Developing higher-order scientific enquiry skills

Llywodraeth Cynulliad Cymru
Welsh Assembly Government

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Young Wales

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Developing higher-order scientific enquiry skills

Audience

Secondary school science teachers and senior managers; local authorities; national bodies with an interest in education.

Overview

This document is designed to assist teachers to recognise and promote higher-order scientific enquiry skills within Key Stage 3 and through to Key Stage 4. It provides examples of learners' work showing characteristics of Level 7 to Exceptional Performance (EP) within the national curriculum for science. Learners' work is accompanied by commentary that identifies the characteristics of higher-order scientific enquiry skills.

The resources are based on best practice in science departments across Wales. They will support learning, teaching and the assessment of science enquiry.

Action required

Schools' senior managers and subject leaders, and local authority advisers, are requested to raise awareness of this new resource within their science departments, and to encourage teachers to use the materials to support their focus on securing and improving learners' enquiry skills.

Further information

Enquiries about this guidance should be directed to:
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Or by visiting the Welsh Assembly Government's website
www.wales.gov.uk/educationandskills

Related documents

Science in the National Curriculum for Wales; Making the most of learning: Implementing the revised curriculum (Welsh Assembly Government, 2008); *Science: Guidance for Key Stages 2 and 3* (Welsh Assembly Government, 2009)

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Foreword

Good enquiry skills are key for all learners. Those learners who analyse and probe deeply into the meaning of information or data, presented through a variety of media, can engage more effectively with the subject content and gain great satisfaction from their work and achievement.

This applies in all subjects, but none more so than in science. Estyn's inspection evidence indicates that too few Welsh pupils are achieving the highest standards. Results of national and international assessments – GCSE and PISA in particular – identify scope for more able learners in Wales to have stronger scientific enquiry skills.

This guidance is intended to support science teachers working with able learners in Key Stage 3, to help them achieve better results at the end of Year 9 and at GCSE and beyond.

The materials have been developed in collaboration with subject specialists in schools and local authorities. Feedback from science teachers and local authority advisers confirms that this focused guidance is both timely and appropriate. I am delighted to commend this booklet to all schools and local authorities and to confirm our support for higher-order skills as part of the wider focus on effective schools.

David Hawker
Director General,
Department for Children, Education, Lifelong Learning and Skills

Introduction

Why has this guidance been produced?

The Welsh Assembly Government (WAG) is committed to supporting schools to raise standards of learners' enquiry skills. This new guidance focuses on raising the standard of scientific enquiry for all learners during Key Stage 3, and into Key Stage 4. In particular, it supports science teachers to meet the needs of their most able learners.

Estyn's annual report 2007–08 drew attention to underachievement where the most able learners do not reach their full potential. Teachers tend to praise learners who produce work at high levels (for example, work that shows characteristics of Level 7) with comments such as 'Excellent work' or 'Very mature work' but do not necessarily identify areas for refinement or suggest the best ways to improve further. However, these learners are most likely to be able to respond to diagnostic comments and implement them.

The examples of work in this guidance aim to exemplify what Key Stage 3 learners, working at the highest levels, can achieve. The examples provide commentaries that will help teachers to identify characteristics of Levels 7, 8 and Exceptional Performance. They are intended to provide a stimulus for both learning and teaching, and to encourage effective day-to-day formative assessment. The guidance also considers transition to post-14 work, to demonstrate how high expectations and achievements can be carried through to improve learners' performance within Key Stage 4.

The Department for Children, Education, Lifelong Learning and Skills (DCELLS) curriculum guidance, *Science: Guidance for Key Stages 2 and 3* (Welsh Assembly Government, 2009) provides key messages for planning learning and teaching in science to support Curriculum 2008. It includes learner profiles exemplifying how to use level descriptions to make best-fit judgements at the end of Key Stages 2 and 3.

Many of the key messages from the curriculum guidance are further developed in this higher-order scientific enquiry booklet, and are therefore relevant to **all** learners. However, there are obvious differences in that this new guidance provides commentaries on recognising characteristics of level descriptions in individual examples of learners' work rather than focusing on end of key stage judgements.

Using this guidance

The guidance is divided into three sections.

Section 1	reviews the characteristics of higher-order scientific enquiry skills.
Section 2	describes the features of enquiries, which could be set to give learners opportunities to demonstrate higher-order skills.
Section 3	contains examples of learners' work exemplifying higher-order level characteristics. The contexts and skills used by learners are then linked with possibilities for further development in Key Stage 4.

This guidance is for science teachers to:

- extend understanding of the science Order 2008
- review learning plans and activities
- consider the characteristics of level descriptions set out in the science Order 2008
- work with other teachers to reach a shared understanding of the level descriptions
- develop departmental portfolios to exemplify characteristics of level descriptions.

This guidance is part of a range of DCELLS materials that will help teachers to implement the curriculum and its associated assessment arrangements. This includes materials focused on science and also on the wider aspects of effective learning and development of skills. Section 4 provides a list of useful references for science teachers.

Section 1

What characterises higher-order scientific enquiry skills?

What characterises higher-order scientific enquiry skills?

Learners take responsibility for their own learning and, where appropriate, demonstrate a range of the following:

Plan

- recognise that science is based on evidenced theories rather than facts
- justify the methods and strategies that are going to be used in the enquiry
- use concepts such as reliability, accuracy of measuring, validity of data/information when justifying a planned method
- make multiple links between what is already known and/or independent research in order to plan
- take account of any possible problems with their plan in order to refine it
- justify their predictions, which can be quantitative, by using abstract scientific ideas, including linking models, theories and systems
- determine success criteria in complex, abstract tasks

Develop

- communicate effectively, choosing an appropriate medium, selecting only relevant points of interest and taking full account of the audience
- measure systematically with accuracy
- justify any amendments they make to their methodology
- understand the purposes of, and utilise, a wide range of learning/thinking strategies
- use calculations to demonstrate or explore findings[1], and in doing so confidently and accurately rearrange equations
- analyse and evaluate findings, looking to see if they present any further issues or modifications to the process they have used
- apply the conventions of reliability and validity to their findings
- explore any uncertainties or anomalies using scientific reasoning
- evaluate findings in terms of levels of bias, reliability and validity
- critically evaluate findings in terms of their prior scientific knowledge and understanding
- apply abstract, linked scientific knowledge in a way that demonstrates understanding

[1] The term ‘findings’ is used throughout the science national curriculum Order 2008 and the guidance. It is used as a general term for outcomes and therefore is equally relevant to any type of enquiry.

Reflect

- evaluate success criteria in complex, abstract tasks
- link the learning to abstract ideas in order to make further predictions
- evaluate the learning/thinking strategies used
- refine learning/thinking strategies for further use
- develop alternative learning/thinking strategies
- critically reflect on their learning and develop their own next steps.

Section 2

What are the features of quality enquiries?

What are the features of quality enquiries?

Curriculum 2008 is learner-centred and skills-focused. It gives opportunities for schools to provide a relevant and motivating educational experience for learners. Scientific enquiry is at the heart of developing such experiences. The use of scientific enquiries to challenge learners' current understanding and for them to better their skills and knowledge will lead to more resilient and reflective learners. The use of scientific enquiries that will challenge learners to progress their learning is essential to raising expectations and, ultimately, achievement. Below are a number of factors that need to be taken into account when planning for scientific enquiries for **all** learners.

Learner-centred learning

In order to set appropriate enquiries, it is important to know learners' prior skills, knowledge and understanding. Knowing where learners are in a continuum will enable teachers and learners to better negotiate where learners need to go next and how best to get there.

The level descriptions offer such a learning continuum for teachers. However, level descriptions are holistic descriptions of position, considering a wide range of evidence over a period of time. Therefore most learners' negotiated 'next steps' will be small steps within a level description as exemplified in this guidance rather than taken from the next description. Learners do not need knowledge of the level descriptions to negotiate next steps. To be most effective, next steps should be based on qualitative statements alone, rather than being combined with grades and/or marks. Teachers' knowledge of the learner and the level descriptions should focus planning of appropriate enquiries to enable learners to progress.

Classroom management

Learners work best when they can share ideas and articulate their thoughts.

Establishing effective collaboration in the classroom is key to successful learning. Through working in random pairs and small groups, learners learn from each other, raising their expectations and achievements. Teachers are able to listen in to conversations, and ask leading questions as in the enquiry 'What's the best way to minimise global warming?', in order to ascertain progress or otherwise. Learners need to agree on, and be frequently reminded of, the basic rules for interaction[2]. They also need to feel that the classroom is a safe and reflective environment in which to take risks with their ideas.

[2] Further information on how to ensure successful collaboration can be found in *How to develop thinking and assessment for learning in the classroom* referenced in the 'Useful information and websites' section.

Contexts of enquiries

Enquiry types

Enquiries can take many different forms, as stated in *Science in the National Curriculum for Wales*, and reflected in the associated guidance, *Science: Guidance for Key Stages 2 and 3* (both Welsh Assembly Government, 2008).

All enquiry types can be used to develop higher-order scientific enquiry skills. However, as learners progress, the enquiries they carry out will become more complex and as such are combinations of the different enquiry types. Most of the enquiries in this guidance exemplify this. Enquiries that involve Using and applying models require the application of abstract scientific ideas, and as such are more relevant for learners working at the higher levels. Therefore, many of the examples of learners' work in this guidance demonstrate using and applying models.

Enquiries in this guidance

Title of enquiry	Enquiry types					
	pattern-seeking	exploring	classifying and identifying	making things	fair testing	using and applying models
Apocalypse ride		✓				✓
How could the space shuttle stop quicker?					✓	✓
How could people in an economically developing country get clean water? (Improving learners' work)				✓		✓
How does a hairdryer work?		✓				✓
Were the Moon landing photos fake?		✓				
How is the food you eat used to give energy for moving muscles when you exercise?				✓		✓
What's the best way to minimise global warming?		✓				
An ice problem?		✓				✓
Are single-celled organisms plants or animals? Explain.			✓			

The Range

In order for learners to demonstrate characteristics of the highest national curriculum levels, they usually need to link knowledge and understanding from across areas of the Range. Therefore, questions posed for enquiry should allow for this to happen naturally. Enquiries related to respiration and combustion (as in Ben's profile in *Science: Guidance for Key Stages 2 and 3*, for example) allow learners to demonstrate an understanding of:

IO2: how food is used by the body as fuel during respiration…

TSE3: the differences between…chemical changes

HTW2: the conservation of energy…

(See page 16 for explanation of references.)

A seemingly simple enquiry such as 'How do respiration and combustion compare?' can challenge learners and lead to the demonstration of a wide range of level characteristics from Level 5 to Exceptional Performance.

Task demand

All learners need challenging tasks to engage and motivate them to succeed. The *Skills framework for 3 to 19-year-olds in Wales* (Welsh Assembly Government, 2008) states that the challenge of tasks increases as they move from:

- concrete to abstract
- simple to complex
- personal to the 'big picture'
- familiar to unfamiliar.

Using open-ended 'big' questions as contexts for enquiries is likely to engage more learners and improve their achievements. Examples in this guidance such as 'What's the best way to minimise global warming?' or 'How could the space shuttle stop quicker?' give opportunities for learners to refine and use their skills, knowledge and understanding and therefore demonstrate higher level characteristics.

When using open-ended 'big' questions, learners will need to plan carefully and initially will need support to tread a successful path through the enquiry. Teachers can facilitate this by asking probing questions, such as in the enquiry 'Are single-celled organisms plants or animals? Explain.' Here the teacher leads Ali into reviewing his original findings to improve his work.

In addition, learners will need to use thinking tools[3] to organise their thoughts and ideas so that the planning, organisation and reflection processes are clear and meaningful. This is exemplified in 'What's the best way to minimise global warming?', where George designs and later modifies a graphic organiser, and in 'Are single-celled organisms plants or animals? Explain.', where Ali uses a teacher-modified PMI diagram*. Also, in 'An ice problem?' Sam uses several tools, such as stepping stones* for metacognition, as well as others such as skimming, scanning and diamond ranking*.

Reflecting on learning

This is a new element of the level descriptions for the science national curriculum Order 2008. It encourages a focus on how learning is taking place, in addition to what has been learned. Focusing on the process of learning, and allowing time in lessons for reflection leads to faster and more sustained progression.

The planning and management of enquiries should allow learners the time that they need to 'think about their thinking' rather than rushing too quickly to arrive at outcomes. Initially, learners may require teachers to pose reflective questions. Learners working at the highest levels will be more likely to pose such questions and insist on the time they need both to explore the process of learning as well as to push the boundaries of the enquiry.

Learners will need a repertoire of thinking strategies and tools to draw upon when they encounter new situations. They also need an agreed shared vocabulary so that they can have 'learning conversations' between themselves and with their teachers. Science always requires significant thought to plan, improve methods, analyse findings and explain anomalies. For such reflection to be valuable, it needs to occur throughout the learning experience, and not just towards the end of the task, lesson or module. Learners need

[3] See the Welsh Assembly Government's 2009 booklet *How to develop thinking and assessment for learning in the classroom*, referenced in the 'Useful information and websites' section of this guidance – throughout the guidance, examples of such tools are denoted with an asterisk.

to focus on the process of learning, how they are going to do it, how they are doing it and eventually how they have done it. This is exemplified in 'An ice problem' where Sam uses metacognitive stepping stones* to deconstruct his learning and make it visible.

Transferring learning

Learners need to be able to transfer skills, knowledge and understanding from one lesson to another and from one subject to another. Through asking questions such as "How do you know that?" and "Where did you get that idea from?" teachers will lead learners to articulate their thought processes and make these initial transfers. Towards the end of an enquiry, questions such as "Where else could you use that idea/skill/strategy?" or "How could you adapt the tool/strategy you used to be used elsewhere?" will enable learners to firmly root their understanding in other contexts. Once these transfers have been made, the deeper understanding reached will lead to improved learner performance. In 'An ice problem?', the teacher leads the learners into the initial tasks by asking them to record what they did and how they did it. In this enquiry, this gives a platform for the teacher to ask questions as described above. The conversation that the teacher then has with Sam regarding his choice of tools enables Sam to be even more explicit about why he might have used an alternative strategy.

Learners working at the highest levels might well transfer skills, knowledge and understanding consistently but without necessarily articulating their ideas. Allowing the time for these articulations and ensuring a reflective environment will better enable these learners to consolidate their learning. Equally, it will open up their thought processes to other class members and so help to raise the expectations of the whole class.

Section 3

Examples of learners' work exemplifying higher-order level characteristics

Examples of learners' work exemplifying higher-order level characteristics

This section contains examples of learners' work within Key Stage 3 that demonstrate characteristics of Levels 7, 8 and Exceptional Performance. At times characteristics of lower level descriptions are in evidence. As actual examples of learners' work, there are, at times, some misconceptions evident in the science used. However, these do not detract from the characteristics of the level descriptions shown in the examples. The work was collected from across Wales in the summer term of 2009.

As in *Science: Guidance for Key Stages 2 and 3*, at the end of each piece of work are 'next steps' statements for the learner. One of the enquiries in this guidance uses 'next steps' statements as a starting point. Learners were given the original work and asked to take the 'next steps'.

The references to the science programme of study are the same in both documents, and are given below.

Skills	**Range**
C = Communication	IO = Interdependence of organisms
EP = Enquiry planning	TSE = The sustainable Earth
ED = Enquiry developing	HTW = How things work
ER = Enquiry reflecting	

Exploring and using and applying models enquiry

Skills
C1, 2, 3; EP2, 3, 6; ED4; ER4.

Range
HTW 2, 3, 4.

Apocalypse ride

Learners were asked to research a theme park ride in terms of energy transfers and work done. The class had recently visited the theme park and many learners had been on the ride itself.

Apocalypse ride

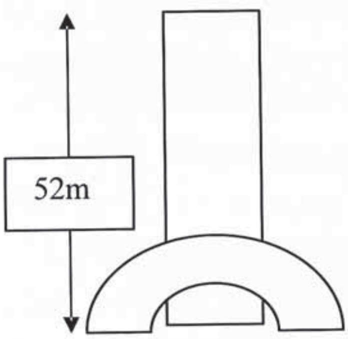
Research

1. Discuss the energy changes taking place. You may want to draw a diagram.
2. If your group was to go on the ride, explain what you would need to know to calculate how much work was done by the ride to lift you to the top. Calculate the work done to lift the group to the top.
3. What happens to all the energy the machine uses to lift you up?

Nicola used the internet to find out more about the ride. She discovered the height to which people were lifted and how the ride was powered. The learners worked in pairs to discuss the posed questions and then wrote individual accounts. Nicola's work is reproduced on the following page.

Apocalypse ride

1. **Energy changes**



When you get on the ride you have no energy. The ride uses a motor (which changes electrical energy into kinetic) to lift you up. This gives you gravitational potential energy. When you are being lifted up you have both potential (which is increasing) and kinetic energy (constant) coming from the energy of the motor. When you get to the top and stop you only have potential energy. All the energy from the motor (electrical) has been changed to potential.

Going up

Electrical (motor) → potential (person)

When the ride lets you go, the potential energy is being changed to kinetic as you fall through the air.

Falling

Potential → kinetic + heat + sound.
Not all the potential energy is changed into kinetic because you have overcome air resistance which creates unwanted heat and sound.

Stopping

Kinetic → heat + sound
The brakes are then applied which stops you and changes the kinetic energy into mostly heat and some sound energy.

2. **Work done**

You would use this equation
work done = force x distance moved

We found our weight by standing on Newton scales. Our forces were 450N, 520N, 650N and 430N. This gives a total weight of 2050N.

We found out on the internet that the ride is 52m high.
Work done = 2050 x 52 = 106,600J or 106.6kJ

3. **What happens to the energy?**

Moving up

The energy supplied by the motor lifts us to the top of the ride. We have gained 106.6kJ of energy in the form of gravitational potential. We think that the motor must have done more work than this because it has to overcome air resistance when moving up (releasing heat energy) and the motor wasted energy in the forms of heat and sound.

Falling down

All of the potential energy is not converted into kinetic as some is wasted as sound and heat when overcoming air resistance. The brakes then convert our kinetic energy into heat and sound when stopping us. This energy then goes into the surroundings and warms up the air.

Nicola's next steps

- Find out if the weight of the people on your section of the ride is the only weight that the motor has to lift. Then, you might like to review your calculations.
- Record how you go about the internet search to verify your calculations and evaluate the decisions you make when searching.

Nicola clearly described the energy changes/transfers that occur as the ride lifts people up and lets them fall down. This is characteristic of Level 6 as she used abstract scientific ideas when predicting the energy changes. She used some quantitative definitions and performed calculations using the correct units to work out the work done and energy involved, which is characteristic of Level 7. She also recognised that more energy would be needed than that calculated to overcome air resistance as the ride moves up, which is a further characteristic of Level 7 as she was explaining to what extent her findings (in this case predictive calculations) were consistent with scientific knowledge and understanding. However, she didn't take into account the weight of the section of the ride in which people sit. Had she done so, the latter characteristic could have been more clearly demonstrated.

Characteristics of the **Level 7 description** include:

- *…in explanations apply abstract ideas and make links between processes…*
- *use some quantitative definitions and perform calculations using the correct unit*
- *explain to what extent their findings are consistent with scientific knowledge and understanding…*

How could this work be developed in Key Stage 4?

Developing ideas about the equations for kinetic and potential energy, and energy efficiency, could lead to enquiries such as:

- How could you find out the efficiency of the motor?
- Compare the efficiency of two motors found in electrical appliances.

Fair test and applying models enquiry

Skills
C2; EP2, 4, 5, 6; ED2, 3, 4, 5; ER2.

Range
HTW2, 4.

How could the space shuttle stop quicker?

Learners planned and carried out the enquiry in pairs, although they wrote up the investigation individually. Nia's work is shown below.

Investigation: How could the space shuttle stop quicker?

What I already know

I know that the shuttle is slowed down by opening a parachute. A parachute works by increasing the air resistance and this force acts in the opposite direction to the movement and so slows it down.

Air resistance is made by the hitting the air particles (putting a force on them) and then the air particles push back with an equal and opposite force. This is the force that slows the shuttle down.

When the shuttle lands on the ground it has only kinetic energy. To stop the shuttle moving on the ground, work has to be done. To do this work a force needs to act against the movement. I know this because:

Work done (J) = force x distance moved.

© NASA

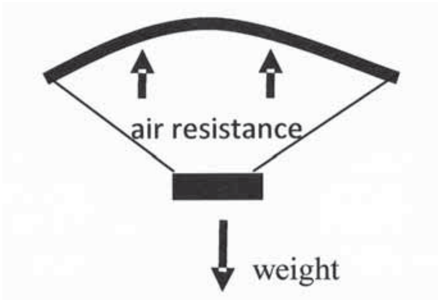
To stop the shuttle, work has to be done in the opposite direction to reduce the kinetic energy to zero (when stopped).

To stop the shuttle quicker, which travels a shorter distance, you would need a larger force. I am going to investigate how you could increase this force from the parachute.

Prediction

The parachute can be modelled by one falling through the air. I think as I increase the surface area of the parachute, the air resistance will increase and the weight will fall at a slower rate. This is different to the shuttle because its forward movement (kinetic energy) would be in the position of the weight and also gravity would act vertically. This is why it's important that the parachute is lightweight.

Parachute falling in air.



Why I think this

The bigger the area of the paper parachute, there will be more surface area, so it will hit more air particles creating a bigger air resistance. This will result in the weight falling slower because the resultant force will be smaller causing a smaller acceleration.

Variables

Independent variable: surface area of parachute (using 1 piece of A4 paper)

Dependent variable: time taken to drop – so we can measure average speed.

Control variables: drop height, total weight of paper parachute and 10g mass. Try to make sure it falls in a straight line.

Plan

1. Construct parachute using all the area of a piece of A4 paper, thread and a 10g mass.
2. Calculate the exposed area using area = length x width.
3. Drop the parachute from a height of 1m.
4. Time how long it takes to reach the floor.
5. Repeat twice to achieve reliability in our results.
6. Check results for any anomalies and repeat these to check.
7. Average results and use this average to calculate the speed of the parachute using the equation; speed = distance/time.
8. Repeat using different areas of paper exposed to the air. Do not cut the paper, just fold it to maintain the same overall weight.

Problem

We tried dropping the weight from 1m and there wasn't a big difference between times even when I tried A4 size and halved it. This is probably because it is still accelerating and hasn't reached a constant speed, when both forces are balanced.

Solution

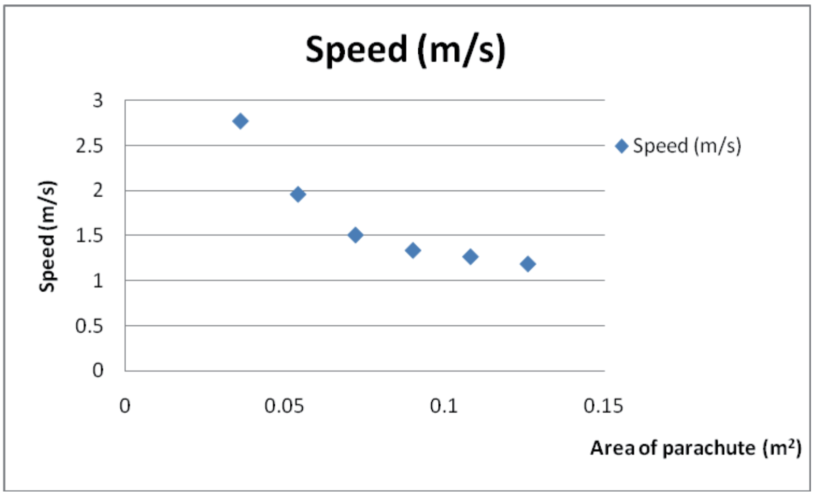
So we a going to drop the weight from 2 metres. To make sure the total weight stays the same we are going to fold the paper and not cut it into different sizes. When we folded the parachute it didn't fall in a straight line so we folded all sides to make sure it fell as straight as possible.

Results tables

Area (m^2)	**Time 1 (s)**	**Time 2 (s)**	**Time 3 (s)**	**Average time (s)**	**Speed (m/s)**
0.126	1.82	1.58	1.64	1.68	1.19
0.108	1.65	1.47	1.62	1.58	1.27
0.090	1.56	1.53	1.38	1.49	1.34
0.072	1.37	1.43	1.16	1.32	1.51
0.054	0.94	0.98	1.14	1.02	1.96
0.036	0.70	0.74	0.72	0.72	2.77

As all the times for each area were less than the average of the area before, we decided that our results didn't show any anomalies. Therefore we didn't repeat any of the tests. Also the pattern of the average times was as we expected.

Graph



My graph was done by importing the results into Excel and producing a scatter graph.

What I found out

I found out that if I want to slow down the shuttle quickly, I must use a very large area of parachute. The graph shows that the area does make a difference but as the area gets smaller it doesn't make as much difference to the average speed. The air resistance from the parachute must be making the weight reach its top speed (terminal velocity) quicker and the top speed must be lower because of this extra resistive force. So a larger surface area for the parachute does produce a greater resistance force and will therefore slow the shuttle down quicker and stop it in a smaller distance.

With the small times being recorded human reaction time could make a significant difference to the results. I think we could get more accurate results by using light gates and a computer to measure the time of drop as this would get rid of the issue of human reaction time.

We also could have dropped the parachute from a greater height as this would have made the time taken longer and be less affected by reaction time. But 2m was as high as we could do it otherwise it wouldn't have been safe.

Nia's next steps:
In your planning you recognised that the parachute needed to fall in a straight line every time. Where did you get this idea from and why do you think this? Add your ideas to your write-up.

Nia gave some justification for the method she used to maintain the overall weight of the parachute. To explain how the shuttle stops she made qualitative predictions using linked scientific knowledge and understanding about the force of air resistance and work done, as well as about work done and kinetic energy. She systematically measured and justified the amendments she made to her method. She used quantitative definitions and performed calculations using the correct units. When explaining her findings she applied abstract ideas of terminal velocity and air resistance. All of these are characteristics of the Level 7 description.

Characteristics of the **Level 7 description** include:

- *give some justification for the methods…they plan to use*
- *make qualitative predictions using linked scientific knowledge and understanding*
- *systematically…measure, justifying any amendments made to the method…*
- *use some quantitative definitions and perform calculations using the correct units*
- *in explanations apply abstract ideas…*

How could this work be developed in Key Stage 4?

Developing ideas about forces, speed and fuels could lead to enquiries such as:

- What is the braking distance of a car? How is it calculated? Review the braking distance table and find out whether these figures are as accurate today as they were 10 years ago. Present your evidence to your group.
- What are the main issues confronting car designers and makers as they try and develop cars with better fuel efficiency and/or alternative fuels?

Making things and using and applying models enquiry

Skills
C2; EP2; ED4; ER4.

Range
IO7; TSE1, 2.

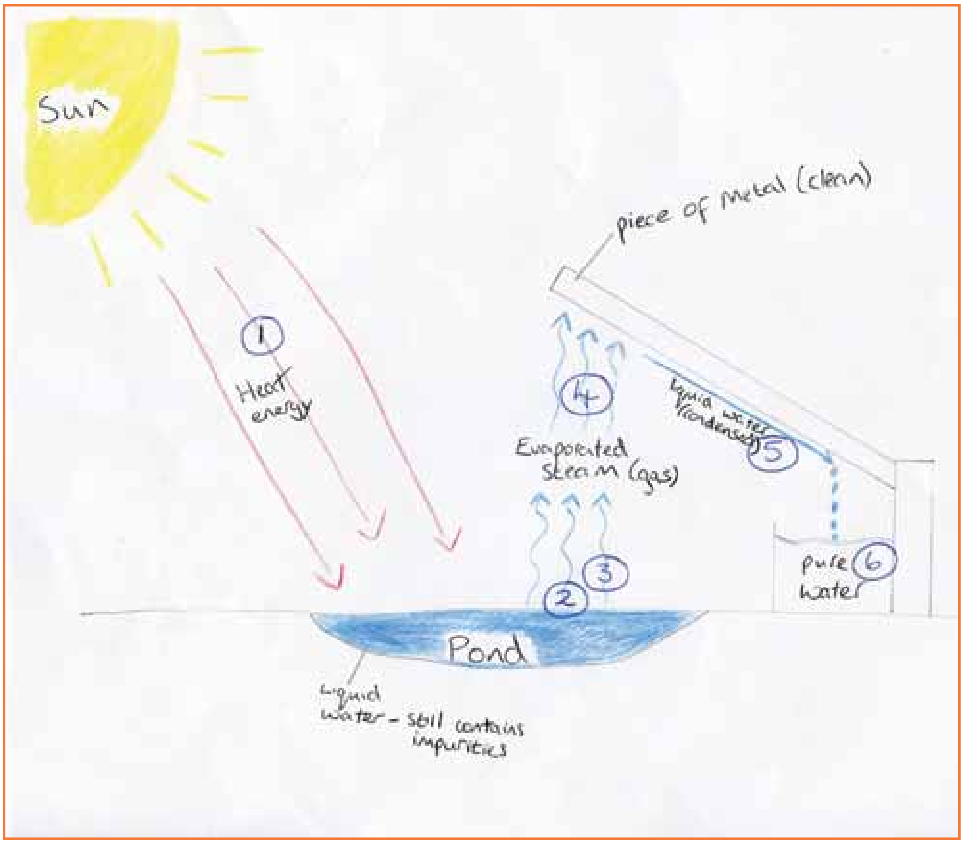
How could people in an economically developing country get clean water? (Improving learners' work)

Learners were given an example of work with its 'next steps' from Sian's profile (Level 5) in *Science: Guidance for Key Stages 2 and 3* (page 99).

The next steps were:

> Look in your text book to find out the difference between steam and water vapour. Make any changes to your diagram to take this into account.

After discussing in pairs, James wrote numbers on the different part of Sian's poster before explaining what was happening at each of these points.



Owing to the way in which James developed Sian's work, the enquiry moved from one of just making things to include using and applying models.

1. Radiant heat energy from the Sun heats up the pond water, especially at the pond surface.
2. Pond water molecules move faster and become further apart. The forces of attraction between the molecules weaken until the liquid water becomes a gas (water vapour). This is evaporation.
3. I think that the attraction between the water and the impurities must be weaker than those between the water molecules. Otherwise the water evaporated off wouldn't be pure. So if these weaker forces break first because the molecules are moving faster the water vapour is pure water and the impurities stay in the pond.
4. The water vapour rises from the pond as it is less dense than the liquid water and it is hotter than the air nearer the pond.
5. When the water vapour hits the piece of metal it condenses. This is because the metal is colder than the air. As the vapour cools, the molecules slow down and become closer together. This means that the forces between the molecules are now greater than in the water vapour. So the vapour turns into liquid water.
6. The impurities have all been left in the pond. Therefore the condensed water vapour is now pure water and fit to drink as it is collected in the container.

James' next steps:
Can you describe any improvements you might make to Sian's method for collecting water? You might like to look at Dylan's work to help you.

Throughout the enquiry, James has applied abstract ideas of particle theory to explain and link the processes of evaporation and condensation, as described in the Level 7 description. The enquiry could be seen as being predictive, as the learners were asked to design a means of producing clean water. Looking at the description for Level 8, part of the knowledge he used to predict would be classed as using detailed abstract ideas. That is, James suggested a possible difference in the relative strength of forces between molecules of water to water, and water to impurities. As there is no need to predict quantitatively in this enquiry, this work demonstrates a characteristic of the Level 8 description.

Characteristics of the **Level 7 description** include:

- *…in explanations apply abstract ideas and make links between processes…*

Characteristics of the **Level 8 description** include:

- *they make…predictions, using detailed scientific knowledge and abstract ideas.*

How could this work be developed in Key Stage 4?

Developing ideas about particle theory, chemical reactions and bond energy could lead to enquiries such as:

- How is crude oil separated?
- Explain why the burning of fossil fuels is exothermic, using ideas of bonds breaking and forming.

Exploring and using and applying models enquiry

Skills
C1, 2; EP2, 3; ED4, 7; ER4.

Range
HTW1, 3.

How does a hairdryer work?

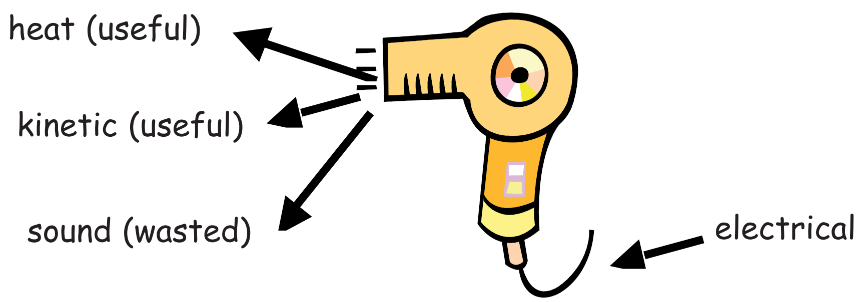
Learners had prior knowledge of electrical currents, variable resistors, insulators and conductors before being set this task. As it is aimed at a wide range of level descriptions, the task set gave opportunities for learners with a wide range of differing abilities to achieve. In the first lesson they researched the task before discussing their findings in groups. Individually they produced written work in the second lesson. Steffan's work is shown below.

How does a hairdryer work?

1. What do we use hairdryers for?
2. Discuss what it is made of and try to explain why.
3. List the energy changes taking place, trying to list useful and wasted forms.
4. Research its basic parts. Produce a report on how it works.
5. List the options available when using a hairdryer and try to explain how it makes these changes.

<u>How does a hairdryer work?</u>

1. We use hairdryers to dry our hair or anything that is wet (my dog).
2. Most hairdryers are made of plastic. I think this is because plastic is a good insulator and you won't burn your hands when you are holding it.
3. Electrical energy goes in from the plug. Heat, movement (kinetic) and sound comes out.



4. I found out from the internet that the hairdryer is made up of two basic parts. A fan (motor and blades) and a heating element.

   The motor changes electrical energy into kinetic (movement). This is what pushes the hot air out of it. The motor is connected to blades which spin, a bit like a wind turbine, but the motor makes the blades turn and not wind. The fan pushes cold air over the heating element and this heats up the air as it passes through it.

   The heating element is a coil of wire that gives out a lot of heat when current flows through it. I know that it gets hot because it has a lot of resistance. It is made of a type of metal wire that is not a good conductor. My teacher showed us that when you stop cold air blowing over it, it glows red. You can see it gives off heat.

5. Our hairdryer allows us to change the temperature of the air and how fast the air comes out.

How can you change the speed of the air?
I think that if you make the current smaller, this will make the motor spin slower and so the air will come out of the dryer slower. There must be a variable resistor in it to do this. We have used them in experiments and I know they can change the current.

What would happen to the temperature of the air now?
If the air is blowing slower over the heating coil it will heat the air up more and so the air would get hotter. To control the temperature the motor and the coil must be connected together. So if the motor spins slower it has less current and so less current must also go to the heating coil to produce less heat to stop the temperature of the air coming out increasing.

How can you change the temperature of the air?
If less current flows through the heating element it will produce less heat and so the air will be colder coming out of it. A variable resistor can do this job. This would then reduce the speed of the air so a variable resistor can't be used. The current must stay the same the keep the air speed constant. More wire would produce more heat at the same current and so perhaps the switch for heat increases the length of coil of wire and so makes more heat and therefore increases the temperature for the same current.

Steffan's next steps:
How could you test your ideas about how to change the temperature of the air? Think about what experiments you could do. You might like to talk to James and share ideas.

In his work, Steffan links learning from a variety of abstract contexts to explain how a hairdryer works. This is characteristic of Level 7. He goes further by making multiple abstract links in his predictions and explanations between air speed, air temperature, energy transfers and current flow. The making of multiple abstract links is characteristic of the Exceptional Performance description.

Characteristics of the **Level 7 description** include:

- *link the learning to more abstract situations.*

Characteristics of the **Exceptional Performance description** include:

- *justify their predictions by making multiple links between scientific models, theories…*
- *use complex abstract ideas or combinations of models/systems to explain their findings.*

How could this work be developed in Key Stage 4?

Further enquiries could be undertaken, such as:

- Investigate the energy efficiency of different lamps.
- How could you make a bulb more energy efficient?
- Mr and Mrs Pugh need to reduce their electricity bill. Review the table of energy efficiency and costs for various electrical appliances. What should they do and what difference might this make to their electricity bill?

Exploring enquiry

Skills
C1, 2; EP2; ED4, 5, 6, 7; ER4.

Range
IO7; HTW3.

Were the Moon landing photos fake?

Within the school, the Key Stage 3 learning programme has been divided into cross-curricular topics. In Year 9, learners study the 1960s for half a term. The History department had suggested this theme, and learners looked at how American politics through this decade influenced British life. Part of this theme used the following excerpt describing the space race, before the learners were introduced to the science task.

The Space race

On May 25, 1961, President John F. Kennedy announced before a special joint session of Congress the dramatic and ambitious goal of sending an American safely to the Moon before the end of the decade. A number of political factors affected Kennedy's decision and the timing of it. In general, Kennedy felt great pressure to have the United States "catch up to and overtake" the Soviet Union in the "space race." Four years after the Sputnik shock of 1957, the cosmonaut Yuri Gagarin had become the first human in space on April 12, 1961, greatly embarrassing the U.S. While Alan Shepard became the first American in space on May 5, he only flew on a short suborbital flight instead of orbiting the Earth, as Gagarin had done.

After consulting with Vice President Johnson, NASA Administrator James Webb, and other officials, he concluded that landing an American on the Moon would be a very challenging technological feat, but an area of space exploration in which the U.S. actually had a potential lead.

©NASA

In science, learners were given the discussion sheets below in hard copy and electronically. They discussed the evidence in groups and also had access to the internet. Individually learners added their own text (shown in italics below) of their decisions. This is Kate's work.

Did the USA really land on the Moon?

In July 1969, more than 600 million people watched TV to see Neil Armstrong walking on the Moon. This was a momentous achievement and one that most Americans hailed as a great victory. However, others thought that the Moon landing was fake. The photographs have been widely scrutinised and questioned by these groups of people. Some of their questions are given below.

Were the Moon landing photos fake?

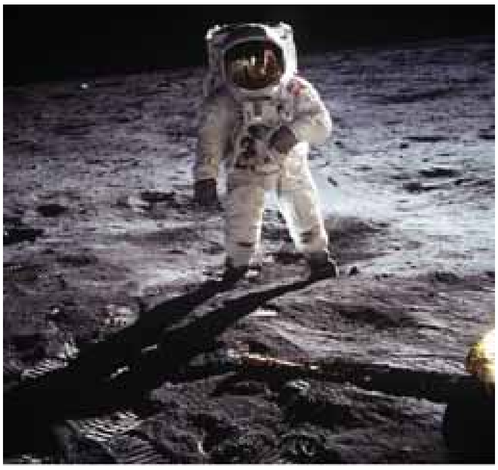
Look at the evidence and decide for yourself. Present your findings in any form you consider appropriate.

© NASA

The photo was taken by a camera mounted on the lunar module. If the only light source is the Sun – why is one shadow (Buzz Aldrin's) longer than Neil Armstrong's?

Most of the difference can be explained by the fact that the Moon's surface is not flat, e.g. there are craters, mounds, gullies etc. The top left shadow from Armstrong appears shorter than the shadow of the other astronaut as Armstrong is on a slight incline. The area directly behind Armstrong is dark as it is on the decline of the slope. This area is less well lit by the Sun from its low position in the sky. This is also the point where Aldrin's longer shadow ends.

Also, when we consider the height of the two astronauts, the image of Aldrin on the right suggests that Aldrin is taller than Armstrong on the left. The astronauts are actually the same height. This anomaly could be due to the effects of perspective changing the apparent size and length of the shadows in the image compared to their actual size or length.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The Sun is shining down across Buzz Aldrin's left shoulder. There seems to be a lot of detail showing on his right side – which could be too much detail? The way in which the light fades into the background is also not expected. As there is only the Sun as a source, and no light pollution on the Moon the photo should be bright and crisp with no fading.

Also, there is something reflected in his visor. Some theorists think that it is a helicopter, others say that it is a 12-metre glass structure. NASA claims that it is a piece of equipment on the lunar surface.

The Sun is the only light source on the Moon, it lights up not only the Moon's surface, but the Lunar Module, the astronauts spacesuit, and anything else on the lunar surface so the light scattered off of those objects will fill the dark shadows with some light. Also the astronaut's spacesuit is very white while the Moon's surface is black. Because of the photo the surface of the Moon looks much lighter in colour than it actually is and also allows the images to show detail in the shadows.

The so called mysterious objects are easily explained. One of them is the Solar Wind Collection (SWC) experiment and the second is the Flag. The location of the two astronauts in this image is around on the left side of the Lunar Module. The picture was taken by Armstrong from the area right of the SWC while Aldrin was standing just on the other side of the footpad visible on the right in this image. So it is the reflection of this SWC experiment that can be observed.

In conclusion, *we think that the Moon landing shots were not fake as there is clear evidence (as shown above) that explains the various hoax theories which try to prove the shots were faked. After all, 600,000,000 people watched the launch, are you really going to try and say that they were all wrong?*

Kate's next steps:
What inventions have been made following the Moon landing? As you look at these inventions, think about whether their invention adds any further evidence for the Moon landing. Prepare to speak for one minute about one of these inventions to the class next lesson. You might like to use the NASA website www.nasa.gov

The learners were actually being asked whether the photos were valid and could be used as evidence that the Americans had landed on the Moon. Kate explored these uncertainties and tried to explain the anomalies pointed out in the evidence. She also explained to what extent her findings are consistent with abstract scientific ideas. Both of these are consistent with the Level 8 description.

Characteristics of the **Level 8 description** include:

- *explore uncertainties and explain anomalies*
- *explain to what extent their findings are consistent with abstract scientific ideas.*

How could this work be developed in Key Stage 4?

Further enquiries could be undertaken, such as:

- How did the Apollo 11 command module stay in orbit around the Moon while Aldrin and Armstrong were on the Moon surface?
- How do satellites stay in orbit around the Earth?
- Why are satellites in different orbits around the Earth?
- Investigate spacesuits. What features do they have that enable them to support life in space?

Making things and using and applying models enquiry

Skills
C2; EP1; ED4, 7; ER1, 2.

Range
IO1, 2.

How is the food you eat used to give energy for moving muscles when you exercise?

Learners were asked to produce and deliver a presentation entitled 'From dinner to winner' to the school's BTEC Sports Science group.

They started working in groups and used a placemat activity* to develop their success criteria for the presentation. Helen's group's ideas:

Group's success criteria

- Correct use of science terminology and ideas.
- Describe what actually happens.
- Make sure we understand everything we write as they might ask questions.
- Do it on one page, using a PC, so it's clear – include pictures.

Helen worked on her own to develop her presentation. Firstly, she drafted the text she would use to make sure the first two criteria would be met. At this point she recognised that she needed to link the functions of the different systems in the body so that the presentation made sense; an additional success criterion. She also decided that as the audience was older and therefore probably more knowledgeable, she ought to give greater detail as to what happens at a cellular level.

When working on what the presentation should look like, Helen added another success criterion when she recognised the need to represent the journey of the food from dinner to winner. She spent some time trying out different layouts and diagrams, and eventually settled on one that clearly showed the path through the body.

Therefore Helen had amended the group's success criteria to give:

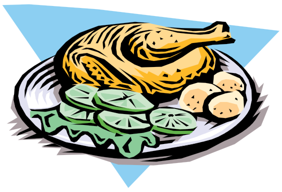
Helen's success criteria

- Correct use of science terminology and ideas.
- Link the functions of the different systems in the body.
- Describe what actually happens in the cells.
- Make sure we understand everything we write as they might ask questions.
- Do it on one page, using a PC, so it's clear – try to include pictures.
- Develop a way of showing a path through the body from the dinner to the muscles. Use this as the skeleton of the presentation.

Helen practised her presentation by sharing it with the original group and asking them to assess it according to her success criteria, which she justified. She also explained to members of the group why she modified their original criteria. The group agreed that Helen had met her success criteria but Ben asked her whether she could make the science stand out more. After some thought, Helen decided to underline key terms – another additional success criterion.

From dinner to winner

How is the food you eat used to give energy for moving muscles when you exercise?



When you eat your dinner goes into your digestive system which starts at the mouth and food pipe into the stomach. The food is churned and digested in the stomach and then it goes into the small intestine which carries on digesting the food. As the food is digested large insoluble molecules are broken down by enzymes into smaller soluble molecules. The smaller molecules can then be absorbed through the villi in the small intestine walls. The villi make the small intestine have a larger surface area so that the molecules can be absorbed quickly. Also the walls of the villi are only one cell thick and moist – this makes absorption faster too. The blood capillaries (also with one cell thick walls) are very close to the villi and the molecules can go quickly into the bloodstream.

In the bloodstream the molecules dissolve in the blood plasma, which is mainly water. The heart pumps the blood around the body. The blood picks up the food molecules, which includes glucose, in the small intestine. It carries the glucose around the body to where it's needed – to the muscles.

In the lungs the blood picks up oxygen. The lungs have an increased surface area as they are made up of lots of air sacs called alveoli. The alveoli increase the surface area of the lungs so that the oxygen can diffuse through the lung walls and into the bloodstream. Also the alveolus walls are only one cell thick and moist – this also makes diffusion faster. The blood capillary walls are 1 cell thick and so diffusion happens easily from the air sacs and into the bloodstream. The oxygen is carried to the muscles.

The blood brings the glucose and oxygen to the muscles. When you are exercising the glucose and oxygen move from the blood and into the muscle cells. Again the blood capillary walls are only 1 cell thick – so it happens quickly. They diffuse into the muscles cells.

In the muscle cells respiration happens. This is when the oxygen and glucose react to release energy. The equation is oxygen + glucose → carbon dioxide + water. The energy that is released can be used by the muscles so that they can move. The waste carbon dioxide is diffused into the bloodstream and is taken around the body to the lungs. It is breathed out in the lungs. Waste water is taken to the kidneys – in the blood plasma where it is excreted in urine. Some water is also used for other reactions in the muscle cells.

Helen's next steps:
Look at digestion again. Try and explain how glucose ends up in the blood. Look in your textbook to help. Do you want to amend your diagram – if so how?

Helen justified her success criteria, a characteristic of Level 6. By adding to the groups' success criteria and modifying them, she was evaluating their usefulness (a characteristic of Level 6) and refining them for future use (a characteristic of Level 7). She justified the amendments she made to the strategy she used to present her findings, a feature of Level 7.

Helen explained the impact of one body system on another (a characteristic of Level 8) using complex, abstract ideas and combinations of systems (a feature of Exceptional Performance). The way in which she presented the text as a clear journey through the body is also a characteristic of Exceptional Performance in that she developed an organised system to record and clearly convey points of interest.

Characteristics of the **Level 6 description** include:

- *justify their success criteria*
- *evaluate how far their success criteria fully reflect successful outcomes.*

Characteristics of the **Level 7 description** include:

- *refine success criteria in the light of experience*
- *justifying any amendments made to the method/strategy.*

Characteristics of the **Level 8 description** include:

- *explain the impact of one system on another.*

Characteristics of the **Exceptional Performance description** include:

- *develop an organised system to record findings clearly conveying points of interest*
- *use complex…abstract ideas or combinations of models/systems to explain their findings.*

How could this work be developed in Key Stage 4?

Further enquiries could be undertaken, such as:

- What are the causes of cramp in muscles and how best could athletes reduce the occurrence of cramp?
- How does the human body regulate glucose?
- What is homeostasis and how does it work?

Exploring enquiry

Skills
C1, 2; EP3; ED4, 5.

Range
IO6, 7.

What's the best way to minimise global warming?

Learners had already studied the theoretical causes of global warming before being given this enquiry. They were asked to find out about new technologies under development that might reduce the speed of global warming. They had access to the library and the internet. The members of the group brainstormed* what they were going to do. Each member then described their plan. This is George's plan (using his own graphic organiser):

Internet search – find 3 or 4 technologies under development

↓

Read and try to understand the science – only pick ones I understand

↓

Print off about 2 pages per technology – read and underline key points

↓

Prioritise and summarise key points – check understanding

The group carried out their searches and drafting of ideas before reconvening to compare notes. George chaired his group. The teacher listened in to some of the group's discussion and made the following notes in his planner:

> *George*
> *Justified his plan – reliability + problems with search/quantity + depth.*
> *Questioned evidence found – biased (commercial sources).*
> *Explained cloud seeding – used + linked abstract science, e.g. particle theory + energy transfers.*

At this point George had demonstrated characteristics of Level 5 in that he had started to question whether some of the evidence was biased. He had applied abstract ideas in his explanations to the group, and made links between particle theory and energy transfers. Both of these are features of the Level 7 description. However, the justifications of his plan recognised the need for reliable, concise, easily understandable information with account taken of possible problems in these areas. These are characteristic of the Level 8 description.

Each learner planned how best to present their findings. George added the following to his graphic organiser:

↓

Reduce text so end up with 2 pages (one with ideas other with decision)

↓

Use Publisher so it looks like a science newspaper.

By adding these ideas, George's plan now indicates how he is going to develop an organised system to clearly convey points of interest.

George's findings:

Some new technologies under development, which might reduce the speed of global warming

Global warming happens because the heat from the Sun is trapped by carbon dioxide in the atmosphere. Scientists believe that they can slow down global warming by stopping some of the heat from reaching the Earth or by having less carbon dioxide in the atmosphere.

Cloud-seeding

Cloud-seeding is a form of weather modification. Hundreds of boats controlled by computers spray salt water into the air and the salt water create clouds in the sky. The clouds help reflect the Sun's rays back into space, so the Sun doesn't increase the temperature of the carbon dioxide. This doesn't cost much money when compared to the space mirrors, but would create more carbon dioxide by burning oil to fuel the boats.

Reflective Space Mirrors

The US government wants the world's scientists to develop technology to block sunlight to halt global warming. One such idea is space mirrors that would reflect sunlight, which would compensate for greenhouse emissions. Research has shown that reflecting less than 1% of sunlight would be enough. The advantage of this idea would be that global warming would be slowed down in a relatively short amount of time. But placing space mirrors in space can cost a lot of money since the mirrors are gigantic and they could break easily when placing them there.

Other similar ideas are putting thousands of shiny balloons high up in the atmosphere or using rockets to pump small particles high up into the atmosphere to reflect sunlight and have the same effect as a volcano blocking sunlight. These seem more straightforward than using space mirrors. But since sunlight is lost there might be less photosynthesis so more carbon dioxide stays in the atmosphere.

Turning Carbon dioxide into Limestone

A new way to capture carbon dioxide is turning it into limestone or bicarbonate in a bioreactor but this requires a lot of energy that produces more carbon dioxide.

Ocean Fertilization

Ocean fertilization is a process that will decrease the amount of CO_2 in the atmosphere. The phytoplankton in the sea helps the environment by using carbon dioxide in photosynthesis. The phytoplankton are eaten by animals and are turned into solid carbon products that are egested and sink to the bottom of the ocean. We can help this by putting iron (in the form of a tonic currently used to help iron deficient blood) in the sea that will fertilize the phytoplankton and increase their numbers. This is a cheaper way to try to halt global warming, but scientists are worried that toxic plankton and other plankton that produce even more harmful gases will increase their numbers.

The learners shared their presentations. The teacher questioned George about his presentation:

Teacher:
Why did you write so little about converting carbon dioxide into limestone?

George:
I didn't think that this was a good idea as it uses a lot of energy. To get the energy you would need to burn fossil fuels, so releasing more carbon dioxide into the atmosphere. I suppose I shouldn't have used this idea. But I wanted to balance the page.

When asked how he could improve his presentation, George said that he would have included a better method rather than converting carbon dioxide into limestone. Had he actually changed this idea, his justifications would have demonstrated a characteristic of Level 7.

The learners were then asked to individually evaluate their findings in order to make a decision as to which of the ways of slowing global warming would be the one to choose. Here is George's evaluation.

Decision

Ocean fertilization is the best way to try to reduce the speed of global warming. It is the most natural of the ones we found out about therefore it should have less chance of upsetting other natural systems. If you were to use iron tonic or fertilizer in the oceans, the fertiliser would have to be an organic one and not just a mixture of chemicals. Otherwise it might cause more harm than good.
Cloud seeding can involve using silver iodide (instead of salt water) in the atmosphere and this isn't normally found there. Therefore it could have other effects that might be harmful. It also would change the weather (like the snow in China) and this could mean we have less crops and so cause a world food shortage.
The mirrors in space would cost a lot to make and transport into space. Making the mirrors might also cause some pollution, such as the need for burning fossil fuels and releasing more carbon dioxide. Reducing the amount of sunlight that hits Earth might also reduce crop production.
Turning carbon dioxide into limestone also requires the use of energy from burning fossil fuels, so again would release more carbon dioxide into the atmosphere.
With ocean fertilisation, some people believe that there will even be more fish in the oceans for us to feed on because the fish will have plenty of phytoplankton to feed on. As the population of phytoplankton increases, so will the fish population. This would give more food for humans and other animals that eat fish. However, it would have to be monitored to check for growths of poisonous algae (algal blooms). These might be a problem in holiday resorts so before we started ocean fertilisation we would need to make sure that we could safely kill any of these algal blooms if they did appear.

George has started to think about the impact that each method might have on systems, such as food webs, and the possible global effects on agriculture. He has also started to recognise a degree of uncertainty in his decision making but as yet the signs aren't clear enough to safely say whether these are features of the Level 8 description. In fact throughout the enquiry George is showing enough scientific understanding to suggest that with further guided questioning his future work will show many more characteristics of the Level 8 description.

George has actually demonstrated characteristics of Level 7 in that he has linked processes in explanations and applied abstract ideas. He has also linked his learning to more abstract situations, another feature of this level description.

The teacher asked George to write his own next steps.

George's next steps:

- Try and decide how biased each piece of information might be.
- Rewrite the explanation as to how ocean fertilisation works – look at textbooks.

After discussing these next steps with the teacher, George suggested that he could share his findings with the class next time. They both decided that this would be done in just one minute.

Characteristics of the **Level 7 description** include:

- *in explanations apply abstract ideas and make links between processes...*
- *link the learning to more abstract situations.*

Characteristics of the **Level 8 description** include:

- *justify their methods…in view of the reliability of information*
- *identify any possible problems with the method/strategy.*

Characteristics of the **Exceptional Performance description** include:

- *develop an organised system to record findings, clearly conveying points of interest.*

How could this work be developed in Key Stage 4?

Further enquiries could be undertaken, such as:

- Review changes in the Earth's atmosphere over time.
- What indicators are used to monitor global warming? Assess each one's reliability.

Exploring and using and applying models enquiry

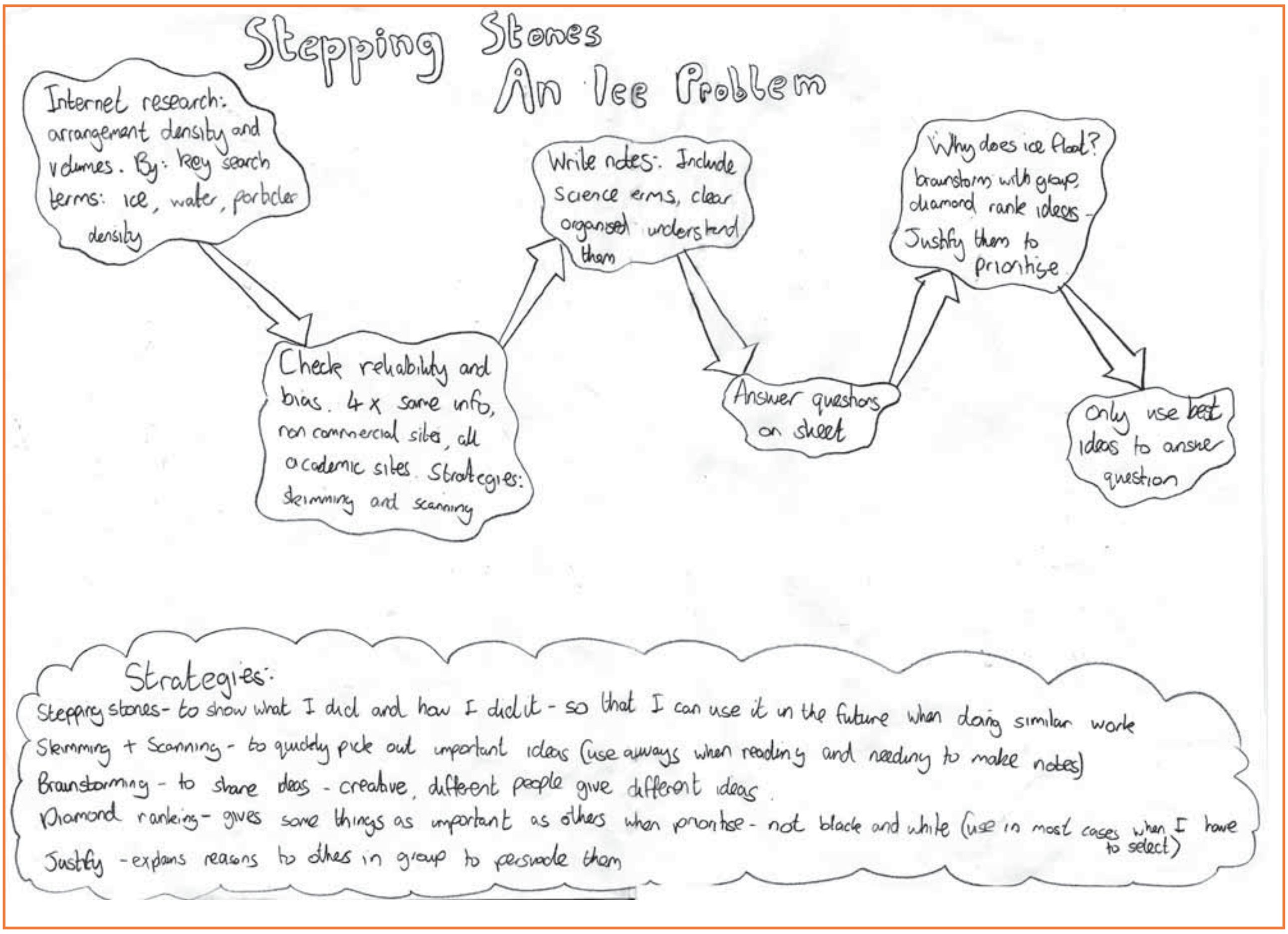
Skills
C1, 2; EP2, 3; ED3, 4, 6, 7; ER3, 4.

Range
TSE1, 2.

An ice problem?

Learners were first asked to find out why ice floated on water. They were given a series of smaller, focused tasks to build up their knowledge-base and understanding before they attempted the main enquiry. This approach enables learners to increase in confidence as they construct their learning. So that this construction is visible, the learners were asked to note what they did and how they did it as they developed the task. They were also asked to justify any strategies they used.

Sam's metacognitive stepping stones* are shown below, which he used to answer 'Why does ice float on water?'



Sam gave some justifications for the strategies he used (a feature of Level 7). He considered reliability when looking for the same information on multiple websites. He is also starting to justify using these strategies by making some links to prior learning, for example when he stated where he has used these strategies before. More importantly he recognised the importance of using a metacognitive tool to assist future learning.

The teacher asked Sam a few questions about his diagram:

Teacher:
Could you have used any other tools/strategies?

Sam:
Probably a fish-bone diagram* would have helped me to write the answer to 'Why does ice float on water?'

Teacher:
Why do you think this?

Sam:
Because it shows cause and effect really well and would have made sure that I considered all the ideas.

Teacher:
Where have you used this tool before?

Sam:
When we looked at how a smell spreads through a house – you know, gas particles moving and what might make them move faster through a house.

Sam reviewed his strategies and suggested an alternative strategy he could have used for looking at cause and effect. This is a characteristic of the Level 8 description.

Research:

WHY DOES ICE FLOAT ON WATER ?

To solve this problem you will need to find out about the following:

* the arrangement of the particles in ice and water

Water (liquid)
The particles in water are close together
They have a random arrangement
They have low forces of attraction
They can move freely

Ice (solid)
The particles in ice are in regular rows
* They have large spaces between particles *
The gaps between the particles are bigger than the gaps in water.

* compare the densities of ice and water

Ice will have a lower density than water with the same volume.
Water will have a greater density because the particles are more tightly packed than ice.

* compare the volumes of an equal number of ice and water particles

Ice has a greater volume than water with the same amount of particles (due to the bigger spaces between particles in ice)
Water has a lower volume than ice with the same amount of particles

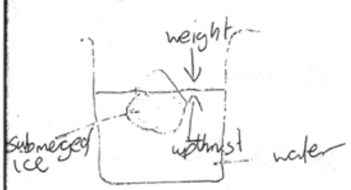
Problem:

WHY DOES ICE FLOAT ON WATER ?

Use your research to explain why you think that ice floats on water.(You may decide to include diagrams to help you make this explanation)

Ice floats on water because because water has a higher density than ice. The ice would sink when it is first dropped into the water due to the weight of the ice but after a time the ice will float because the forces between the weight of the ice and the upthrust of the water are balanced. The level of water would have increased by the amount of volume of the submerged part of the ice cube

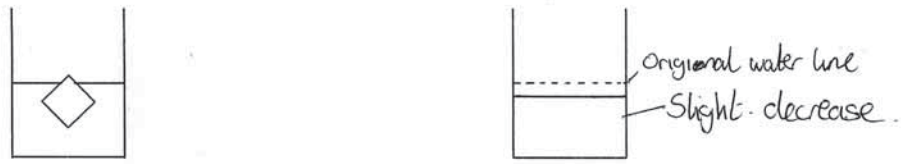
Diagram



Sam then moved on to the main enquiry.

An Ice Problem

A large ice cube is left in a beaker of water for 4 hours at room temperature.



a beaker of ice containing an ice cube

after 4 hours at room temperature

In the second diagram, draw the beaker showing the water level after the 4 hours. Try to explain why this happens.

The particles in water are close together, they are in a random arrangement and they can move freely. The particles in ice are in regular rows, but unlike a usual solid the spaces between the particles are bigger than the spaces between the particles in water. When ice melts to water, the volume decreases because ice has a strange property: It has spaces between its particles which makes it have a greater volume and less density than water. Ice floats in water because water has a higher density than ice. The ice would sink when it is first dropped into the water, due to the weight of the ice. After a time the ice will float because the forces between the weight (Gravity) of the ice and the upthrust of the water are balanced.

> Over the four hours the ice will melt into the water. At the beginning the submerged ice is accounted for because it has displaced the water in the beaker. When the submerged ice melts the overall level of the water will decrease because the volume of ice drops when it melts. However the ice above the water is not accounted for because it has not displaced any water. When this ice melts new water is being added. Thus increasing the overall level of the water in the container. This has caused a dilemma, because I don't know how much the submerged or not submerged ice will affect the overall level of the water

> So, in conclusion, I think that the overall level of the water, after the four hours will go down. I think this because in the initial diagram the amount of ice which is submerged in the water looks as it it would make more of an effect on the overall level of the water because it looks bigger. The ice above the water looks smaller. So it wouldn't change the overall level very much. There fore I think there will be a slight decrease in the overall level of the water.

Sam's next steps:
How might your predictions relate to the expected melting of ice caps owing to global warming? You might want to do some more research on the internet to help you.

Sam used abstract ideas when he answered the initial three research questions relating to the properties of ice and water. In doing so, he linked particle theory with ideas of density, a characteristic of the Level 7 description. As he developed his ideas as to 'Why does ice float on water?' he also applied knowledge and understanding of weight, upthrust and balanced forces. This is more characteristic of the Exceptional Performance description as he is justifying his predictions by making multiple links between scientific models and theories. Sam's prediction as to what will happen over time, in the final part of the enquiry, also makes these multiple links. In doing so, he recognises that he has conflicting scientific ideas as to the outcome. Having given both sides of the argument he made his conclusion recognising the dilemma. This is a feature of the Level 8 description.

Characteristics of the **Level 7 description** include:

- *give some justifications for the…strategies…*
- *make qualitative predictions using linked scientific knowledge and understanding…*
- *begin to evaluate their findings in order to gauge bias, reliability…*
- *review their strategies.*

Characteristics of the **Level 8 description** include:

- *explain to what extent their findings are consistent with abstract scientific ideas*
- *draw conclusions showing an awareness of the degree of uncertainty…*
- *suggest alternative learning/thinking strategies.*

Characteristics of the **Exceptional Performance description** include:

- *...justify their predictions by making multiple links between scientific models, theories…*

How could this work be developed in Key Stage 4?

Further enquiries could be undertaken, such as:

- What are the possible causes of global warming?
- What are the possible causes of acid rain?
- How could we reduce the emissions that can lead to global warming/acid rain? Evaluate the effectiveness of your methods.

Classifying and identifying enquiry

Skills
C2; EP2; ED3, 4, 5, 7; ER4.

Range
IO1.

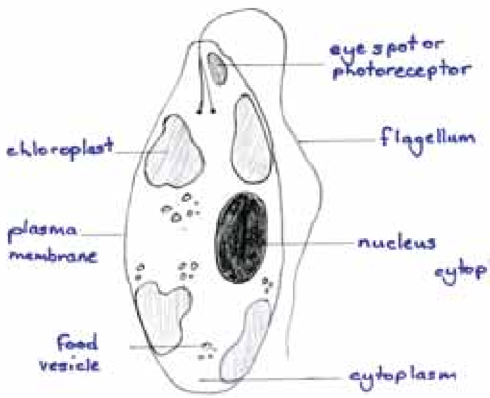
Are single-celled organisms plants or animals? Explain.

Learners were set a two-part task. The first part was to compare detailed diagrams of three single-celled organisms to decide if they were plant or animal cells. They had already learned about the basic structure to function of plant and animal cells. However, many of the labels on the diagrams were unfamiliar to them. They had also previously looked at *Euglena* in a similar way (see *Science: Guidance for Key Stages 2 and 3*, page 127). The first task is shown below.

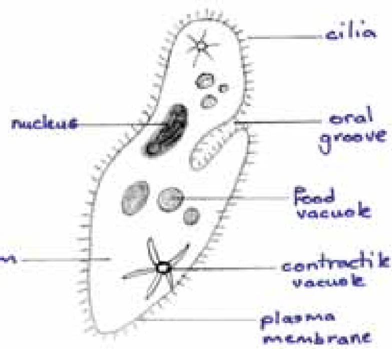
Are single celled organisms plants or animals? Explain your ideas.

Here are some diagrams of single celled organisms.

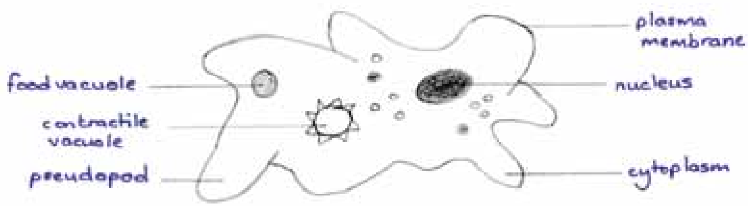
Euglena



Paramecium



Amoeba



Try and decide what you think each one is; a plant or an animal. Explain for each organism why you think this is.

Learners, in groups of four, discussed the diagrams and tried to apply prior scientific knowledge and understanding. They had no access to reference books or the internet. The teacher had used the concept of PMI diagrams* to produce a graphic organiser for the learners to use. Individually they completed the modified PMI diagrams.

Euglena

PLANT

Chloroplasts — only seen in plant cells to produce their own food via photosynthesis.

ANIMAL

Eyespot (photoreceptor) which is light sensitive — animals have eyes.

Flagellum which allows it to move around — sperm, another animal cell, also has a flagellum which allows it to swim.

INTERESTING

BUT — eyespot (photoreceptor) — plants are also sensitive to light.

Plants grow towards light.

In conclusion I think it is more likely that Euglena is a plant cell because although it has an eyespot (photoreceptor) plants are sensitive to light, it has chloroplasts.

****

Amoeba

PLANT

Food vacuole which suggests that it could produce its own food and store it there.

ANIMAL

Contractile vacuole – shows it can move and change its physical appearance.

Does not have the characteristics of an average plant cell – cell wall or chloroplasts – these are essential for plants as they need to make their own food via photosynthesis.

INTERESTING

Pseudopod – what is this?

In conclusion I think that the Amoeba is more likely to be an animal cell. I think this because it does not have the vital characteristics of a plant cell, however it contains all the basic characteristics of an animal cell. And the contractile vacuole also makes it more likely to be an animal cell because it can change its shape.

****

Paramecium

PLANT

Food vacuoles – can store and create its own food

ANIMAL

Cilia – suggests it doesn't make its own food but collects it from the outside

No chloroplasts or cell wall – commonly found in plant cells

INTERESTING

Oral groove – suggests it consumes other organisms (animal?) but could be like a Venus fly trap – a plant?

In conclusion I think the Paramecium is more likely to be an animal. I think this because although it has food vacuoles these could be used to store food that the animal has taken in until it digests it. The oral groove makes me think that it takes in food rather than makes its own.

Ali used linked scientific knowledge and understanding gained from previous learning in order to predict whether each of the organisms was a plant or an animal. This is a characteristic of Level 7. However, Ali's conclusions show an awareness of uncertainty, which is more characteristic of the Level 8 description.

The learners were then asked to compose questions related to their findings, which when answered might clarify their reasoning. The questions were shared in groups. Here are Ali's questions (his own next steps):

Does the *Euglena* have an eyespot (photoreceptor) so it can sense light and move towards it – so make more food from photosynthesis?

What is a pseudopod and what is it used for? Is it for moving or eating?

Does the *Paramecium* have an oral groove so it can eat?

How big are these organisms?

The group discussed all their questions and gave their own thoughts and opinions. Ali decided that he still needed more information to help him reach more valid conclusions. He did this as homework by researching on the internet. Ali reported back to the group in the following lesson. In doing so, Ali identified and explored uncertainties to try and explain anomalies, a feature of Level 8.

The teacher was aware that Ali had some misconceptions about vacuoles and their functions. Even though this is higher-order scientific knowledge and understanding, beyond Key Stage 3, she decided that it was more important for Ali to try and quash these misconceptions now.

Ali's next steps:
Try and find out what vacuoles are and do. Write a short paragraph to describe what you did and what you have found out.

What I did

I had to read quite a lot of different websites to write this. I used the search term 'vacuoles' first. But this gave me websites that I didn't always understand. They used scientific terms that just confused me. So I found one with 'kids' in the title. This was much clearer and gave me the idea that vacuoles were 'storage bins' in cells. But after reading a bit more on another kids' website, I thought that they weren't both telling me exactly the same thing. So then I went and looked at my sister's A level Biology text book. She also explained what she thought vacuoles were for. I thought that I understood then so wrote this.

What I found out

Vacuoles

Vacuoles are a type of organelle (this means 'small organ') found in cells of both plants and animals. There are two main types:

- Contractile vacuoles
- Food vacuoles.

Contractile vacuoles are used to control the water content of a cell. They can move to the edge of a cell to get rid of excess water or they can take in water from outside.

Food vacuoles are made when the membrane of a cell surrounds food which is outside a cell. The food in the vacuole can then be digested and the molecules absorbed into the cytoplasm. The remains are then taken back out of the cell.

Both these types of vacuoles can move in the cytoplasm (like jelly). Plant cells have a vacuole but this is fixed in the middle of the cell and contains cell sap. Only animal cells have food and contractile vacuoles.

Ali was then asked to read his original work and decide if he wanted to make any changes. He deleted the references to vacuoles throughout the work and added detail about vacuoles in animal cells.

A conversation between Ali and his teacher is given below:

Teacher:
Does this change any of your conclusions?

Ali:
Both *Paramecium* and *Amoeba* are animal cells as they have food and contractile vacuoles. These types of vacuoles are only found in animal cells. *Amoeba* and *Paramecium* must take food into a vacuole from the outside to digest it. They also control the water content of their cell using a contractile vacuole.

Teacher:
What about the *Euglena*?

Ali:
I'm now more certain that the *Euglena* is a plant because it doesn't have these types of vacuoles.

Ali could now be said to have formed consistent conclusions using detailed evidence, a feature of Exceptional Performance.

The learners were then asked:

Where do you think these single-celled organisms could all be found? Explain why you think this.

Again, they worked in small groups to discuss and compare ideas. For homework, the learners wrote up their ideas.

Where do you think these single celled organisms could all be found? Explain why you think this.

I think that these single celled organisms could live in water sources, such as oceans, lakes and rivers. I came to this conclusion because in water you don't need as much energy to move around. In addition, the cells would be able to feed on microscopic nutrients in the water, which they could take in via filter feeding. This can be seen in the Paramecium because it has cilia on its body, which are used for transporting nutrients to the oral groove. The food could be put in a food vacuole and digested. The Amoeba surrounds its food to make a food vacuole. However, if the single celled organisms are plant related (like Euglena) they could create their own food using the sunlight.

In the water the sunlight would be magnified and therefore stronger so it would be easier to photosynthesise. In conclusion it is more convenient for single celled organisms to live in water. This is clearly seen, by the fact that sunlight is magnified in water and there are more water based nutrients than air based nutrients.

Ali's next steps:

Looking at the way you have worked through this task, what other thinking/learning tools could you have used? Look in your thinking log to help you.

Ali has linked his learning about the single-celled organisms to predict where they would live. This is a characteristic of Level 8. He has also, again, used detailed evidence to form consistent conclusions, a feature of Exceptional Performance.

Characteristics of the **Level 7 description** include:

- *make qualitative predictions using linked scientific knowledge and understanding gained from a variety of sources*
- *in explanations they apply abstract ideas and make links between processes.*

Characteristics of the **Level 8 description** include:

- *draw conclusions showing an awareness of the degree of uncertainty*
- *identify and explore uncertainties and explain anomalies*
- *link the learning to make further predictions.*

Characteristics of the **Exceptional Performance description** include:

- *use detailed evidence to form consistent conclusions.*

How could this work be developed in Key Stage 4?

Further enquiries could be undertaken, such as:

- Describe how organism X is adapted to suit its environment.
- How does digestion in humans differ from that in an *Amoeba*?
- Are bacteria and viruses alive? Why do you think this?

Useful information and websites

Materials developed by or in conjunction with DCELLS

Science in the National Curriculum for Wales (Welsh Assembly Government, 2008)

Making the most of learning: Implementing the revised curriculum (Welsh Assembly Government, 2008)
Overview guidance on implementing the revised curriculum.

Science: Guidance for Key Stages 2 and 3 (Welsh Assembly Government, 2009)
Key messages for planning learning and teaching in science and the use of level descriptions to make best-fit judgements at the end of Key Stages 2 and 3.

Ensuring consistency in teacher assessment: Guidance for Key Stages 2 and 3 (Welsh Assembly Government, 2008)

A curriculum of opportunity: developing potential into performance (ACCAC, 2003)
To support teachers of more able and talented learners.

Skills framework for 3 to 19-year-olds in Wales (Welsh Assembly Government, 2008)

Developing thinking and assessment for learning programme (Welsh Assembly Government):

- *Why develop thinking and assessment for learning in the classroom?*
- *How to develop thinking and assessment for learning in the classroom*
- Developing thinking and assessment for learning poster and leaflet.

All these materials are available from the 'Curriculum and assessment' section at: www.wales.gov.uk/educationandskills

Aiming for Excellence: Developing thinking (BBC, Estyn, Welsh Assembly Government) 2006
A coaching/training DVD pack.

Other useful references with websites

King's College London

- The ASE – King's Science Investigation in Schools Project (AKSIS)
  www.kcl.ac.uk (search for AKSIS)
- Cognitive Acceleration through Science Education (CASE)
  www.kcl.ac.uk (search for CASE)
- SKEES Project (Science Enhancement Programme – King's Enhancing Enquiries in Schools)
  www.kcl.ac.uk (search for SKEES)
- Talking to Learn, Learning to Talk in Secondary Science (ESRC: Principal Investigator: Professor Jonathan Osborne, King's College, London)
  www.kcl.ac.uk (Search for talking to learn)

The University of York (Nuffield Curriculum Centre)

- 21st Century Science
  www.21stcenturyscience.org
- Encouraging experimentation and investigation in school science learning (NESTA) – Real Science
  www.nesta.org.uk (search for Real Science)

Other publications

Improving teaching and learning in schools (TLRP, ESRC) 2006

Science Education in schools, Issues, evidence and proposals
(TLRP: Gilbert, J (Ed)) 2006

Science inside the black box by Bethan Marshall, Jeremy Hodgen and Chris Harrison (NFER, 2006)
ISBN: 9780708714447/N0078

The role of teachers in the assessment for learning (E) (Nuffield Foundation: Harlan et al) 2006
www.k1.ioe.ac.uk

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