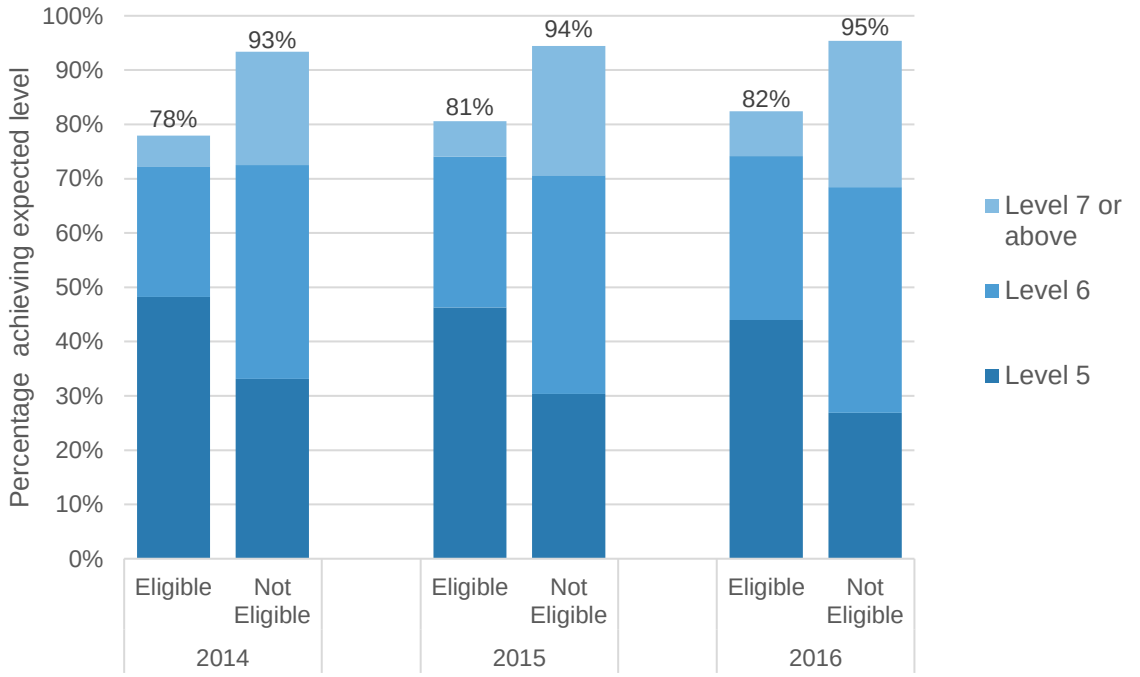
Figure 11: Percentage of pupils achieving different levels in science teacher assessments by school medium, Wales, 2017



Source: Welsh Government (2017b)

136 Since 2012, performance of pupils eligible for free school meals has improved year-on-year at level 5 or above, level 6 or above and level 7 or above (see figure 12 below). Despite this improvement, their performance remains lower than that for other pupils. The difference in performance at level 5 or above has closed gradually over the four years. The difference in performance at level 6 or above has remained at a similar level. At level 7 or above the difference between the attainment of pupils eligible for free school meals and those who are not has widened. This suggests that more able pupils eligible for free school meals do not do as well in science as their peers (Welsh Government, 2016b & 2016c).

Figure 12: Percentage of pupils achieving each the expected level (5 or more) in science teacher assessments by free school meal eligibility, Wales, 2014 to 2016



Source: Welsh Government (2016b & 2016c)

Appendix 2: Questions for schools to consider as part of their self-evaluation

As a starting point for reviewing current practice in science, schools can use the following questions as part of their self-evaluation:

Standards

1 Do leaders and teachers know the standards that pupils are achieving in science at all stages across the school?
2 Have we analysed the performance of different groups of learners carefully and over time? What messages does this analysis give and are we acting on findings robustly?
3 Do we have high expectations of all learners, including the more able?
4 Do we have an understanding of what pupils enjoy or dislike about science lessons? Are pupils involved in what and how they learn?

Provision

5 Do we ensure that all teachers are planning learning in science lessons that challenges all pupils at an appropriate level, and particularly the more able?
6 Do we have detailed plans to develop pupils' subject knowledge, understanding and skills in science?
7 Do we ensure continuity and progression from one key stage to the next and ensure that there is no repetition?
8 Do science teachers provide useful opportunities for pupils to develop their literacy, numeracy, ICT and thinking skills?
9 Is there an opportunity for teachers to be innovative in their planning? For example:
   - Do teachers relate pupils' working to a local context whenever possible, including environmental issues?
   - Are the topics taught relevant and current?
   - Do teachers respond to current national and international developments, including developments in medicine, uses of nanotechnology or advances in gene technology?
   - Do teachers use technology creatively to support the learning such as modelling through virtual reality?
10 Does our science curriculum offer engaging and relevant enrichment experiences in the classroom, local community and further afield? For example:
   - Links with local businesses, societies, exhibitions and museums?
   - Visits to and from universities and research institutions?
   - Presentations from pioneering scientists or science related project workers?

Leadership

11 Do we have a clearly understood rationale for the way we plan and deliver our science and technology curriculum?

12 Do we use a wide range of information, including all available data, lesson observations and scrutiny of pupils' work to evaluate standards comprehensively? Is the information specific to science?
13 Are we aware of the quality of teaching in science and do we provide suitable professional learning opportunities and support for staff?
14 Do we use our pupil deprivation grant effectively to reduce gaps in performance and ensure equality of access for disadvantaged learners?

Appendix 3: Evidence base

The findings and recommendations in this report draw on:

- data from teacher assessments at the end of key stage 3 and examination outcomes at the end of key stage 4
- visits to 20 providers, including secondary and all age schools

Schools have been selected following an analysis of data, consideration of inspection findings and feedback from HMI. The majority of the schools visited have been judged good or excellent for standards in core inspections since 2010. Otherwise, the sample is as diverse as possible, based on a proportionate number of English-medium and Welsh-medium schools, geographical location and socio economic factors. The sample also includes a small number of curriculum pioneer schools.

The visits included:

- interviews with senior leaders, subject leaders and pupils
- two lesson observations to evaluate standards and quality of teaching in both key stages
- interviews with pupils to include scrutiny of their science work and to gather their views on the provision and options available at the school
- scrutiny of school documents prior to visit, including the most recent school and science department self-evaluation reports and improvement plans

Each science subject officer from a regional consortium was interviewed individually.

Data for recruitment of science teachers and from initial teacher education and training establishments was also considered.

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Ysgol John Bright, Conwy
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Ysgol Gyfun Cymer Rhondda, Rhondda Cynon Taff
Ysgol Gyfun Llanhari, Rhondda Cynon Taff
Ysgol Gyfun Bryn Tawe, Swansea
Mary Immaculate High School, Cardiff
Whitchurch High School, Cardiff
Cefn Hengoed Community School, Swansea
Alun School Mold, Flintshire
Eirias High School, Conwy
Llanidloes High School, Powys
Bryntirion Comprehensive School, Bridgend
St Joseph's RC High School, Newport
Ysgol Uwchradd Aberteifi, Ceredigion

Bryngwyn Comprehensive School, Carmarthenshire
Ysgol Gyfun y Strade, Carmarthenshire
Radyr Comprehensive School, Cardiff
Cardinal Newman RC Comprehensive School, Rhondda Cynon Taff
Bishopston Comprehensive School, Swansea

Glossary

BTEC	Business and Technology Education Council
Early entry	Pupils entered for GCSE examinations before the end of Year 11
Level 1 qualification	Grades A*-G at GCSE or equivalent
Level 2 qualification	Grades A*-C at GCSE or equivalent
OECD	Organisation for Economic Co-operation and Development
PISA	Programme for international student assessment
Statistically significant	One way to account for the fact PISA is based upon a sample is to report whether differences between countries are 'statistically significant'. A 'significant' difference between countries is reported when it is almost certain that this is not the result of a sampling error. (PISA 2015)
STEM	Science, technology, engineering and mathematics
Techniquest	A Welsh science and discovery centre. It has locations in Cardiff Bay and Glyndŵr University in Wrexham.

Numbers – quantities and proportions

nearly all =	with very few exceptions
most =	90% or more
many =	70% or more
a majority =	over 60%
half =	50%
around half =	close to 50%
a minority =	below 40%
few =	below 20%
very few =	less than 10%

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