Research – 2 – Practice

Supporting Primary School Teachers to Engage with Science Education Research

A Wellcome Trust Funded Project

Background to the Research-2-Practice Project

Evidence-informed teaching has been a focus for the UK government since 2014 and whilst there is a suggestion that engagement with research to inform practice can enhance the quality of teaching, access to high quality research is a challenge for school-based practitioners. Successful schools make research more accessible to staff by building research resource banks and by collaborating with universities. Whilst stronger schools also support teaching staff to become more independent in their engagement with research, there can be a tension between access to research and the judgement of its quality. Furthermore, teacher workload has been highlighted as a concern across the education sector and this includes that of trainees engaged in initial teacher education. Lesson planning has been identified as something that can be burdensome for trainees and the expectation that they develop individual lesson plans should be reviewed to help address workload issues.

Project Details

The research team at the University of Lincoln, University of Roehampton, York St John University and KYRA Research School worked together to develop packages of research summaries and lesson plans to enhance the quality of teaching and learning in a bid to reduce trainee workload and help them to engage with research. These materials have been designed to support primary PGCE trainees and their school-based mentors.

There are 20 research summaries and exemplar lesson plans available for a range of science topics across Key Stage 1 and Key Stage 2. The materials comprise two documents per science topic:

A research summary that synthesises and condenses academic science education research about tricky topics in a short summary about what the research says about these issues and how they can be remedied through specific pedagogical approaches.

A lesson plan that has been developed by experienced classroom practitioners to illustrate the most effective way of teaching science in a way that draws on the findings reported in the research summaries.

The materials are also available to download from www.research-2-practice.org.uk

Feedback from a Year 3 mentor stated:

"the strengths of the plans from the research project are that the science behind each lesson is clearly defined in terms of expectation on the age of the children"

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Science – Key stage 1 (Year 2)

Statement of issue

Research in science education has found that pupils commonly find chemistry to be a difficult and abstract subject, and therefore they hold alternative explanations of various chemistry concepts (Coll & Treagust, 2003). Pupils have some difficulty in understanding the word *materials,* and of their uses, and these difficulties lead to a variety of misconceptions (Tarhan et al., 2013). For example, pupils can use the word *material* purely in its everyday sense, e.g., bricks are a form of building material, fabrics are clothing material, and stationery is writing material (Bouma et al., 1990). Pupils can then think that anything outside of these examples is not a material. In addition, pupils sometimes confuse the name of an object with the name of the material from which it is made (Driver et al., 2015). For example, Jones et al. (1989) found that pupils often perceived small pieces (samples) of materials such as wood, wax or glass as objects.

Main findings from the research

The development of the concept of matter (materials) is one of the fundamental aims of chemistry courses. Krnel et al. (2003) argued that one key feature in the early development of the concept of matter is that pupils learn how to distinguish between matter and objects: that they learn to distinguish between the intensive properties that characterise matter and the extensive properties that characterise objects. An intensive property is a property of matter that depends only on the type of matter in a sample, such as colour, temperature, density, and solubility (Redlich, 1970). Meanwhile, an extensive property is a property that depends on the amount of matter in a sample, such as size, weight, volume, mass and length (Redlich, 1970). Another key feature in the development process of the concept of matter is that pupils learn to do this by experiencing materials in their environment. In doing this, they gradually build up more elaborate schemata that form the basis of concept development (Mariani & Ogborn, 1990).

Modelling in science teaching and learning

It is known that pupils bring their own ideas into the classroom and organise them. These organised ideas are not usually used in order to generate a school science activity, but rather “extracts” are transmitted from the scientific consensus model to the pupils, to contrast and highlight the differences between these and the pupils’ often alternative ideas (Joshua & Dupin, 1993). In this way, schools tend towards the teaching of a *standard* science, a *true* science that is more or less related to the scientific consensus model (Clement, 2000).

Teaching and learning about science is seen as a modelling process, which is different from the transmission of a “scientific consensus model,” and involves teaching that is adapted to the age of the pupils (Acher et al., 2007). The various models that can be generated by pupils in the early school years are provisional representations that explain some aspects of reality, but which then gradually become associated with the scientific consensus ideas, thereby leading to the evolution and reframing of ideas (Acher et al., 2007). As Giere (1988) indicates, “The model-reality adjustment is not overall, but rather relative to those aspects of the world that the models attempt to capture” (p. 64). This is why the models that the pupils construct themselves have to be interpreted by the teacher so that the pupils can be supported towards developing models that are consistent with that of the scientific community.

Archer et al. (2007) explored *modelling* as a process whereby primary school pupils worked with recognisable and manageable materials as a way of thinking and talking about their individual ideas (models) about the more complex ideas about matter. Two teachers and 24 pupils (Year 3) took part in the study. A total of nine lessons were developed over a period of 2 months, in a weekly lesson of an hour and a half. The classroom was organised into six groups of four pupils, each of which manipulated a different kind of material: clay, sponge, water, stones, wood, and metal. The choice of these materials was based on their availability in the classroom (i.e., familiar materials for art activities) and its appropriateness in supporting activities that would elicit pupils' individual mental models about matter. All the groups followed the same tasks that consisted of looking at different ways of breaking down materials into smaller components (mechanical actions or by using water, for example).

The findings from Archer et al.'s (2007) study suggest some points for consideration. First, the teacher's role concentrated on identifying pupils' ideas that were consistent with accepted scientific thinking so that they could be further developed. Second, the experiences introduced throughout the study allowed the pupils to not only manipulate objects and materials, observe properties and changes, or recognise similarities and differences, but also to construct a model of the different materials as *matter*, which helped both their perceptions and their explanations. Third, the pupils' organisation of ideas within their model development was reached gradually and at different times by different pupils.

Findings from other related research

In another study, Krnel et al. (2003) explored the development of the concept of matter with 84 pupils (Years R (Reception) to Year 8). The pupils were asked to classify four sets of objects and materials and to explain their classifications during interviews. The study found that younger pupils tended to classify using a mixture of extensive properties (e.g., shape, size, weight, and volume) and intensive properties (e.g., colour, substance, and hardness), whereas older pupils (above Year 5) tended to use intensive properties most of the time. The study supports the idea of specific pathways in the development of scientific concepts. It also has specific implications for the modelling process of classification and the role of practical work in science lessons.

Krnel et al. (2003) suggests that with young pupils the task of the teacher should be to help them to develop the language to makes explicit their tacit knowledge and to extend their concrete knowledge of the properties of objects and substances. Besides this, a special emphasis should be placed on the actions of grinding, crushing, and dividing, as the underlying substance from which objects are made is revealed through these processes. In addition, different classification activities elicit different responses from pupils. The criteria which they use to classify objects depend on the sets of materials used. Once pupils have grouped objects or substances together, the educational task is not finished. The teacher should ask pupils to explain why they have grouped the objects and substances in different ways and should make explicit those criteria that identify the underlying matter from which the objects and substances are made.

In summary, the modelling process in science teaching and learning provides a systematic method when facilitating pupils to classify materials. Previous research has provided insights into how to design classification activities.

Therefore, a lesson plan was produced to incorporate the modelling process to help pupils to classify materials.

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Lesson Plan

Uses of everyday materials

Using a modelling process to teach about the uses of materials

Pupils should be taught to: (i) identify and compare the suitability of a variety of everyday materials, including wood, metal, plastic, glass, brick, rock, paper and cardboard for particular uses, and (ii) find out how the shapes of solid objects made from some materials can be changed by squashing, bending, twisting and stretching. Science – Key stage 1 (Year 2)

Research recommendation(s) and rationale	Research has shown that: The development of the concept of matter (materials) is one of the fundamental aims of chemistry courses. Krnel et al. (2003) argued that one key feature in the early development of the concept of matter is that pupils learn how to distinguish between matter and objects: that they learn to distinguish between the intensive properties that characterise matter and the extensive properties that characterise objects. Another key feature in this process is that pupils learn to do this by experiencing materials in their environment. In doing this, they gradually build up more elaborated schemata that form the basis of concept development (Mariani & Ogborn, 1990). Use of the modelling process, developing scientific language and schemata, individual support to move pupils on in their understanding/schemata, providing hands on opportunities to manipulate materials and targeted probing questions planned within the lesson should support in developing pupils' models at an individual level.
Lesson aim	To explore materials through hands on activities to develop an understanding of their materials and uses.
Learning objective	To identify, name and describe the properties of different everyday materials. To identify uses of everyday materials.
Intended learning outcomes	At the end of the lesson, pupils will be able to state: i. The difference between a material and an object. ii. That materials have different properties. iii. That the properties of materials make them suitable for different objects.
Scientific vocabulary	**Material –** The matter from which a thing is or can be made. **Squash –** crush or squeeze (something) with force so that it becomes flat, soft, or out of shape **Bend –** shape or force (something straight) into a curve or angle **Twist –** bend an object into a curled shape by turning ends the opposite direction to one another **Stretch –** be made longer or wider without tearing or breaking. Expose students to key vocabulary throughout the session, particularly during the 'real world activity' sections where the key terms will be pre-taught. As a follow up to the lesson ensure that students revisit these key word flashcards on a regular basis until they are secure, possibly using the Leitner 3 box system (https://www.youtube.com/watch?v=C20EvKtdJwQ&safe=active)
Suggested lesson sequence and activities	Introduction/Diagnostic assessment As an initial diagnostic assessment ask pupils to tick which of the following are types of material:

wood	glass	tree	fabric	pencil	window

Discuss the language of material and the contexts in which they have heard it used. Discuss examples e.g. bricks are a form of building material, fabrics are clothing material, and stationery is writing material, but remind pupils that a material as a scientific term is the matter from which a thing is or can be made.

Real-world activity
Give the pupils a range of materials and objects made from those materials – glass (object such as jar only due to health and safety), metal (small piece of scrap metal and a spoon), wood (a piece of wood and a wooden ruler), plastic (a piece of plastic and a plastic toy), fabric (a scrap of fabric and an item of clothing), brick (a piece of rubble and a whole brick), paper (a small ripped piece of paper and a paperback book) which they can feel and explore. In partners ask the pupils to discuss what each is. Then ask which are materials and which are objects? Ask pupils to sort into two piles.
During this activity look at diagnostic assessments and target individual pupils with questions to help clarify their understanding and further develop their models at an individual level.

Come together as a class to discuss and clarify any further misconceptions to ensure pupils are not confusing the name of an object with the name of the material from which it is made. You may need to offer real-life examples, e.g. discuss that a tree is a living object that provides wood and is used to make paper but is not a material until this point. Discuss that windows and pencils are objects made from a chosen material with suitable properties.

Vocabulary instruction
Pupils to spend 5-10 minutes recapping on previously covered vocabulary flash cards that link to today's learning (possibly using the Leitner 3 box system) and testing their partners knowledge e.g. material names, properties (hard, soft, smooth, transparent, opaque, waterproof etc.) Use this as an opportunity to assess pupils' understanding of materials based on previous learning.

Naming and identifying Activity – materials
Ask pupils to look around the classroom and spot objects made from the following materials: wood, plastic, glass, metal, fabric.
probing questions about materials and their properties, e.g. what properties does wood/metal/fabric usually have? Which of the materials is transparent? Which are absorbent?

Vocabulary instruction:
Introduce new key vocabulary linked to today's learning (squash, bend, twist, stretch), giving concise explanations whilst demonstrating on an object.

	Squash – crush or squeeze (something) with force so that it becomes flat, soft, or out of shape **Bend –** shape or force (something straight) into a curve or angle **Twist –** bend an object into a curled shape by turning ends the opposite direction to one another **Stretch –** be made longer or wider without tearing or breaking. Real-world activity - Exploring and testing suitability – materials: Looking at the selection on your table and around the room can you find an object which can be squashed? Can you find an object which can be bent? Can you find an object which can be twisted? Stretched? Can they find an object which cannot be squashed? An object which cannot be stretched? In talking partners ask pupils to discuss what material a table might be made from and what properties it requires to be to be suitable. Ask probing questions e.g. why would cardboard not be suitable? Why would you choose wood/plastic? Share with the pupils different objects (window, sock, bench, bucket, mattress, wall, ladder, towel) and for each one ask them to suggest different properties that a suitable material should have. Encourage pupils to consider all properties including the ones focussed on during the vocabulary instruction of today's session (bendy, stretchy, twisty, squashy). Use activity recording sheet to record the appropriate properties for each object. Pupils can explore the materials provided, testing which properties each material has and suggest a suitable material for each object (recording this on the attached resource sheet). Summarise/discuss: Pupils to share ideas about necessary properties of different objects and suitable materials for each object. Recap on the definitions of the new scientific vocabulary (bendy, stretchy, squashy, and twisty) asking pupils to mime each word. Which of the following materials can be changed in shape by bending, stretching, squashing, or twisting? Wood, metal, plastic, glass, brick, rock, paper, and cardboard. Discuss how the thickness of a material can influence how rigid and hard it is and therefore whether it can be stretched, bent, squashed, or twisted, using examples such as a plastic chair and a plastic straw.
Key questions	Can you find objects in the room which you cannot bend, stretch, twist or squash? What are they made from? Why can you not change their shape in any way? What properties do these objects have that make them impossible to bend, stretch, twist or squash? Can you bend, stretch, twist, and squash a sock? Ask pupils to demonstrate. Why is it important that you can do this to a sock? What are socks made from? Can you bend, stretch, twist, and squash a pencil? Ask pupils to demonstrate. Why is it important that you can't do these things to a pencil? What are pencils made from?

	What are the necessary properties for a window? What would a suitable material be? Would any other materials be suitable? Why? What are the important properties of a bench? What would a suitable material be? Would any other materials be suitable? Why? Can you show me how you would check to see if a material was bendy, stretchy, twisty, squashy, opaque, rigid etc.
Assessment opportunities	During class discussion and real-life activities, ask pupils key questions. Allow pupils to test each other on key vocabulary using flashcards made and use this as an opportunity to gauge understanding of key vocabulary (both previously taught vocabulary and new vocabulary introduced during today's session. Use naming and classification activities to gauge level of understanding.
Resources **H&S considerations**	Resources: • Initial diagnostic question • Range of different materials (wood, glass, metal, paper, brick, fabric, plastic) • Sheet to complete during real-world activity Please consult with your school's health and safety policy. Before beginning any practical activities, check all objects are safe to be manipulated by pupils without causing any injury. Before giving any materials/objects to pupils check for sharp edges, splinters etc..

LO - To identify, name and describe the properties of different everyday materials. To identify uses of everyday materials.

Object	**Required properties (use the word bank below)**	**Suitable material**
Window		
Sock		
Bench		
Bucket		
Mattress		
Towel		
Ladder		
Wall		

bendy squashy twisty stretchy opaque transparent
hard soft smooth rough waterproof absorbent rigid

Research Summary

Healthy Eating

Using a cognitive theory of learning to develop activities to teach about nutrition and healthy behaviours

Pupils should be taught to: describe the importance for humans of exercise, eating the right amounts of different types of food, and hygiene

Science – KS1 (Year 2)

Statement of issue

Globally, education on nutrition and healthy behaviour for young pupils is considered of great importance (Wang et al., 2012), as poor or unbalanced nutrition in childhood can inhibit development (Wang et al., 2000), cause issues with weight (Wake et al., 2009), and lead to medical problems (Branca et al., 2007).

Mikkelsen et al. (2014) conducted a review of nutrition and healthy behaviour interventions in young pupils, finding that there was *no* single pedagogy that was more successful than another; rather that successful studies similarly designed the education intervention using a cognitive theory of development. For example, Başkale and Bahar (2011) used *Piaget's Cognitive Development Theory* and Céspedes (2013) and Nemet et al. (2013) used *Social Cognitive Theory*.

Piaget's Cognitive Development Theory defines stages of cognitive development in pupils adopts a learner-centred approach and recommends self-discovery (Contento, 1981). Using *Piaget's Cognitive Development Theory,* Year 2 pupils are classified as being in the preoperational stage - meaning they are in the stage when they learn basic concepts - they learn by imitating the environment, exploring, asking questions, and classifying. Piaget's theory (1999) suggests that pupils learn more when they actively take part in activities. Therefore, educational material on nutrition that follows the Piagetian theory is designed to contain simple, positive, and behaviour-orientated messages that pupils can actively demonstrate.

Social Cognitive Theory proposes that learning occurs in a social context, as learning relies on interactions with others, and knowledge and competencies is modelled (Bandura, 1977). Adopting *Social Cognitive Theory* lessons for Year 2 pupils, teachers would promote opportunities that create a feeling of accomplishment of a skill, (e.g. cooking and then eating what they made), and when learning about a behaviour (i.e. the health benefits of a daily walk), the behaviour would be adopted by the class (Luszczynska & Schwarzer, 2013). Educational approaches that adopt this theory aim to increase pupils' knowledge and alter their behaviour (i.e. making more healthy choices to alter weight; Luszczynska & Schwarzer, 2013). Evidence of studies designed to alter pupils' behaviour focuses on evidence of changes in behaviour (e.g. 'do pupils make healthier choices at lunchtime?'), or changes in body mass index (BMI) measurements pre-and-post the intervention (e.g. Hendy, 2002).

Main findings from the research

What the research shows

Başkale and Bahar (2011) developed and tested a nutrition education programme for Year 1 pupils based on *Piaget's Cognitive Development Theory* in Turkey. Six infant schools took part, comprising 227 Year 1 pupils, the schools were paired; one school received the intervention, and the other acted as a control, that received the national nutrition education programme prescribed by the Ministry of National Education. Pupils took part in the nutritional education programme delivered by their school-based teacher for one 20-minute session every week for six weeks. Each lesson of the nutritional education intervention programme was designed to follow the process of assimilation, accommodation, and equilibration (Piaget, 1999). Lessons focused on discovering the food pyramid, learning about healthy eating, and the consequences of eating unhealthily. Pupils were introduced to each nutrition concept and then asked to draw and colour pictures, play games, listen to stories, and take part in a plenary at the end of each lesson. Pupils' nutritional knowledge was measured individually using *MyPyramid for Kids* (Bowman et al., 2008). The researcher read aloud the questions, and the pupils pointed to the correct pictorial answer. Pupils' knowledge was measured pre-and-post intervention, revealing that the pupils who took part in the intervention had statistically significantly more knowledge from the pre- to post-test and had a statistically significant better understanding of nutrition than pupils in the control group who received the national nutritional education programme. Approximately 50% of pupils from the original sample completed a follow up a year later with the same test; the results revealed that the pupils who had taken part in the intervention had retained statistically significantly more knowledge than their pre-test scores. This suggests that using *Piaget's Cognitive Development Theory* to design a nutritional education programme for young pupils effectively supports their learning because the interactive activities are appropriate for their cognitive development stage.

Similarly, Céspedes (2013) examined the effectiveness of a combined nutrition and healthy behaviour programme using *Social Cognitive Theory* in Colombia. A, intervention that recruited 14 schools from across the country implemented an intervention that lasted for 5 months, with lessons lasting for 1 hour every day. The intervention was designed to be playful and educational and centred around interactive activities driven by *Social Cognitive Theory*. There was a varied programme of interactive activities, including storybooks, videos, posters, games, songs, and letters sent home to parents. The sample comprised 564 Year 1 pupils and 652 pupils aged 3. Half of the schools received the intervention from school-based staff, and half were assigned to a control group, where pupils received their usual nutritional education as prescribed by the curriculum. Pupils' knowledge was measured using a questionnaire, which revealed that pupils who took part in the intervention performed statistically significantly better than those in the control group. Approximately 50% of the original sample was followed up 18 months later and again 36 months later, showing that pupils in the intervention maintained their knowledge gains. This demonstrated that the educational intervention had a long-lasting impact on pupils' knowledge and suggested the importance of teaching about nutrition and healthy behaviours together can have a long-lasting effect on pupils' understanding, even for pupils as young as 3 years old.

Nemet et al. (2013) designed and examined the effectiveness of a nutritional programme for low-socioeconomic Arab-Israeli infant school pupils using *Social Cognitive Theory*. Critically, pupil knowledge was measured pre- and post- the intervention, using a guided interview format. This is an age-appropriate method to measure young pupils' understanding, where pupils were handed a doll and asked how the doll could stay healthy, pupils were also prompted with picture-pairs of a healthy and unhealthy choice and were asked to choose the picture that would help the doll stay healthy. A sample of 342 Year 1 pupils took part, half receiving the intervention by school-based staff, and half receiving their normal curriculum with no additional lessons on nutrition or health (i.e. a control group). The intervention was targeted at three areas: nutritional knowledge, physical activity knowledge, and a physical activity programme, and lasted for a year. The teachers ensured that the teaching was appropriate to the cognitive and social development of the pre-school pupils. The nutritional knowledge focused on food groups, vitamins, making healthy food choices, food preparation, and healthy cooking methods. Topics were taught through short introductory talks, games, singing and reading. Pupils in the intervention also took part in 15 minutes of daily exercise, which included games based on football, dodge ball, hide and seek, or relays. They found a statistically significant increase in knowledge of nutrition and healthy behaviours for those pupils that took part in the intervention compared to those pupils in the control group.

Nemet et al. (2013) followed up approximately 60% of their cohort one year later to examine the long-term effects of the nutritional programme. They found that knowledge of nutrition and healthy behaviours was statistically significantly better for pupils who had taken part in the intervention than the control. Although using a different method of assessing knowledge, Nemet et al. (2013) has similarly demonstrated that using theory to drive the design of nutrition and healthy behaviour activities is both effective and long-lasting.

Summary

Research demonstrates the effectiveness of using a cognitive theoretical framework to design activities to teach nutrition and healthy behaviour (Başkale & Bahar, 2011; Céspedes, 2013; Nemet et al., 2013). As Céspedes (2013) study highlights, it is essential to teach nutrition alongside healthy behaviours, as stated in the curriculum. The research interventions lasted for different lengths of time, ranging from 6 weeks (Başkale & Bahar, 2011) to a year (Nemet et al., 2013). However, they also used short daily and weekly activities, for example, 15 minutes playing games as daily exercise (Nemet et al., 2013), or 20 minutes listening to stories or drawing about healthy eating (Başkale & Bahar, 2011). The literature suggests the possible value of creating several short activity sessions that are theoretically driven, and that education on nutrition and healthy behaviour is repeated weekly for at least 6 weeks (Başkale & Bahar, 2011).

Therefore, a lesson was produced to incorporate activities designed using a cognitive theoretical framework into nutrition and healthy behaviour.

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Lesson Plan

Healthy Eating
Using a cognitive theory of learning to develop activities to teach about nutrition and healthy behaviours.
Pupils should be taught to: describe the importance for humans of exercise, eating the right amounts of food, and hygiene.
Science – Key stage 1 (Year 2

Research recommendation(s) and rationale	Globally, education on nutrition and healthy behaviour for young pupils is considered of great importance (Wang et al., 2012), as poor or unbalanced nutrition in childhood can inhibit development (Wang et al., 2000), cause issues with weight (Wake et al., 2009), and lead to medical problems (Branca et al., 2007). Mikkelsen et al. (2014) conducted a review of nutrition and healthy behaviour interventions in young pupils, finding that there was *no* single pedagogy that was more successful than another; rather that successful studies similarly designed the education intervention using a cognitive theory of development. For example, Başkale and Bahar (2011) used *Piaget's Cognitive Development Theory* and Céspedes (2013) and Nemet et al. (2013) used *Social Cognitive Theory.*
Lesson aim	To improve pupil understanding of what it means to maintain a healthy lifestyle through healthy food choices and exercising.
Learning objective	To make positive food choices and take part in exercise to encourage a healthy lifestyle.
Intended learning outcomes	At the end of the lesson pupils will be able to: • Classify foods into their correct food groups. • Identify foods which are healthy and unhealthy. • Suggest exercise activities which contribute towards a healthy lifestyle.
Scientific vocabulary	Fat – a nutrient found in foods and is the major storage form of energy in the human body. Protein – an essential nutrient for the human building. Helps with building body tissue (muscle) and growth. Carbohydrate – these are sugar molecules and one of the three main nutrients found in foods and drinks. Body breaks them down to create glucose which is the main source of energy for your body's cells, tissues and organs. Vegetables – the edible portion of a plant. They are an essential part of the diet and play an important role in human nutrition, being mostly low in fat and carbohydrates but high in vitamins, minerals and dietary fibre. Calcium – a mineral found in foods, specifically dairy and stored in bones and teeth in our body. Essential for growth and development of pupils and adolescents as it maintains strong bones and teeth. Vitamin – an essential nutrient for the human body. Perform hundreds of roles in the body such as healing wounds and generally improving the body's immune system. Exercise – an activity which requires physical effort, carried out to sustain or improve health and fitness. Nutrition – the process of eating a healthy and balanced diet for health and growth. Bones – the substance which forms the skeleton of the body.

	Healthy Eating – a diet which helps to maintain or improve overall health. Provides the body with essential nutrition to protect it from diseases and ill health. Mineral – the elements in food which our bodies need to develop and function normally. Fuel – a word used when describing the energy our body uses/needs to continue to function normally. Muscle Energy – the fuel a muscle uses to complete a movement. This could be as basic as breathing up to running in a sprint race.
Suggested lesson sequence and activities	This particular objective is most successfully completed over a series of lessons in order for pupils to relate to how a consistent change to diet and exercise can improve and maintain a healthy lifestyle. A suggested time scale has been included next to each activity so that teacher discretion can be used when grouping some activities together etc. 1) Complete Pre-assessment below. *10 minutes* Başkale and Bahar (2011) suggested using assessments before the lessons to gage progress and attainment after pupils receive educational input. 2) Introduce the unit of healthy eating and gather information from pupils about what they think it means to maintain a healthy lifestyle. Explain to the pupils that a healthy lifestyle includes having a balanced diet and completing regular exercise. *10 minutes* 3) Piaget (2013) suggests pupils learn more when actively taking part in a lesson. Show pupils examples of different foods (real life items will make this more engaging and memorable for pupils). Ask pupils to vote as a class if they think it is healthy or unhealthy. Then go through the correct answers with the pupils. From this go into more detail on the unhealthy foods and explain to the pupils that they are unhealthy if eaten in large proportions but a small portion of them is good for humans. For example, fats are used to keep the body warm and as a source of energy. But this only needs to be in small, well balanced portions. (Work with the food wheel/pyramid will display this for the pupils). *15 minutes* 4) Introduce the food wheel to the pupils using websites below: https://www.nhs.uk/live-well/eat-well/the-eatwell-guide/ https://www.gov.uk/government/publications/the-eatwell-guide These demonstrate which food groups should make up most of a diet in a healthy person. This is a good opportunity to introduce lots of the key vocabulary above and check for understanding. Give pupils food items of pictures of food items and allow them to group these items based on their food groups. *30minutes* Piaget's Cognitive Developmental Theory believes that pupils in Year 2 are in the preoperational stage of development and learn by exploring asking questions and classifying. 5) Ask the pupils about the activities they complete which require physical effort (heart rate quickens, becoming out of breath, sweating). As a class pick a few which are measurable for example, lengths of a hall in one minute, number of jumping jacks in a minute etc. Give pupils the opportunity to complete each activity and keep a log of their results. Explain to the pupils that each day they will be completing an activity to improve their fitness so that by the end of the unit, they will repeat the activities before and hopefully see an improvement in scores. Daily activities could include: 10 minutes of walking/running around playground, dancing – search for Just Dance videos, which can be done in the classroom as well as *Supermovers* (https://www.bbc.co.uk/teach/supermovers). *45 minute for initial lesson and then 10 minutes daily for exercise until the end of unit/term.* Bandura's Social Cognitive Theory (1978) suggests pupils learn through a feeling of accomplishment and seeing a change in behaviour or actions. So by allowing pupils to collect results at the beginning and end they can see how their behaviours and actions have altered their results.

	6) For remainder of unit, expose pupils to regular lessons in nutritional education. This would work well as a carousel of activities if completing in one session or distributed to one shorter session a week. i) Activity 1 – Pupils to make some healthy food recipes following recipes. ‘Search for healthy food recipes KS1’ for inspiration. *30-60 minutes (dependent on chosen recipe)* Social Cognitive Theory believes giving pupils feeling of accomplishment helps them to learn. ii) Activity 2 – Share healthy eating stories with pupils. ‘Search for healthy eating stories KS1’ for examples. This is a good opportunity to explain to the pupils the possible effects of being unhealthy can be e.g. heart disease, type 2 diabetes etc. *30-60 minutes* Başkale and Bahar (2011) iii) Activity 3 – Show pupils some examples of lunchboxes; either with real food or pictures. Ask pupils to identify the food item and sort into food group. Pupils to then decide as to whether the lunch is balanced and healthy or unbalanced and therefore could be healthier. Pupils to suggest improvements to balance lunchbox examples. *30-60 minutes* 7) Complete post-assessment task below. *10 minutes* 8) Complete the activities lesson 5 at the end of the unit so pupils can see if any of their scores have improved from the initial set of results.
Key questions	- What are the food groups? - Which food groups should make up most of balanced diet? - Which food groups should you only have small amounts of? - What role does [insert key vocab word e.g. fat] have in the human body? - What activities can you complete to improve your fitness? - What food group does [insert food] belong to? - Why do we need some unhealthy foods in our diet? - What do foods contain which are considered healthy? - What do foods contain which are considered unhealthy? - Why do you think your scores improved in the exercise activities?
Assessment suggestions	1) Pre-assessment: Provide pupils with pictures of different foods from all of the food groups. Give pupils three plates in which to sort the foods onto. Plates should be labelled as follows: i) I should eat lots of these foods. ii) I should eat these foods sometimes. iii) I should only eat a little bit of these foods. Take a picture of the end result and keep for tracking progress. 2) Post-assessment: Pupils to repeat the work above at the end of the unit of work. Take a picture again of the end result to see the progress made by pupils.

	3) A further form of assessment which could be completed would be for the pupils to create informative posters to display their knowledge from the unit of work. Some teacher input would be needed to explain to the pupils they need to include information about food groups, exercise, and possible risks if an unhealthy diet is followed.
Resources	Food samples or pictures of food items. Food pyramids/wheels. Stopwatches/timers for exercises. Food items for recipes. Healthy eating stories. Healthy and unhealthy lunchbox examples.
H&S considerations	Please consult with your school's health and safety policy, particularly with regard to potential food allergies.

Research Summary

Living, Dead and Never Been Alive
Using direct encounters with animals and plants to teach about the difference between the living, dead and things that have never been alive
Pupils should be taught to: explore and compare the differences between things that are living, dead, and things that have never been alive
Science – KS1 (Year 2)

Statement of issue

Studies show that Year 1 pupils struggle to distinguish between living and non-living things (e.g. Carey, 1985; Jipson & Gelman, 2007). Indeed, as many pupils solely use the criteria of movement to decide as to whether something is alive or not this leads them to mistakenly attribute life to moving toys, clouds and computers (i.e. which have moving images on the screen) and to attribute non-living classification to plants (Villarroel & Infante, 2014; Venville, 2004). However, it is important to develop this foundational knowledge to distinguish between living, dead and things that have never been alive, to build on in later science lessons (Siegal & Peterson, 1999).

Main findings from the research

Research suggests that pupils need to expand their scientific framework by learning to classify living and non-living things with additional criteria (Villarroel & Infante, 2014). Venville (2004) conducted a study exploring Year 1 pupils' construction of scientific knowledge for living, dead, and things that have never been alive. They found that most pupils classified an organism as living if it was moving, and non-living if it was not moving. Venville (2004) demonstrated that pupils could learn how to identify other differentiating criteria such as dependence on food, water and aspects in their environment for life. Research shows that the most effective way to teach differentiation between things that are living and dead is to have encounters with living and dead organisms (Nxumalo, 2018; Venville, 2004; Zogza & Papamichael, 2000).

What the research shows
Gasparatou et al.(2020) challenged pupils' sole criterion of movement for attributing life by presenting them with an aquarium that contained a living fish and a mechanical toy fish (these were identical in shape, colour and movement). Fifteen Year 1 pupils were individually interviewed before and after the class, they were asked to sort pictorial cards into living and things that have never been alive and give a reason (a different set of cards was used when setting up the class discussion before introducing the fish). They replicated previous research findings (Venville, 2004; Villarroel & Infante, 2014) that reported that pupils did not have difficulty correctly classifying living things that they could attribute movement to. They also found that compared to the pre-test, pupils who struggled to correctly classify living and non-living things markedly improved, either correctly classifying all cards, or with one incorrect classification in the post-test (previously correctly classifying 1 of 17 cards). Improvement was attributed to the development of additional criteria about living organisms dependence on food and aspects within their environment. This suggests that an encounter with a living and never-been alive fish helped pupils understand how to correctly classify animals.

Zogza and Papamichael (2000) designed and tested a Year 1 class intervention for teaching the classification of living and non-living. The intervention focused on building pupils' understanding that animals and plants are dependent on food, water, and other aspects within their environment if they are to remain alive, and when one of these criterion stop, a living organism dies. They tested 46 Year 1 pupils' ability to distinguish between living and non-living. From those tests they identified 18 pupils who had not yet developed an understanding of living and non-living, as they classified plants as non-living and it is those pupils who participated in their intervention study. The pupils were grouped into two classes of 9, one class received the experimental intervention, and the other 9 pupils were used as a control. Both classes observed spiders and a flowering plant. The intervention consisted of two steps, first observing living spiders, a dead spider and then a picture showing spiders on their web. The pupils were then told a story about a spider which emphasised the spider's need for food and other environmental factors to remain alive. A class discussion ensued, focusing on what the spider needed to stay alive and what a dead spider cannot do. Secondly, pupils were shown a living, flowering plant and discussed what the plant needed to stay alive. A short presentation on the plant's needs was given, emphasising what the plant needed to stay alive. A dead plant was then shown to the pupils, and they were asked to explain how it had become like that (emphasising comparisons between the living and the dead plant). They were then shown an artificial flowering plant, and asked if they thought it was alive and how they knew.

The research found that pupils who received the intervention were better at classifying objects into the three groups (living, dead and never been alive) than pupils in the control class. The post-test included extra items, a cloth spider, and a moving toy car to ensure that pupils' understanding could be attributed to an improvement in their ability to classify rather that just being more knowledagble about the specific instances of the plant and spider that they had learned about. All pupils in the intervention class correctly classified the living plant as alive (in the pre-test no pupil could do this). This compared to the control class where at the end of the lesson only one pupil classified the living plant correctly, suggesting that the intervention was successful. All pupils, across both classes, correctly classified the living spiders in both the pre-and-post tests. However, the pupils who received the intervention were better at classifying the dead and cloth spiders as non-living than pupils in the control class. The pupils in the intervention class were also able to apply their ideas to the moving toy car and cloth spider, correctly identifying them as non-living; again, none of the pupils in the control class were able to do this.

Behaviour around bees

It is important to recognise that these findings could be because the pupils became more familiar with an object the more they had experience of it. Nxumalo (2018) addressed the issue of familiarity by conducting a case study on Year 1 pupils about living, dead and dying; they focused on pupils' encounters with bees in their everyday lives. Bees were chosen because this class of pupils were familiar with observing pictures of bees, having previously identified colour patterns, counted body parts, distinguished bees from wasps and pollinated an apple tree using paint brushes. Before the intervention (and previous learning about bees), interactions with live bees in the playground was strongly discouraged and learning about bees was more classroom-based without real examples. The intervention addressed this by encouraging pupils to notice bees outside in the playground, for example.

Choosing Animals

It is important to consider how we use animals in teaching, and use naturally occurring instances of life, death and dying, and focusing on animals that are naturally readily accessible to us within the school environment (Smith & Smith, 2004). Research suggests selecting an animal that has an obvious way of feeding and selecting an animal that pupils will not be upset about if it has died (Zogza & Papamichael, 2000). Research further recommends providing opportunities for pupils to have experience of live, dead and artificial animals and plants which they are familiar with in order to be able to differentiate between them (Nxumalo, 2018; Gasparatou et al., 2020; Zogza & Papamichael, 2000).

Caution is needed when using living organisms such as plants and animals with young pupils and a careful risk assessment should be carried out. However, research suggests that providing these real-life encounters with different examples of living, dead and things that have never been alive is key to pupils' developing understanding (Ghafouri, 2014; Nxumalo, 2018).

Therefore, a lesson was produced to provide pupils with examples of living, dead and artificial animals and plants to help them to differentiate between things that are living, dead and have never been alive.

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Lesson Plan

Living, Dead and Never Been Alive
Using direct encounters with animals and plants to teach about the difference between the living, dead and things that have never been alive.
Pupils should be taught to: explore and compare the differences between things that are living, dead, and things that have never been alive.
Science – KS1 (Year 2)

Research recommendation(s) and rationale	Studies show that Year 1 pupils struggle to distinguish between living and non-living things (e.g. Carey, 1985; Jipson & Gelman, 2007). Indeed, as many pupils solely use the criteria of movement to decide as to whether something is alive or not this leads them to mistakenly attribute life to moving toys, clouds and computers (i.e. which have moving images on the screen) and to attribute non-living classification to plants (Villarroel & Infante, 2014; Venville, 2004). However, it is important to develop this foundational knowledge to distinguish between living, dead and things that have never been alive, to build on in later science lessons (Siegal & Peterson, 1999).
Lesson aim	Using direct encounters with animals and plants to teach about the difference between the living, dead and things that have never been alive
Learning objective	To understand how to classify things as living, once lived, never lived.
Intended learning outcomes	Pupils can: Describe characteristics that allow things to be classed as living/alive, once lived, never lived Collect a range of suitable objects/things that match the sorting criteria of living, once lived, never lived Sort and classify a range of things into the categories living, once lived, never lived – explaining their reasoning
Scientific vocabulary	**Alive/living:** Anything that is currently alive. **Once lived/dead:** Something that used to be alive but is no longer living. **Never lived:** Anything that can be classed as having never been alive e.g., anything man-made (plastic), mechanical, naturally occurring such as rocks, soil, air etc. Classify/sort: Animal/plant names (good retrieval exercise on things they have learned previously to before). Specific vocabulary linked to parts of animals/plants – again this knowledge should already be embedded from previous years - e.g. fur, hair, shell, twig, leaf, stem, branch, bones, logs.
Suggested lesson sequence and activities	Teacher notes: Once-lived is something that used to be alive but is no longer living. Examples include a dead animal/ plant or part of a plant/ animal, such as leaves, twigs, logs, empty seed cases, bones, dead skin or hair. These are usually referred to as dead, but the more appropriate

scientific term is ‘once-lived’. Examples of things that have never lived may be naturally occurring, such as rocks, soil, air and water, or manufactured materials such as refined metal and plastic.
Note: Living is anything that is currently alive. Seeds can be classed as living, as they are able to germinate and grow, given the right conditions. Berries and fruits contain seeds so can therefore be classed as living.

Vocabulary:
A large percentage of the vocabulary used in this lesson should already be embedded from previous learning in other year groups, with the specific Tier 3 vocabulary being discussed and taught through the early activities in the lesson. Class Teachers may wish to refer to a vocabulary wall in the classroom or play some brief vocabulary bingo games to revisit words they believe the pupils will not know.

This lesson can be taught as the first lesson in the sequence of this topic but will be useful if it is taught after Animals inc. Humans topic and Plants Topic in Y2, so that pupils have a good understanding of plants/animal classifications, so they can use this knowledge to really understand why something is classed as living/once lived. It will also build on knowledge gained from Y1 topics: Plants and Animals inc. Humans.

Explore:

Show pupils a small collection of items for example a rock, some soil, a dead leaf, a branch, a piece of bone and a living thing. Choose three of the items and ask pupils to think about which object is the odd one out and why this is. When they have had time to think, ask them to share their idea with a partner. Repeat with another three items and gather ideas from different pupils. Encourage them to use the structure ‘I think…is the odd one out because…’. Explain to pupils that all ideas are valid but they should give reasons to support their ideas.
Begin to develop the ideas around these items all being classified as: living, once lived, never lived.

Pose question **Am I alive?** How do they know? What do you do that shows you are alive? Share ideas e.g. grow, eat, drink, move, reproduce. Collect these ideas on a class display/flip chart paper etc.

Show pupils a pot plant and ask them if they can think of anything that the plant does that is similar to what you/they do: (This can be a good opportunity to reinforce/revisit previous learning) e.g. grow, reproduce (seeds). Can you think of other things/organisms that are alive, e.g. pets, trees, minibeasts of various kinds, etc.? How do we know they are alive? Discuss.

Show pupils the artificial plant. Again, ask the question: Is this alive? Encourage the pupils to start thinking the criteria they have begun to assemble around how to decide if something is alive or not. Encourage the pupils to again give reasons for their answers. These discussion can be done verbally, ideas written on Post-It notes, whole class scrap books etc. (Pupils should be able to come to the

	conclusion that the artificial plant is not alive, but there may need to be more discussion around is the artificial plant once alive or never been alive. Questions should be posed to the pupils to facilitate this discussion and allow pupils to formulate the idea around how to distinguish something which is dead and has never lived). Next show pupils the live goldfish/fish and the dead fish. (Or equivalent animals with one alive and one dead). This can be facilitated either with each group having a goldfish and dead fish to compare on their tables, or just an example at the front. Give the pupils 5-10 minutes to discuss in groups/pairs what the two fish in front of them would be classified as (living, once lived, never lived). Ask the pupils to note down their responses, and again, give reasons why. Pupils can then share thoughts on what they have put. (Assessment opportunity during and after the activity for the teacher to assess pupils understanding on how to categorise things into living, once lived, never lived.) **<u>Enquiry:</u>** Pupils to go out and explore their school grounds, a local habitat etc. and collect items/objects/things which match the criteria of living, once lived, never lived (Care needs to be taken here, as pupils may not be allowed/wat to 'pull' up plants, capture minibeasts etc. photographs with child friendly tough cams etc. would potentially be more applicable). Pupils can place their items into clear bags, ready for taking back into the classroom. Once back in the classroom, the pupils can share their findings as a table or in groups. Ask the pupils to then sort the range of objects, things they have found on their walk into the three categories: living, once lived, never lived(You may wish to add some extra items in to challenge the pupils and ensure they have a mixture that will allow all categories to be sorted.) The pupils can do this physically into hoops or can record this on their own sorting tables by sticking/drawing the things/objects into the correct categories. (NB: Health & Safety procedures would need to be followed regarding pupils handling 'foreign' objects etc.) **<u>Review/Discussion:</u>** Bring the pupils together so they can share their classifying. Invite pupils from different groups to describe how and why they have sorted the objects as they have, always referring back to the 'criteria' that was discussed as a class at the start of the lesson.
Key questions	How do we know if something is alive? What do we mean by something that has never lived? If something moves, does it mean it is alive? Why? How do you know it once lived? What helped you decide?
Assessment suggestions	WS Skill: Sorting & Classifying.

	Pupils can be assessed whether they can accurately sort a range of objects/things accurately, using defined criteria. Pupils can explain the difference between things/objects which are living, never lived, once lived – showing clear understanding between things which were once alive and things which have never lived.
Resources	A ‘real’ plant and artificial plant An alive animal (fish, worm, etc.) and a dead animal (dead fish from the fishmonger etc.) Range of objects that are alive, never been alive (mechanical, artificial plants/animals), dead (twigs, branches, leaves, parts of animals - shed skins etc.)
H&S considerations	When handling objects/materials ensure hand washing procedures are in place. When looking at ‘dead’ animals, make sure this is sensitive to the pupils.

Research Summary

Plants

Using less obvious anatomical features, generic names and real plants to help pupils to identify, name and classify plant types

Pupils should be taught to: (i) identify and name a variety of common wild and garden plants, including deciduous and evergreen trees, and (ii) identify and describe the basic structure of a variety of common flowering plants, including trees.

Science – Key stage 1 (Year 1)

Statement of issue

In broad terms, classification involves placing objects into categories (Tull, 1994). Botanists categorise plants as *monocot* and *dicot* based on their morphology (life-form, fruits, leaves, and flowers), habitat and usage (Poncet et al., 2015). However, these three aspects seem to be mutually interlinked for certain plant groups, which always results in the same groups, independent from the different sorting criteria (Poncet et al., 2015). Lay person categories for the plants that young pupils typically engage with include trees, bushes, vines, and wildflowers (Tull, 1994). Allen (2020) classified young pupils' plant kingdom into four main criteria: i) lichens, ii) mosses and liverworts, iii) ferns, horsetails and clubmosses, and iv) flowering plants and conifers.

Research indicates that pupils have a poor understanding of plant classification (Bell, 1981). Primary school pupils build their understanding of biological concepts through direct, concrete experiences with living things, their life cycles, and their habitats (Barman et al., 2006). However, research has shown that pupils often develop understandings about the physical and natural world, which are quite different to those presented by the scientific community (Angus, 1981; Osborne & Freyberg, 1985). For example, Bell (1981) found that some pupils did not consider trees to be plants. It was also found that many pupils did not consider an organism to be a plant, unless it possessed specific characteristics or parts such as a flower or stem.

Main findings from the research

The three case studies presented below were extracted from previous research (see Patrick & Tunnicliffe, 2011; Tull, 1994; Tunnicliffe & Reiss, 2000) related to the ways primary school pupils name, identify and classify plants. These case studies provide important considerations for teachers when teaching pupils about this topic.

Case study 1

Tunnicliffe and Reiss (2000) explored how 36 pupils spread across Years 1, 4, 6 and 9 used their existing mental models to recognise, identify, and group six different plants (strictly, five plants and a fungus). The study was carried out in two schools in the UK. Each pupil was shown the six plants and asked to put them into the order in which they would like to talk about them. For each one, the pupils were asked a series of questions about what the plant was, why they had named the plant *X*, and what made it an *X*. The pupils were then asked to group the plants, with the researcher saying: '*Would you group the plants for me, please? Do any of them belong together?*'. Finally, they were asked to justify their choice of grouping.

The study reported that pupils had to recall their existing mental model of a closest fit and match that to the plant they observed. Pupils' responses from all ages indicated that they mainly recognised and used anatomical features when naming the plants and explaining why they are what they are. However, the study showed that older pupils are more likely to also use habitat features. For pupils, the home setting and direct observations were more important sources of knowledge than what they learnt at school. As pupils age, their reasons for grouping plants become more complicated: in addition to relying on shared anatomical and habitat features, they begin to show evidence of a knowledge of taxonomy and use this knowledge to group plants.

Tunnicliffe and Reiss's (2000) research has important implications for primary science learning. Although plants readily engage pupils' interest, pupils tend to focus on striking anatomical features. Teachers can help pupils to learn by encouraging them to describe and comment on less obvious anatomical features. In other words, pupils can be helped to observe with greater precision. For example, teachers could point out that fungi are not green, that mosses do not have flowers, that conifers often have thin needle-shaped leaves, etc. Furthermore, teachers need to play a greater role if pupils are to learn accepted scientific views. It is particularly worth teachers discussing with pupils their prior knowledge before attempting to teach them new material in this field.

Case study 2

In another study, Patrick and Tunnicliffe (2011) investigated how 108 pupils spread across Years 0 (Reception), 2, 4 and 6 in England and North Carolina, United States, listed the names of the plants and where they could be seen. The study was conducted using a structured three-layered interview. The first layer used free-listing and asked pupils to list all the plants they knew in one minute. The second layer asked pupils to state where they saw the plants. The third layer provided pupils with a habitat and asked them to identify a plant found in that specific habitat. For example: 'Name a plant that lives in the water'.

The study found that pupils in England successfully named domesticated plants more often than exotic, endemic wild, and farmed plants. Meanwhile, pupils in the US named farmed plants more often than exotic, endemic wild, and domesticated plants. When the plants named by pupils were broken down into scientific categories, the results for the two countries were nearly the same. *Dicots* and *monocots* were named more often than any other type of plant. The most frequently named *dicot* was the rose. The most frequently named *monocot* was grass. Bryophytes were not identified by pupils in the US, but four bryophytes were named in England.

Patrick and Tunnicliffe's (2011) research have important implications for teaching about plants in the primary science curriculum. Pupils' prior experiences with family, in which they ate plants or planted, seemed to make a difference to pupils' plant knowledge. Therefore, when teachers teach about plants, it is paramount that they include hands-on interactions such as planting, dissecting flowers, touching seeds, and comparing real plant parts. The study emphasised that teachers must be hands-on when developing young pupils' biological understandings of plants because they remember plants that have been introduced to them outside of school.

Case study 3

In an earlier study, Tull (1994) examined how nine pupils (Year 7) responded to questions about plant identification. Each pupil was interviewed separately in their homes and in the outdoors. Each pupil identified plants on two fieldtrips, one in the familiar setting of the pupil's own neighbourhood and one on a trail near their homes. To elicit names, the researcher asked questions such as: '*What are the names of the things you see around us?*' and '*What do you call this?*'. Each pupil named as many species as could be examined in two outings, ranging from 40 to 86 species.

The findings from the study indicated that the pupils used a wide variety of generic names for plants (e.g. - dandelion, sunflower, oak), ranging from 41 to 65 names per pupil. Only seven pupils used any specific names (e.g. - Johnson grass, five-leaf clover). No one used more than three specific names for the plants.

Some important implications of Tull's (1994) research are that pupils prefer to identify plants at the generic level (e.g. – naming a plant an oak rather than a tree), which suggests that primary school pupils should be introduced to the concept of genus (e.g. - oak, lily) before being introduced to the more abstract levels of the botanical classification scheme (e.g. - *monocot*, *dicot*). The current study suggests that even in urban culture, where the study was conducted, pupils are most comfortable with the generic level when naming plants. Therefore, teachers should ask questions in which the pupils feel comfortable to respond and are encouraged in their inquiry.

The presented case studies from the research above (Patrick & Tunnicliffe, 2011; Tull, 1994; Tunnicliffe & Reiss, 2000) highlighted some important considerations when teaching pupils to identify, name and classify plants. Tunnicliffe and Reiss's (2000) research suggests that teachers should help pupils to observe plants more carefully and to classify them based on less obvious anatomical features. Patrick and Tunnicliffe's (2011) research further suggest that teachers must use real plants and hands-on activities when teaching pupils about plants. Meanwhile, Tull's (1994) research suggests that teachers should allow pupils to use generic rather than life-form names when asking pupils to identify and name plants.

Therefore, a lesson plan was produced that incorporated the use of less obvious anatomical features, generic names and real plants to help pupils to identify, name and classify plant types.

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Lesson Plan

Plants

Using less obvious anatomical features, generic names and real plants to help pupils to identify, name and classify plant types

Pupils should be taught to: (i) identify and name a variety of common wild and garden plants, including deciduous and evergreen trees, and (ii) identify and describe the basic structure of a variety of common flowering plants, including trees.

Science – Key stage 1 (Year 1)

Research recommendation(s) and rationale	Research indicates that pupils have a poor understanding of plant classification (Bell, 1981). Tunnicliffe and Reiss (2000) research suggests that teachers should help pupils to observe plants more carefully and to classify them based on less obvious anatomical features. Patrick and Tunnicliffe's (2011) research further suggest that teachers must use real plants and hands-on activities when teaching pupils about plants. Meanwhile, Tull's (1994) research suggests that teachers should allow pupils to use generic rather than life-form names when asking pupils to identify and name plants.
Lesson aim	To use real plants and hands-on activities to teach about plants and classification
Learning objective	To name and classify plants, including trees.
Intended learning outcomes	At the end of the lesson, pupils will be able to: i. Explain that plants have different names ii. Talk about how plants can be classified into different groups iii. Explain / discuss the fact that plants can be identified based on their physical features NB – You may find it easier to split this lesson into two, focussing first on plants in general, then trees specifically.
Scientific vocabulary	**Garden plants** - plants that people choose to grow in their gardens. **Wild plants** - a wild plant seed grows where it falls. It does not need to be planted or cared for as it grows. People sometimes call wild plants weeds if they grow in places where they do not want them. **Deciduous Trees** – lose all of their leaves for part of the year. In cold climates this happens during the autumn, so trees are bare throughout the winter. **Evergreen Trees** – do not lose all their leaves at the same time, they always have some leaves. They do lose their leaves a little at a time with new ones growing in to replace the old, but they are never completely without leaves. Introduce pupils to key vocabulary throughout the lesson, particulary during the 'real world activity' sections where the key terms will be pre-taught. As a follow up to the lesson ensure that pupils revisit these key word flashcards on a regular basis

	until they are secure, possibly using the Leitner 3 box system: (https://www.youtube.com/watch?v=C20EvKtdJwQ&safe=active)
Suggested lesson sequence and activities	*Introduction/Diagnostic assessment* As an initial diagnostic assessment ask pupils to tick all that are plants: **nettle** / **daisy** / **dragonfly** / **oak tree** / **lizard** / **rose** (each with an empty tick box below) Ask pupils to work in pairs to discuss what they know about plants and their features. Pupils to recap on previously covered vocabulary flash cards that link to today's learning e.g. plant, root, flower, bed, leaves etc. Use this as an opportunity to assess pupils' understanding of plants based on previous learning. Give feedback on diagnostic assessments and ask probing questions about plants and their features. *Vocabulary instruction* Explain to the pupils that plants can be garden plants or wild plants. Use vocabulary flash cards to introduce key words that link to today's learning: **Garden plants** - plants that people choose to grow in their gardens. **Wild plants** - a wild plant seed grows where it falls. It does not need to be planted or cared for as it grows. People sometimes call wild plants weeds if they grow in places where they do not want them. *Naming and identifying Activity – plants* Ask pupils if they can name any plants and flowers they have seen in their gardens, school grounds, park, countryside etc. Produce a mind map with all their ideas on the board, discussing whether they are garden plants, wild plants or weeds. Type some of their ideas into google images on the IWB to display them for the class to see as you create the mind map. **Real-world activity:** Take class on nature walk around school grounds or out into the local community if appropriate to look for different types of plants. Provide pupils with a plant identification sheet with some of the most common plants and flowers the pupils are likely to see (e.g. nettles, dock, primrose, cow parsley, dandelion, cowslip, forget-me-not, bluebell, snow-drop, red campion). The Woodland Trust has a useful range of resources on its Nature Detectives website, including some plant spotter sheets: http://www.naturedetectives.org.uk/packs/pack_spotting.htm

nettle	daisy	dragonfly	oak tree	lizard	rose

	It might be useful for pupils to take a magnifying glass with them to look closely at the details and physical features of each plant to support with identification. During the walk ask key questions about whether pupils would categorise plants as garden plants or wild plants. **Summary/discussion:** On return to the classroom ask pupils to work with a partner using vocabulary flashcards to define each of the terms (garden plants and wild plants) and ask them to draw an image to go with each on their vocabulary cards to refer back to in subsequent sessions. Offer examples of what they may draw and briefly model this. Partners to work together to verbalise a sentence for each giving an example from today's lesson and share their sentences with the class. **Class discussion:** Show pupils a selection of photos taken from the walk (may have been taken during or prior to the walk) of different plants and ask them to discuss with a partner whether they would classify them as garden plants, wild plants or weeds. Show images of trees, and ask what category these would come into, encouraging pupils to recognise the differences between trees and plants. Ask the pupils to draw a tree and label the parts they already know. They may need a few questions to prompt them: Do trees have the same parts as other plants or are they different? Are their roots different? How? Share with the pupils a basic image of the tree's structure, including roots, trunk, braches and leaves. Discuss the fact that unlike most other plants, tree roots can often be seen above the ground. Introduce the pupils to the fact that there are different types of trees. Show 1 minute of the YouTube clip: https://www.youtube.com/watch?v=7h5TiPevd-Q **Vocabulary Instruction:** Use vocabulary flash cards to introduce key words that link to today's learning: **Deciduous Trees** – lose all of their leaves for part of the year. **Evergreen Trees** – always have some leaves, even in the winter. Discuss that deciduous trees lose all of their leaves for part of the year. In cold climates this happens during the autumn, so trees are bare throughout the winter and that evergreen trees – do not lose all their leaves at the same time, they always have some leaves. They do lose their leaves a little at a time with new ones growing in to replace the old, but they are

	never completely without leaves. Show the woodland trust clip a year in the life of a tree e.g. an oak tree https://naturescalendar.woodlandtrust.org.uk/blog/2019/a-year-in-the-life-of-a-tree/ (choose a tree pupils might have seen on their walk or may be able to see in their school environment). **Real-world activity:** Provide the pupils with leaves from a range of trees and ask them to identify the tree the leaf is from using a tree spotter sheet with images of leaves from trees: (http://www.treetoolsforschools.org.uk/activities/pdfs/pdf_leaf_spotter_sheet.pdf) Depending on the time available and nature of the school environment (if leaves were taken from trees on school grounds), pupils could take a small number of leaves outside and find the tree that it came from. Encourage the pupils to identify whether each tree is an evergreen or a deciduous tree. **Summarise/discussion:** Ask pupils to work with a partner with vocabulary flashcards to define each of the terms (deciduous and evergreen trees) and ask them to draw an image to go with each on their vocabulary cards to refer back to in subsequent sessions. Offer examples of what they may draw and briefly model this. Partners to work together to verbalise a sentence for each giving an example from today's lesson and share their sentences with the class.
Key questions	**How can different plants be identified and classified?** • What are the key features of a plant? • How do you know that is a plant? What features does it have that tells you it is a plant? • What is the name of this tree/plant? • What key features can you see on this plant? • Is this a garden plant or a wild plant? How do you know? Where is it? Do you think someone planted it? Why/why not? • How do you know this is a tree? What key features does it have? • What features does a tree have that is different to the features of other plants? • Is this a deciduous or an evergreen tree? How do you know? • What sort of tree is this leaf from? How do you know? What features does it have?
Assessment opportunities	During class discussion and whilst on nature walks, ask pupils key questions. Allow pupils to test each other on key vocabulary using flashcards, and use this as an opportunity to guage understanding of key vocabulary (both previously taught vocabulary and new vocabulary introduced during today's session.

	Use naming and classification activities to guage level of understanding.
Resources **H&S considerations**	Resources: • Vocabulary flashcards (see attached document) • Initial diagnostic question (see attached document) • For the nature walk provide pencils, magnifying glasses and plant spotter sheets: http://www.naturedetectives.org.uk/packs/pack_spotting.htm • Video clips https://www.youtube.com/watch?v=7h5TiPevd-Q and https://naturescalendar.woodlandtrust.org.uk/blog/2019/a-year-in-the-life-of-a-tree/ • A selection of leaves from a variety of trees • Tree spotting sheet - http://www.treetoolsforschools.org.uk/activities/pdfs/pdf_leaf_spotter_sheet.pdf **SUPPORT –** Before beginning on any practical activities, it is a good idea to discuss plant safety with the pupils. **Plant Safety for pupils:** ● Always wash your hands after handling plants, soils, compost etc. ● Remember that plants can be poisonous or cause allergic reactions in some people. ● NEVER eat plants found in the wild or your school grounds, unless you have been given instructions by a teacher that you may do so. ● Try to avoid pulling up a growing plant.

Name ________________________________

Tick all that are plants:

nettle	daisy	dragonfly	oak tree	lizard	rose

Name ________________________________

Tick all that are plants:

nettle	daisy	dragonfly	oak tree	lizard	rose

Name ________________________________

Tick all that are plants:

nettle	daisy	dragonfly	oak tree	lizard	rose

Name ________________________________

Tick all that are plants:

nettle	daisy	dragonfly	oak tree	lizard	rose

deciduous tree	evergreen tree
garden plant	wild plant

Print these flashcards back to back and cut up for pupils. The space under the word is where they will draw an image.

Always have some leaves, even in the winter.	Lose all of their leaves for part of the year.
A wild plant seed grows where it falls. It doesn't need to be planted or cared for as it grows. Wild plants can be weeds, which grow in places people don't want them.	Plants that people choose to grow in their gardens.

Research Summary

Vertebrates

Using pupils' experiences of keeping animals to teach them about vertebrates (fish, amphibians, reptiles, birds and mammals)

Pupils should be taught to: (i) identify and name a variety of common animals including fish, amphibians, reptiles, birds and mammals, and (ii) describe and compare the structure of a variety of common animals (fish, amphibians, reptiles, birds and mammals, including pets).

Science – Key stage 1 (Year 3)

Statement of issue

Research has shown that pupils hold several misconceptions that impact their ability to classify animals. For example, Bell (1981) found that only 50% from 39 pupils (Years 6, 7, 9 and 11) knew that frogs are amphibians. Approximately one third of pupils across age groups (Year 1 to 7) incorrectly thought that a tortoise is an amphibian rather than a reptile (Bell, 1981; Braund, 1998; Yen et al., 2004). Similarly, the visual absence of limbs in snakes and the similarity between their movement and that of worms is likely linked to the reason why snakes are frequently misclassified as invertebrates (Braund, 1998; Yen et al., 2004). Even though penguins are birds, from the pupils' point of view they are mammals because they are flightless and live in the sea (Braund, 1991; Trowbridge & Mintzes, 1985, 1988). Habitat and movement patterns seem to be the most important cues when pupils classify an animal (Kattmann, 2001). The effects of pupils' first-hand experiences on their ability to classify animals are poor – indeed, Braund (1998) noted that those pupils who visited zoos, museums, or engaged in birdwatching and fishing, were more successful in animal classification than other pupils.

Main findings from the research

Research has suggested that pupils' biological knowledge and awareness is constructed through daily experiences in their early years (Hatano & Inagaki, 1997). Teixeira (2000), whose study took the human digestive system as an example, found that pupils possess biological knowledge as an independent knowledge domain from the age of four. Jaakkola and Slaughter (2002) proposed the same for Year R (Reception) to Year 1 pupils, with regards to their understanding of bodily functioning. The evidence thus suggests that pupils' biological experiences before schooling influence their ideas about animals therefore, starting instruction of biology at primary schools is possible and can be effective, but the instruction must enhance restructuring of it (Hatano & Inagaki, 1997).

Keeping animals as pets

Looking after pets provides several benefits in terms of pupils' social interactions, and their development of factual and conceptual knowledge about these animals. In a large-scale study, Prokop et al. (2008) investigated the experience of looking after animals on pupils' factual knowledge and alternative conceptions about them. A total of 1,544 pupils (6-15 years old) from six randomly selected Slovak schools participated in the study. Data were obtained from 7,705 pupils' drawings and the study revealed a very strong bias towards the keeping of vertebrates and a general ignorance of invertebrates. The findings of the study indicated that the pupils with greater experience of looking after animals (vertebrates) as pets (the sample for pupils keeping invertebrates as pets was too small to enable statistical conclusions to be drawn) demonstrated a statistically significantly better knowledge when drawing the internal organs of several animal species, as compared with pupils who did not report keeping any animal.

Prokop et al.'s (2008) study concluded that keeping pets contributes in a statistically significant manner to pupils' conceptual understanding of the anatomy of animals, especially of vertebrates. Ignorance of invertebrates – few pupils in the sample had invertebrates as pets – likely influenced misunderstandings related to invertebrates' internal skeleton. Another explanation for this lack of knowledge, compared to knowledge about vertebrates – although these explanations are not mutually exclusive – is the lack of teaching about invertebrates. The study suggested that science teachers should encourage pupils to keep a diverse range of animals, particularly invertebrates that can be obtained and reared easily. Primary teachers should also plan studies with easily available invertebrates such as meal worms (*Tenebrio* sp.) or brine shrimps, *Artemia salina* (Tomkins & Tunnicliffe, 2001). Special attention should be paid to pupils from families from a lower socio-economic status, because these pupils had fewer experiences of rearing animals than other pupils (Prokop et al., 2008).

How pupils classify animals

A group of Taiwanese researchers examined pupils and students' conceptual understanding related to animals, vertebrates, invertebrates, fish, amphibians, reptiles, birds, and mammals, among 592 primary school pupils, 1272 secondary school students and 98 university students (Yen et al., 2007). Findings from the study showed that for most participants, the label *animal* refers to vertebrates, especially to common, well-known mammals and birds; the most common attributes used by participants to define animals are movement and viability (i.e., alive); and many primary school pupils had difficulty in making the distinction between vertebrates and invertebrates. The study found that the most common reasons for classifying an organism as an animal were possession of legs, size, habitat, fur/feathers, production of sounds, movement, a nervous system, legs, viability (i.e., alive), respiration, and reproduction. The study suggested that the most effective teachers provided opportunities for pupils/students to interact with living things in their natural settings. A local park, a beach, or even a roadside or alley can provide a rich, exciting environment where pupils/students can learn not only about animals and plants, but also about important ecological concepts such as diversity of species, predation, population growth, and mortality.

Findings from other related research

Inagaki (1990) investigated Year 1 pupils' knowledge of goldfish and found that pupils who had experienced keeping goldfish acquired a greater amount of both factual and conceptual knowledge, compared to pupils who had never kept goldfish. In addition, pupils who kept goldfish could use their knowledge of goldfish as a source of information to make predictions about the anatomy of an unfamiliar animal (a frog).

In another study, Strommen (1995) interviewed 40 Year 2 pupils via drawings about forests and the types of living things found in them. He found that primary pupils living in a rural habitat (i.e., close to a forest) had better knowledge of forest inhabitants than urban pupils. More frequent visits to the forest resulted in better knowledge amongst those pupils, with regards to the organisms living in it. The study concluded that pupils appear to possess a substantial and varied base of knowledge regarding living things, but their ideas appear to be extremely concrete and isolated from each other, such that they cannot systematically examine what they know and report it.

Tunnicliffe and Reiss (1999) explored how Years 0, 4, 7 and 10 pupils/students recognise, identify and group animals by presenting them with preserved specimens of six different animals and asked a series of questions about the animals. The study found that basic knowledge about animals is mostly influenced by information from home and direct observations and that books, school, or multimedia seemed to be relatively less important sources of knowledge about animals for the pupils interviewed. The study suggests that science teachers can help pupils/students to learn by encouraging them to describe and comment on less obvious anatomical features.

Meanwhile, Tarlowski (2006) studied 45 Year 0 (Reception) pupils' reasoning about animals by exposing them to biological information of direct experience with nature (urban versus rural) and biological expertise of their parents (expert biologist and laypeople). The study found that the effects of direct experiences with nature (examined indirectly by comparing rural versus urban pupils) and the biological expertise of parents affected the ideas Year 0 (Reception) pupils held about humans, other mammals, and insects. In general, the study emphasised the important role of direct experience in pupils' acquisition of biological concepts.

In summary, research has indicated that keeping animals as pets statistically significantly contributes to pupils' factual knowledge of the anatomy of animals, especially of vertebrates compared to those pupils who do not keep pets.

Therefore, a lesson was produced that focused on pupils' experiences of keeping animals to teach them about the nature and characteristics of vertebrates (fish, amphibians, reptiles, birds and mammals).

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Lesson Plan

Vertebrates

Using pupils' experiences of keeping animals to teach them about vertebrates (fish, amphibians, reptiles, birds and mammals)

Pupils should be taught to: (i) identify and name a variety of common animals including fish, amphibians, reptiles, birds and mammals, and (ii) describe and compare the structure of a variety of common animals (fish, amphibians, reptiles, birds and mammals, including pets).

Science – Key stage 1

Research recommendation(s) and rationale	Research has suggested that pupils' biological knowledge and awareness is constructed through daily experiences in their early years (Hatano & Inagaki, 1997). Braund (1998) noted that those pupils who visited zoos, museums, or engaged in birdwatching and fishing, were more successful in animal classification than other pupils. Yen et al. (2007) suggested that the most effective teachers provided opportunities for pupils/pupils to interact with living things in their natural settings. A local park, a beach, or even a roadside or alley can provide a rich, exciting environment where pupils/pupils can learn not only about animals and plants, but also about important ecological concepts such as diversity of species, predation, population growth, and mortality. Prokop et al.'s (2008) study concluded that keeping pets contributes to pupils' conceptual understanding of the anatomy of animals, especially of vertebrates. Tarlowski (2006) found that the effects of direct experiences with nature (examined indirectly by comparing rural versus urban pupils) and the biological expertise of parents affected the ideas Year 0 (Reception) pupils held about humans, other mammals, and insects. In general,the study emphasised the important role of direct experience in pupils' acquisition of biological concepts.
Lesson aim	To use real animals and hands-on real-life experiences to teach about vertebrates
Learning objective	To name, describe and group a variety of common animals
Intended learning outcomes	At the end of the lesson, pupils will be able to: • Describe animals using key physical features • Group animals according to these features
Scientific vocabulary	Expose pupils to key vocabulary throughout the session, particulary during the 'real world activity' sections where the key terms will be pre-taught. As a follow up to the lesson ensure that pupils revisit these key word flashcards on a regular basis until they are secure, possibly using the Leitner 3 box system (https://www.youtube.com/watch?v=C20EvKtdJwQ&safe=active)
Suggested lesson sequence and activities	*Prior learning/previous experiences* Pupils may have encountered a range of animals in Year 1 and throughout EYFS. This may have included visits to a local farm/petting zoo, nature reserve with different habitats including water, zoo, aquarium, an outdoor space, or visits from an organisation such as the Creepy Crawly Roadshow. Ask the pupils to tell you about their experiences and encourage them to recall key features, similarities and differences between animals they have seen.

The school might also keep animals such as hamsters, guinea pigs, fish that you can use aspart of the lesson. When in EYFS pupils might have hatched eggs, observed frogspawn and caterpillars so check this and also ask them if they remember any stories about animals.

Home learning task to be set a week prior to the lesson

Prior to the lesson, set homework to write about a pet of their own or someone they know. Encourage them to find out information about the animal that they can later share with the class. In order to enable pupils to experience animals in a 'real' scenario, pupils should be encouraged to bring in photos/send video clips of their pets to give everyone the opportunity to experience and observe different animals. Some pupils may need additional support with this activity if they do not have any direct experience of caring for pets/animals.

Introduction/Diagnostic assessment

As an initial diagnostic assessment ask pupils to tick all that are types of animals (see attached resource).

amphibians	**evergreens**	**birds**	**reptiles**	**dandelions**	**fish**	**brambles**	**mammals**

Teacher to use this as an initial g uge of pupils's prior knowledge, taking note of pupils with limited knowledge, to target during the session to bridge any gaps. Share answers to the diagnostic activity, explaining that these are all living things, but some are plants not animals. Discuss that all animals have differences, but can be categorised into 'families' according to certain similarities.

Watch a video clip to introduce animal categories e.g. a song **https://www.youtube.com/watch?v=4VixROiu8Qg**

Vocabulary instruction:

Use vocabulary flash cards to introduce key words that link to today's learning:

Amphibians - Amphibians live in the water as babies and on land as they grow older. They have smooth, slimy skin.
Fish - Fish live in water. They have scaly skin, fins to help them swim and they breathe through gills.
Mammals - Mammals breathe air, grow hair or fur and feed on their mother's milk as a baby.
Reptiles - Reptiles breathe air. They have dry scales on their skin.
Birds - Birds lay eggs, have a beak, two legs, feathers and wings.

Display images of five animals (see attached resource sheet 1 below) and ask pupils to discuss in talking partners which animal belongs to which category (amphibians, fish, reptiles, mammals, birds). Move around the pupils listening to discussion, asking probing

	questions and noting/clearing up any misconceptions. Come back together as a class and share answers and address any misconceptions. *Real-world activity:* Follow up the home learning activity by asking pupils to choose a specific animal to research and write about. In mixed-ability groups, assign a mixture of different animals to each group and ask pupils to share the information they have found. Ask the pupils to discuss which animal type they are, and how they know. Circulate asking probing questions to encourage pupils to correctly classify each animal, and discuss its key features. *Vocabulary instruction:* Give pupils a selection of pictures of animals (see resource sheet 2) to stick onto the correct vocabulary flashcard. Encourage pupils to discuss with their partner/table group which group the animals belong to. Move around asking probing questions such as "What can you tell me about that animal? Why do you think it belongs in that group? What characteristics do animals in that group share? Which group do you think a …. belongs in?" *Summary/discussion:* Bring the class together and share how the animals were grouped. Read out the definitions and ask pupils to hold up the corresponding flashcard. Display several more photos on the whiteboard (see attached resource sheet 2 below), including those that research has indicated are a cause for confusion (penguin, tortoise, frog, snake) and ask talking partners to discuss which group they would belong to. Pupils to hold up corresponding flashcard. Discuss correct answer and address any misconceptions.
Key questions	• What type of animal do you think this is? Why do you think that? • How would you describe the features of this animal? • In what way are these two animals similar? In what way are they different? • What is the most common type of animal to have as a pet? Why do you think this is? • Does this animal have…fur, live babies, eggs (do they lay in water or on land), fins, 2 legs, 4 legs, feathers? etc. • If the animal lays eggs what type of animal could it be? • If the animal has scales what type of animal could it be?
Assessment opportunities	Ask pupils key questions during class discussion and during any activities being completed in prior learning section. Allow pupils to test each other on key vocabulary using flashcards, and use this as an opportunity to gauge understanding of key vocabulary. Use naming and classification activities to gauge the level of understanding.
Resources	Resources (see attached documents): • Vocabulary flashcards – publisher document

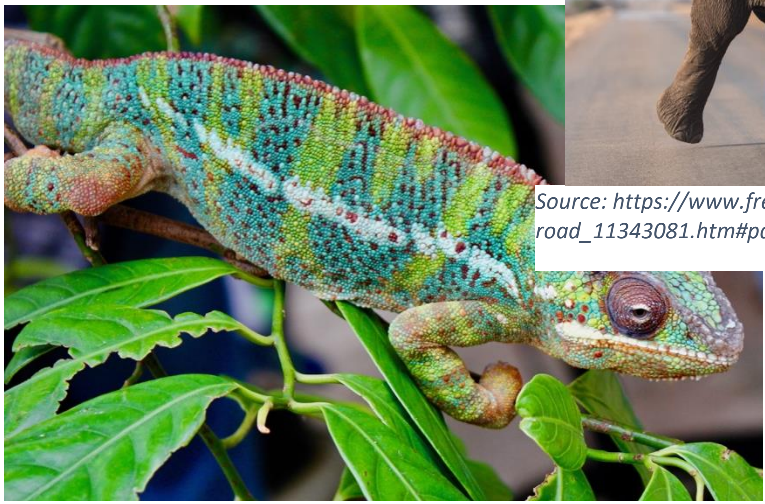
	• Pictures of animals to display on the whiteboard – see below (resource sheet 1 for beginning of lesson, resource sheet 2 for the end of the lesson) • Pictures of animals for pupils to stick onto flashcards – publisher document • Initial diagnostic question - publisher document • Video clips (links in lesson plan)
H&S considerations	Make sure you discuss your lesson plans with your mentor and follow school H&S policy

Resource sheet 1

Source: https://www.freepik.com/free-photo/green-frog_6925879.htm#page=1&query=frog&position=15

Source: https://torange.biz/purple-fish-ocean-beautiful-sea-striped-53922

Source: https://www.freepik.com/free-photo/elephant-walking-road_11343081.htm#page=1&query=elephant&position=12

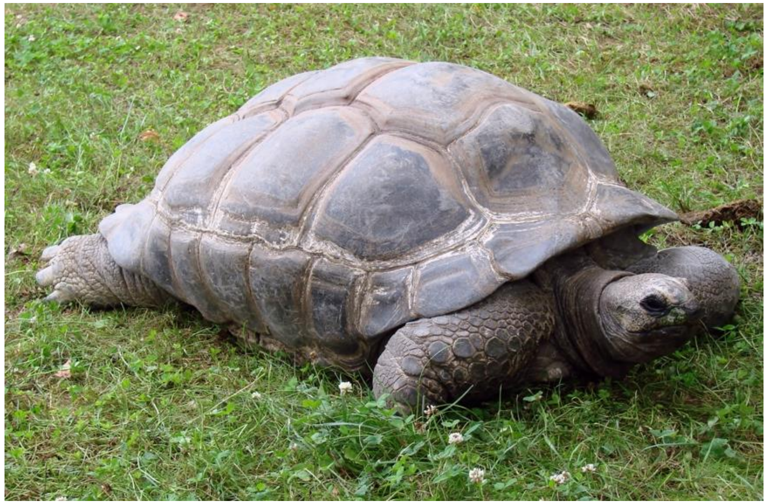


Source: https://www.pxfuel.com/en/free-photo-xtrhz

Source: https://www.freepik.com/free-photo/beautiful-european-robin-standing-moss-covered-branch-tree_11502845.htm#page=1&query=bird&position=10

Resource sheet 2

Source: https://www.pxfuel.com/en/free-photo-qllpe



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Research Summary

Fossils
Making inferences from hands-on activities to teach about fossils
Pupils should be taught to: Describe in simple terms how fossils are formed when things that have lived are trapped within rock
Science – KS2 (Year 3)

Statement of issue

Almost all pupils are familiar with the word 'fossil' (Powell et al., 2007; Russell & McGuigan, 2015). When surveyed 81% of 399 primary aged pupils had seen a fossil, however, 35% (of the 81%) defined a fossil incorrectly, and 46% (of the 81%) did not know how to define a fossil (Duarte et al., 2016). In addition, research suggests that as pupils have difficulty recognising plants (in contrast to animals) as living (Hatano et al., 1993) that a third, additional category '*once-living*' be introduced for fossils, to help pupils to develop an understanding of this link between the other two categories of living and non-living (Borgerding & Raven, 2018).

Main findings from the research

Research suggests that to best support pupils' understanding of how fossils are formed, they use hands-on investigative activities (Akerson & Donnelly, 2010; Borgerding & Raven, 2018; Fragouli et al., 2017).

What the research shows

Borgerding and Raven (2018) qualitatively explored pupils' ideas about fossils during a weeklong STEAM camp (Science, Technology, Engineering, Art, Maths). They focused on 15 American pupils who were in Early Years to Year 1 aiming to understand the lessons from the pupils' perspective. Pupils took part in several different fossil-based investigations over the week, including indoor and outdoor digs, making play-dough casts, scavenger hunts, sorting things into living/non-living and using real fossils. For example, one investigation involved digging for partial fossils (made from baked play-dough) in an outdoor sandpit, then to support pupils' investigations they were asked to complete a drawing of what the fossil came from (i.e. a dinosaur). [More information on the activities can be found in the article 'Dig into Fossils' by Borgerding (2015)]. The activities were framed through a fictional story that pupils engaged with at the start of every day. Given the age of the pupils their choice of activity was guided, and at the end of the lesson pupils took part in a sticker-based, or drawing activity, where researchers assessed their understanding. They assessed pupils' understanding of where fossils are found in four different ways, three sticker placement tasks (e.g. given a picture of earth, ground, mountains, forest and sky and pupils were asked to place the stickers of fossils where they would expect to find them), as well as in an interview. Most of the pupils (14 of the 15 pupils) correctly placed the fossil stickers in the earth, ground, or mountains. Twelve pupils who took part in the camp were also interviewed from which it was found that most understood that different environments created different fossils and were largely able to infer what the organism would have been like. Therefore, this suggests that pre-school pupils already have ideas about fossils and can benefit from investigative hands-on fossil tasks.

Akerson and Donnelly (2010) explored the influence of a 6-week Saturday science programme that gave pupils the opportunity to explore science through hands-on investigations. They focused on 19 American pupils (Year 1 to Year 3) in a 6-week science programme. Several of the activities were based on the topic of fossils, for example, pupils were asked to observe real crinoid fossils and then to infer the rest of the organism and its habitat. A case study approach was adopted collecting as much information about pupils' understanding as possible, from pupils' work, classroom recordings, researchers recorded pupils' exact verbalisations, and interviews. Pupils felt creative but were unsure about what their fossil was like, some responding that they did not know or no one knows for sure. However, following the fossil investigation 13 of the pupils understood that scientists could not just make up a picture from the fossil but had to make inferences, and 12 of the pupils understood that fossils were the evidence they were using in their investigations. As with the previous study (Borgerding & Raven, 2018) some of the Early Years pupils did not understand the task or have the vocabulary to respond. This research suggests that pupils understanding of fossils benefit from hands-on fossil tasks involving pupils making inferences.

Fragouli et al., (2017) explored the inclusion of ammonite fossils in the Greek primary syllabus (ammonites are a commonly found fossil in Greece). A large sample of 376 Year 6 and 7 primary pupils took part in the fossil activities in class, their classwork was analysed, as too were their responses to a questionnaire. The fossil activities were based around ammonite fossils and included creating a fossil map of Greece, making clay model ammonite fossils, drawing layered maps of fossils (using transparent plastic pages), and identifying organisms from real fossils. They then measured the effectiveness of the approach with a questionnaire focused on pupils' understanding of the topic 2-months after they participated in the activities. They found that almost all (97%) of the pupils' drawings accurately represented an ammonite fossil and the living animal, and some pupils added explanatory details to their drawings. The researchers categorised and compared the pre-and-post questionnaires, finding that 83% of pupils knew what an ammonite was, and 56% of those responses included a scientific answer. Many of the pupils understood that ammonites are extinct and can now be found as fossils, and 33% of pupils understood that changing environments meant marine fossils would be found in mountain rocks. Although this study used older pupils it demonstrates an important point about using investigative tasks that include hands-on fossil activities, showing these hands-on tasks are beneficial to pupils' understanding of how fossils are formed and help them make inferences about the organisms in the fossil.

But virtual fossils are not as successful

Innovations in technology make using virtual fossils in the classroom a distinct possibility (Rahman et al., 2012). However, there is strong evidence that primary pupils do not benefit from replacing hands-on activities completely with computer-aided versions of fossil investigations (Klopp et al., 2014).

Klopp et al., (2014) investigated the effect of teaching solely using technology compared to hands-on craft activities. One class of 28 academically advanced (gifted and talented) Year 3 to Year 6 pupils participated in this repeated measures study. Meaning that each pupil took part in all conditions (i.e. craft-only activities, technology only), this method allowed each pupil's individual learning to be compared against themselves. Pupils had a choice to make a wall display, scrapbook page, or 3-D paper fossil for the craft-based activities; and the pupils had a choice to make a movie, a narrated slideshow, or a story that had to include an animated cartoon for the technology activities. They found that when pupils participated in the hands-on craft activities they learned statistically significantly more academic content, than when they used technology alone. Moreover, when pupils participated in the hands-on craft activities they displayed statistically significantly more factual basis and understanding than when they used technology alone. Therefore, the research suggests that hands-on activities are beneficial to pupils' learning and should be central when learning about fossils.

Although most pupils are familiar with, and interested in, fossils (Powell et al., 2007) many do not understand how fossils are formed (Duarte et al., 2016). The research demonstrates that hands-on activities are an effective way to support pupils' learning about the formation of fossils (Borgerding & Raven, 2018). This is particularly successful if activities are focused on pupils making inferences from real fossils, for example, drawing an organism from a fossil (Akerson & Donnelly, 2010; Fragouli et al., 2017).

Therefore, a lesson was produced to incorporate pupils making inferences using hands-on activities into the teaching of fossils.

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Lesson Plan

Fossils

Making inferences from hands-on activities to teach about fossils

Pupils should be taught to: Describe in simple terms how fossils are formed when things that have lived are trapped within rock

Science – KS2 (Year 3)

Research recommendation(s) and rationale	Research suggests that to best support pupils' understanding of how fossils are formed, they use hands-on investigative activities (Akerson & Donnelly, 2010; Borgerding & Raven, 2018; Fragouli et al., 2017). Research by both Akerson and Donnelly (2010) and Fragouli et al. (2017) suggests that allowing pupils to part take in hands-on investigative activities not only develop their understanding of how fossils are formed, gaining a deeper understanding of the relevant language, but also support their ability to make inferences about the living organisms involved. There is strong evidence that primary pupils do not benefit from replacing hands-on activities completely with computer-aided versions of fossil investigations (Klopp et al., 2014).
Lesson aim	To use real-life hands on investigative tasks to develop understanding of how fossils are formed.
Learning objective	To explain how fossils are formed.
Intended learning outcomes	At the end of the lesson, pupils will be able to: i. Explain the difference between a fossil and a bone. ii. Explain how a fossil is formed. iii. Describe, the sequence of steps of how a fossil is formed.
Scientific vocabulary	**Fossil -** Fossils are the remains or traces of ancient life that have been preserved by natural processes, from spectacular skeletons to tiny sea shells. **Fossilisation –** The process by which a fossil is formed is called **fossilisation.** **Palaeontologists -** People who study fossils. Expose pupils to key vocabulary throughout the session, particulary during the 'real world activity' section where the key terms will be pre-taught. As a follow up to the lesson ensure that pupils revisit these key word flashcards on a regular basis until they are secure, possibly using the Leitner 3 box system (https://www.youtube.com/watch?v=C20EvKtdJwQ&safe=active)
Suggested lesson sequence and activities	*Initial diagnostic assessment:* Pupils to complete the following diagnostic assessment prior to beginning lesson:

What can fossils teach us about? Tick all correct answers:	
Animal and plant habitats	
Extinct animals	
Moon phases	
Forces	
How animals have evolved and changed over time	

Exploration activity – fossils:

Group discussion:

Pose question – *Were dinosaurs real?* In pairs pupils to discuss and share ideas with class. Probe further asking for evidence for their answers. Discuss the fact that we know that dinosaurs existed as people around the world have discovered bones or more accurately fossils. Discuss the difference between bones and fossils. Bones are the hard tissue that makes up the skeleton in animals including humans. Share with the pupils a selection of animal bones for them to explore what they look and feel like.

Introduce the scientific word **Fossil** and discuss definition **–** fossils are the remains, or traces, of ancient life that have been preserved by natural processes, from spectacular skeletons to tiny sea shells.

Explore the fact that there are different types of fossils. Chemical fossils, which contain carbon. Body fossils, which are the remains of an animal or plant such as bones, shells or leaves. Trace fossils, which record the activity of an animal, including footprints, trackways and f ces. Explain that today we will focus on body fossils.

Explain that people who study fossils are called palaeontologists and that today they will be palaeontologists, exploring different fossils. Provide pupils with a range of different fossils and images of different creatures and challenge the pupils to match the fossils to the correct creature. Encourage them to look for different clues in fossils to support their decisions. Give each a group a big piece of sugar paper and some pens. Ask them to discuss and then draw pictures to show how they think fossils are formed. There is more than one way. Ask each group to elect a spokesperson and then collect feedback from each group. You are likely to get a variety of answers, some relating to animals getting trapped in ice or insects trapped in amber, trace fossils such as footprints and mould and cast fossils.

Introduce the pupils to the process of **fossilation** and condisder the definition -The process by which a fossil is formed is called **fossilisation.** Watch the linked video clip to support their understanding of the process - https://www.bbc.co.uk/bitesize/topics/z9bbkqt/articles/z2ym2p3

	Practical activity – creating fossils: Explain that the pupils are going to create their own fossils. Use clay and shells to create inprint moulds and then fill the moulds with plaster of paris. As the pupils produce their own fossils compare the process to the process of fossilisation, for example the clay represents the mud and dirt, the shell represents the creatures remains, the plaster represents the minerals which fill the mould and create the fossil. Leave in a warm place to dry. During a future lesson pupils can attempt to excavate their fossils from the clay, identifying which shell the fossil matches and linking to future learning about the evidence fossils provide about living things. *Class discussion and assessment opportuntites – fossilisation process:* In pairs provide pupils with a set of cards showing the fossilisation process at each different stage. Pupils to work together to put the process in the correct order. Review and discuss as a class, identifying and correcting any misconceptions. Use this time to recap on vocabulary cards.
Key questions	**What are fossils? How are fossils formed?** Class discussion: • Were dinosaurs real? How do we know? • What are fossils? How do fossils differ from bones? • How do fossils form? What is a fossil made from?
Assessment opportunities	Use initial diagnostic questioning to g uge pupils' understanding at the beginning of the session and to identify any misconceptions. During class discussion and whilst completing plenary activities, ask key questions. Use class discussion at the end of the session to g uge individual understanding of the fossilisation process.
Resources **H&S considerations**	Resources: • A selection of fossils • Images of different living creatures • Small animal bones • Clay, shells, plaster of paris • Large paper and pens • Fossilisation process cards • Key vocabulary cards Adhere to all school guidance and seek advice if uncertain.

Name ________________________________

What can fossils teach us about? Tick all correct answers:	
Animal and plant habitats	
Extinct animals	
Moon phases	
Forces	
How animals have evolved and changed over time	

Name ________________________________

What can fossils teach us about? Tick all correct answers:	
Animal and plant habitats	
Extinct animals	
Moon phases	
Forces	
How animals have evolved and changed over time	

Name ________________________________

What can fossils teach us about? Tick all correct answers:	
Animal and plant habitats	
Extinct animals	
Moon phases	
Forces	
How animals have evolved and changed over time	

fossil	fossilisation
fossil	fossilisation
fossil	fossilisation

Print these flashcards back to back and cut up for pupils. The space under the word is where they will draw an image.

The process by which a fossil is formed	Fossils are the remains or traces of ancient life that have been preserved by natural processes, from spectacular skeletons to tiny sea shells.
The process by which a fossil is formed	Fossils are the remains or traces of ancient life that have been preserved by natural processes, from spectacular skeletons to tiny sea shells.
The process by which a fossil is formed	Fossils are the remains or traces of ancient life that have been preserved by natural processes, from spectacular skeletons to tiny sea shells.

Research Summary

Magnets

Using a science diagram to teach about magnetism

Pupils should be taught to: (i) compare and group together a variety of everyday materials on the basis of whether they are attracted to a magnet, and identify some magnetic materials, and (ii) predict whether two magnets will attract or repel each other, depending on which poles are facing.

Science – Key stage 2 (Year 3)

Statement of issue

Magnetism is a common topic in primary science curricula and a source of interest for pupils. Barrow (1987) investigated awareness of magnets and magnetism among 78 pupils across between the ages of 3 and 9. The study found that pupils tended to think of poles only at the ends of magnets. Barrow (1987) suggests that pupils might be encouraged to focus on the magnetic force and find the part of the magnet where attraction and repulsion are strongest. The study concluded that pupils' awareness of the uses of magnets had not been extended by teaching and raises the possibility that teaching about magnets might dissociate pupils from their everyday awareness of magnetism (Barrow, 1987).

Main findings from the research

Understanding abstract scientific phenomena like magnetism frequently requires some degree of mental imaging or visualisation. Modern constructivist views of primary pupils' learning involve the construction of ideas (sense-making), development of competencies (in discursive practices), and recognition of the representational nature of science learning (Skamp, 2012). Research into the use of representations, such as science diagrams is continuing to deepen teachers' understanding of pupils' conceptual understanding in science (Preston, 2016). In particular, most research were found involved pupils constructing their own science diagrams, which helped pupils' science learning and their use in communicating conceptual understanding (see Tytler et al., 2009; Prain & Waldrip, 2010).

Research indicates that pupils tend to relate magnetic interactions to common properties, including structural or chemical composition or physical characteristics. For example, Haupt's (1952) study highlighted that 25 pupils/students (Year 2 to 8) are able to explain that one end (N) of a magnet holds onto the other end (S) because it is like tin; has paint on one side; has something/chemical; or has an S on it. Some pupils' (*n*=3) explanations included references to north and south poles and forces, and their ability to attract and pull (Haupt 1952, p. 164). Older pupils (*n*=119, Years 3, 5 and 7) predicted that older magnets would have less strength than newer magnets (53%), and that larger magnets would hold more paper clips than smaller magnets (60 %), indicating that they thought age and size would affect the strength of magnets (Bailey et al., 1987).

The benefits of using scientific diagrams in science learning

Research involving scientific diagrams has indicated that they are effective learning tools (Winn, 1991) that can support pupils' scientific explanations (Ainsworth & Th Loizou, 2003). Scientific diagrams are proclaimed a highly specialised form of visual communication with a heavily coded symbol system requiring in-depth processing for pupils to effectively learn from them (Barlex & Carré, 1985; Levie & Lentz, 1982; Lowe, 1986; Salomon, 1979).

Preston (2016) investigated the effect of scientific diagrams on primary pupils' conceptual understanding of magnets. The researcher was interested in what sense primary pupils could make of magnets from a diagram alone. The study was conducted with 19 pupils, 9 from Year 4 and 10 from Year 6 at a suburban, government, co-educational primary school in Sydney, Australia. Despite the fact that *no* teaching intervention occurred as part of the study, the study showed that primary pupils' conceptual understanding was affected by their interaction with the science diagram when they were shown and responded to questions about the science diagram.

Pupils came to the study with their own background knowledge and their own way of approaching the tasks (Preston, 2016). The data from beginning to end of task-based interviews showed that the use of diagrams resulted in enhanced conceptual understanding of magnets, by means of eliciting further knowledge, introducing new information, aiding explanations, or challenging alternative conceptions. The diagram provided an intellectual scaffold that assisted pupils in recalling or accumulating additional information and incorporating this into an explanation that could be tested through visual observations. Diagram interaction resulted in a reduced understanding of magnets when less detail was provided, or erroneous ideas were promoted.

In conclusion, Preston (2016) confirmed that the individual nature of pupils' learning characteristics, including prior knowledge and meta-conceptual awareness, has implications for teachers using science diagrams as learning aids for pupils. Teachers should not assume that all pupils will approach or make sense of diagrams in the same way. The study suggested that pupils must be taught the meaning of conventions. Individual learning characteristics, combined with repeated interventions meant that diagram features did not prevent pupils from developing enhanced understanding.

Studies exploring the models pupils use to explain magnet action

Erickson (1994) described three models of magnetism in a study of Canadian pupils/students (Years 5 to 9). In the 'Pulling model', pupils/students viewed magnets as objects that can pull other objects towards them or that can stick to objects. The 'Emanating model' explains that magnet action occurs via something (e.g., rays/energy) coming out of the magnet and reaching towards the object it can attract. Extending this idea, the 'Enclosing model' proposes that the rays coming out of the magnet spread over the items the magnet can attract.

Cheng and Brown (2010) investigated 6 pupils' (Years 4 and 7) construction of explanatory models to develop a conceptual understanding of magnetism. Pupils put forward two initial explanations of magnets: composition-based and terminology-based. Composition-based explanations referred to something inside the magnet – "metal, special lead, black metal powder or negatives and positives" – that made it work (Cheng and Brown, p. 2377). Terminology-based explanations included known words – "magnetic material, invisible forces of gravity or electricity" – possibly related to magnetism (Cheng & Brown, p. 2377). Other explanatory models showed that: "magnet-like materials travel from the magnet to the metal bars, making them stick in a chain" and a "sameness view" based on the idea that "same things stick together" (Cheng & Brown 2010, p. 2383).

Furthermore, pupils tended to think the ends of the magnet contained an active agent. A key finding was that pupils in the study were able to express explanatory models by making intuitive connections using science diagrams in different ways (Cheng & Brown, 2010). Intuition and imagination were found to be vital in model construction and a disconnection was identified between prior knowledge of magnetism and pupils' intuitive knowledge. Year 4 pupils were capable of formulating explanatory models and tended to provide more creative explanations based on intuitive thinking than Year 7 pupils, who relied more on prior knowledge they could not explain (Cheng & Brown, 2010).

In summary, research has shown that scientific diagrams are useful learning aids for pupils and research into the models pupils use to explain magnetism has had implications for science teaching and learning.

Therefore, a lesson was produced to incorporate the use of scientific diagrams to teach about magnetism.

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Lesson Plan

Magnets

Using a scientific diagram to teach about magnetism

Pupils should be taught to: (i) compare and group together a variety of everyday materials on the basis of whether they are attracted to a magnet, and identify some magnetic materials, and (ii) predict whether two magnets will attract or repel each other, depending on which poles are facing.

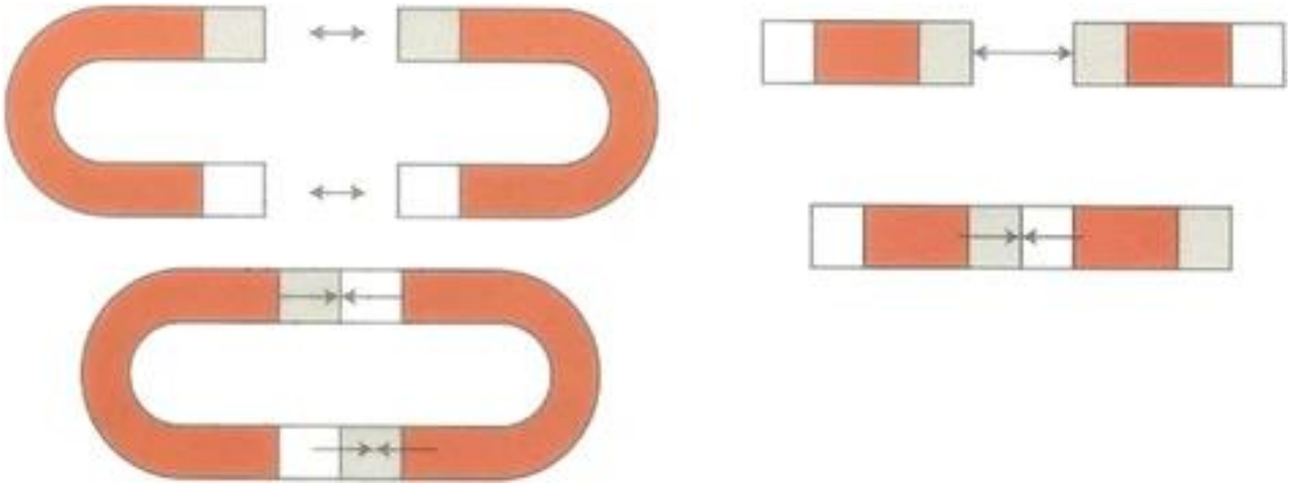
Science – Key stage 2 (Year 3)

Research recommendation(s) and rationale	Understanding abstract scientific phenomena like magnetism frequently require some degree of mental imaging or visualisation. Research involving scientific diagrams has indicated that they are effective learning tools (Winn, 1991) that can support pupils' scientific explanations (Ainsworth & Th Loizou, 2003). Scientific diagrams are proclaimed as a highly specialised form of visual communication with a heavily coded symbol system requiring in-depth processing for pupils to learn from them effectively (Barlex & Carré, 1985; Levie & Lentz, 1982; Lowe, 1986; Salomon, 1979). Research into the use of representations, such as scientific diagrams is continuing to deepen teachers' understanding of pupils' conceptual understanding in science (Preston, 2016). In particular, most research were found involved pupils constructing their own scientific diagrams, which helped pupils' science learning and their use in communicating conceptual understanding (see Tytler et al., 2009; Prain & Waldrip, 2010).
Lesson aim	Using a scientific diagram to teach about magnetism
Learning objective	To describe magnets as having two poles and predict when poles will attract or repel each other.
Intended learning outcomes	At the end of the lesson, pupils will be able to: i. Correctly identify the poles on a bar magnet, and ii. Correctly predict whether the poles will attract or repel each other.
Scientific vocabulary	**Attract** - When magnetic poles attract, they pull towards each other. **Repel** - When magnetic poles repel, they push each other away. **Poles** - Magnetic pole, region at each end of a magnet where the magnetic field is strongest. **North pole** - the end of a bar magnet that points towards the north when the magnet hangs free **South pole** - the end of a bar magnet that points to the south when the magnet hangs free
Common misconceptions	• The bigger the magnet the stronger it is • That all metals are magnetic
Suggested lesson sequence and activities	**Note**: This lesson would be used AFTER pupils have spent time exploring different materials and whether or not they are attracted to magnets. Pupils should be able to identify which materials are magnetic. Beware of the common misconception that all metals are attracted to magnets. If these misconceptions persist, remember to challenge these misconceptions by presenting a range of metals of which only some are attracted to magnets (only those containing iron, nickel and cobalt).

	1. Discuss prior learning. Show pupils a range of objects and ask them to predict which will be attracted to the magnet and which will not. Test their predictions and discuss their findings. Support pupils to make generalisations about which materials are attracted to magnets. 2. Key Question: Do magnets need to touch an iron/nickel/cobalt object to be attracted to it? Demonstrate that a magnet can pick up paper clips without touching them. Discuss that a magnetic force can act at a distance but that it has a limit. The teacher can choose to demonstrate to the class the magnetic field using the encased iron filings (perhaps use a visualiser). 3. Provide pupils with a diagram of a magnet (Resource sheet 1) and provoke their thinking by asking these questions: • Can you tell me what's happening in these pictures? • Why will that happen? • What does the arrow mean in this one? • Do you know any words that mean (e.g., going away, coming together, sticking, won't go together with that pupils use) to do with magnets? 4. Give pupils a pair of unlabelled bar magnets and/or a pair of unlabelled horseshoe magnet and allow them to experiment. What do they notice? How do the magnets behave? Do they notice any patterns? Introduce the terms attract and repel to describe how the magnets behave. Now introduce labelled bar and horseshoe magnets. Can they generalise how the magnets behave, e.g. opposite poles attract, like poles repel each other. 5. Now provide pupils with a different magnet diagram (with text) (Resources sheet 2) and disscuss with pupils by asking these questions: • What does *attracting* mean? • What does *repelling* mean? • Which diagram is showing an attracting force? • Which diagram is showing a repelling force? • What's happening over here (point to diagram part(s)? • Why does that happen? • What happens to the magnets when the arrows look like that? Why?
Key questions	What are magnets attracted to? Are magnets attracts to all metals? Which metals are magnets attracted to? Iron/nickel/cobalt Do magnets need to touch a iron/nickel/cobalt object to be attracted to it? How do the magnets behave? (when the pupils experirment with two magnets) Do they notice any patterns? Which poles attract? Which poles repel?
Assessment suggestions	Pupils create their own drawing for a pair of bar magnets, two attracting poles and two repelling poles (Pupils who struggle with written work could explain their diagrams verbally)
Resources	A range of magnetic and non-magnetic metals Bar magnets Horseshoe magnets

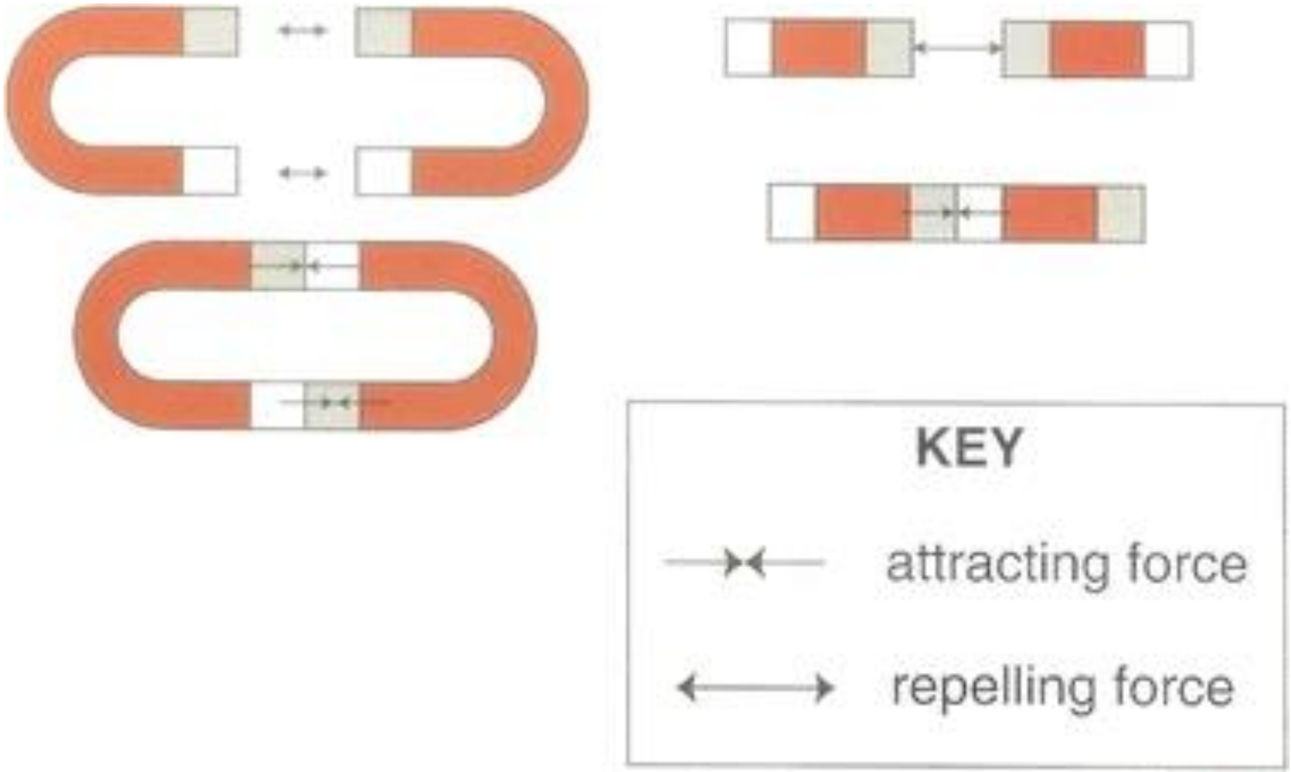
	Encased iron fillings Useful links: https://ece.northeastern.edu/fac-ece/nian/mom/work.html https://www.bbc.co.uk/bitesize/guides/zxxbkqt/revision/2
H&S considerations	Avoid fine iron fillings since they can be inhaled. Please do not buy iron fillings but always purchase iron fillings that are encased in plastic. Iron fillings must be used in a sealed container, such as a sealed petri dish or a box with a transparent lid, to avoid inhal ion by pupils.

Resource sheet 1



Source: Preston (2016) https://doi.org/10.1007/s11165-015-9484-8

Resource sheet 2



Source: Preston (2016) https://doi.org/10.1007/s11165-015-9484-8

Research Summary

Rocks

Using scientific observation to teach about different kinds of rocks and its features.

Pupils should be taught to: compare and group together different kinds of rocks on the basis of their appearance and simple physical properties.

Science – Key stage 2 (Year 3)

Statement of issue

Research since 1929 has shown that rock identification is challenging for pupils despite being a central practice in geology (Frøyland et al., 2016; Kusnick, 2002). Scientists conceptualise rocks as objects that are subject to change as the result of large-scale rock formation processes (Kusnick, 2002), and observe rocks features like patterns, mineral composition, and colour to make scientific observations (Ford, 2005). By contrast, pupils tend to view rocks as static objects and observe features such as colour, shape, and size to identify rocks based on sensory-based approaches (Kusnick, 2002).

Research has found that pupils rarely notice rock features as part of the identification process; instead, they confuse rocks and minerals and do not favour geologically relevant features over other features (Ford, 2005). Research demonstrates that the incorrect use of observation, such as noticing ambiguous features or features that are irrelevant to the situation, can lead to incorrect rock identification (Remmen & Frøyland, 2020). For example, the pupils surveyed by Kortz and Murray (2009) identified rocks based on colour. The pupils believed that black rocks are made of magma and that magmatic rocks are black. Consequently, the pupils failed to identify granite as a magmatic rock.

Main findings from the research

Teaching geology for school science

Research has argued that pupils need to be aware that they are working with rocks from a geological perspective. This perspective implies that teaching needs to address how features of rocks are connected to rock formation processes (Frøyland et al., 2016). In particular, asking pupils how the rocks acquired these features – the same key features that geologists use – can support them in sorting and identifying rocks into the three main groups: igneous, metamorphic, and sedimentary (Hawley, 2002). Thus, a number of researchers have emphasised the importance of scientific observation in identifying rocks and other minerals (Finley, 1982; Finley & Smith, 1980; Frøyland et al., 2016).

Observation is not new in science education; it has been an important focus in the teaching of science (Abrahams & Reiss, 2012; Mestad & Kolstø, 2014). Remmen and Frøyland (2020) have shown that teaching focused on geological observations can enable pupils to apply rock identification in later situations. However, observation is a challenging scientific practice requiring specific disciplinary knowledge of what and how to observe. Thus, teachers need to know how to better facilitate pupils to apply observation in rock identification (Remmen & Frøyland, 2020). Remmen and Frøyland (2020) provide an observation framework to consider how pupils' observations can become increasingly more powerful, productive, and scientific in schools (attached in the lesson plan).

Geologists often undertake observations in a fieldwork environment, where rocks can be found in their natural settings. Research has also indicated that teaching about rock identification as a core geological practice should include pupils' prior knowledge and experiences to observe and interpret geological phenomena in their natural environment (King, 2008). However, Frøyland et al. (2016) have emphasised that before bringing pupils outside of the classroom, the teacher should provide pupils with subject-specific mental tools that will enable them to apply relative dating in the field.

A study was conducted by a group of researchers in Norway, to investigate how teaching that seeks to address scientific observation can support pupils' ability to apply rock identification processes (Frøyland et al., 2016). The study involved a class of seventeen primary school pupils in Grade Two (Year 3) and their teacher. The teacher, who had attended a year-long professional development programme on inquiry-based science education, implemented the teaching intervention: observation. The teaching activities were conducted in the classroom and in the field, and involved practical activities, group work, and whole-class discussions. The teachers and pupils were video-recorded by the researchers during classroom and fieldwork activities and after a year of teaching, the pupils were also video-recorded when applying rock identification processes (Frøyland et al., 2016).

Results indicate that teaching on scientific observation played a key role in supporting the pupils to notice one critical feature (a pattern) for each of the three main groups of rocks, and to explain these features via rock formation theories, in addition to teaching geological vocabulary. This supported the claim that even young pupils can develop as scientific observers when they have the tools, knowledge, and experience (Eberbach & Crowley, 2009). Frøyland et al. (2016) suggest that teaching about rock identification should focus on features that are both familiar to pupils and relevant to the natural phenomena they are studying. The pupils in the study learned to observe only one critical feature for magmatic and metamorphic rocks, and two for sedimentary rocks.

In an earlier study, Remmen and Frøyland (2013) examined how seventeen Grade Twelve (Year 13) pupils were supported to apply geoscientific knowledge learned in the classroom to phenomena in the field. Pupils were initially involved in classroom activities that focused on cognitive, geographical, and psychological preparation to support their learning in the field. The pupils then conducted fieldwork activities that allowed social interactions with their peers and interactions with the phenomena, as well as follow-up activities that supported further learning. The findings of the study suggest that observation and interpretation should build on pupils' everyday experiences, their natural way of thinking, and must consist of clues that direct their observations of essential features and connect these observations to geoscientific interpretations (Remmen & Frøyland, 2013).

The same team of researchers further investigated how fifty-five pupils in Grade Twelve (Year 13) from three different schools in Norway used observation as part of rock identification processes (Remmen & Frøyland, 2020). The pupils were chosen because their teachers had emphasised observation in their teaching of rock identification. Remmen and Frøyland (2020) employed a modified version of Eberbach & Crowley's (2009) observation framework to analyse how pupils noticed features of rocks (noticing) and interpreted the geological processes forming those features (expectations) at different levels: everyday (low), transitional (moderate) or scientific (high).

After ten months of data collection and video analysis, Remmen and Frøyland (2020) found that none of the pupils analysed in this study used observation in a manner consistent with an everyday (naïve) level in their identification of rocks. The findings of the study indicated various qualities in the pupils' use of observation. Four of the nineteen pupil groups used scientific observation in both the noticing and expectation components, whereas the other fifteen pupil groups used observation on a transitional level in the expectation component. Based on these findings, an observation framework for rock identification was proposed by Remmen and Frøyland (2020).

Therefore, a lesson was produced to incorporate scientific observation into approaches to teaching about rock identification and rocks' features.

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Lesson Plan

Rocks
Using scientific observation to teach about different kinds of rocks and its features
Pupils should be taught to: compare and group together different kinds of rocks on the basis of their appearance and simple physical properties
Science – Key stage 2 (Year 3)

Research recommendation(s) and rationale	Research has shown that pupils who memorise the features of rocks they have seen, rather than observing these features with a critical eye, do not follow a procedure that aligns with scientific practice (Frøyland et al., 2016). Therefore, research suggests that teaching about scientific observation can help pupils to develop a more scientific understanding of rocks beyond memorisation, as well as to avoid the misunderstandings reported in previous studies (Eberbach & Crowley, 2009; Frøyland et al., 2016; Remmen & Frøyland, 2013, 2020). The teaching activities suggested in this lesson plan are structured based on Frøyland et al.'s (2016) and Remmen and Frøyland's (2013, 2020) work, as their research offer strong empirical evidence that pupils can develop as scientific observers when they have the tools, knowledge, and experience.
Lesson aim	To use scientific observation to teach about different kinds of rocks and their features.
Learning objective	To enable pupils to differentiate between three main kinds of rocks and to understand their features.
Intended learning outcomes	At the end of the lesson, pupils will be able to: i. Identify and name three of the main kinds of rocks based on their features. ii. Describe that the differences in rock features are linked to how they were formed.
Scientific vocabulary	Igneous rock – formed by the solidification of melted rock beneath or on the surface of the Earth. Sedimentary rock – consists of sediments (e.g., sand, pebbles) deposited in water (e.g., rivers, fjords, basins) and solidified into hard material. Metamorphic rock – rock types that have been exposed to high pressure and temperature, sometimes in a mountain-building process, which changes their chemical composition.
Suggested lesson sequence and activities	***Pre-activity: Tools for observation and interpretation*** ***NB: The lesson focuses on the WS skill of "Observation". Teachers will model the importance of developing observational skills as a tool for identifying & classifying. Within this lesson, children will focus on one observational detail which will enable a broad classification of the 3 main rock types, and not just focussing on the names and remembering what those rocks looked like. This will enable children to apply this knowledge across a broad base. It will be important for children to understand that even though they have identified 1 key feature, this would not necessarily be enough evidence to "classify" the rock.*** At the beginning of the lesson, the teacher will allow the pupils to practise their observational skills using tools of observation and interpretation. For example, pupils will collect and describe items with a dotted pattern, such as clothing, toys, dinner plates, and cups. This activity will aim to help pupils to observe more closely, which will lead to the discovery that dots can be small or large, can have different colours, and that the distance between them can be short or long.

	The teacher will then provide a sample of rocks to pupils and ask them to observe and identify the rocks by focusing on and interpreting their critical features according to a geological framework. Pupils will learn to observe only one feature for magmatic and metamorphic rocks, and two for sedimentary rocks. Pupils will observe and identify rocks based on one pattern, denoting one of the three generic groups of rocks: dotted (magmatic), striped (metamorphic), and layer-on-layer with fossils (sedimentary). Useful links with images: Metamorphic: metamorphic rocks - Bing images Igneous: igneous rock - Bing images Sedimentary: sedimentary rocks - Bing images It will be worth noting the pupils' 'own language' for how they describe the patterns they are looking for – for example they may say the word 'spots' instead of 'dots'. This collection and agreement on language will make it more 'real' to the pupils using terms they have come up with themselves. **Teaching/Reviewing Vocabulary Activity:** (Different activities could be used to help pupils learn and understand specific vocabulary – many can be done easily by short quick games either before this lesson is due to be taught or again at the start of the lesson. Activities used to teach vocabulary need to be 'drip fed' over a number weeks so that pupils embed and apply the vocabulary over time.) • Vocab Bingo • Card Sort – Matching definition to Word • Vocabulary Splat (found in: *Science Enquiry Games book by Anne Goldsworthy with Bob Ponchaud)* ***Activity: Fieldwork*** The teacher will take the pupils outside of the classroom to identify the rocks around the school grounds. If possible, the teacher should take pupils out of the school for short school trips to natural rock areas. During the fieldwork, the teacher will provide opportunities for pupils to apply their knowledge to rocks in their natural environment. The fieldwork activities will provide opportunities for pupils to develop observational records, by keeping a notebook as well as bringing samples of rocks to the school during the rock collection fieldwork (if allowed). The pupils will write about and illustrate their observations in their notebooks, as well as note and describe the locations where the rocks were found in nature. After the pupils have collected samples of dotted and striped rocks in the field, the teacher will ask the pupils to count the number of dotted and stripy specimens in their collection of rocks. If a fieldwork trip is not possible, the teacher will need to provide a selection of rocks for the pupils, so that the observational task can still happen

	Post-fieldwork activity: Supporting further learning The teacher will also provide a worksheet that allows the pupils to discuss the assignment in small groups, as well as to choose the order of tasks. Afterwards, the teacher will allow the pupils to finish their fieldwork tasks on rock identification and create an end product. The pupils will complete the post-fieldwork task to evaluate their learning. For example, the teacher could ask the pupils to design simple classification keys to help sort the rocks into the 3 main types. This would help pupils spot additional features, which may help in the classification process. Pupils could produce a poster/fact sheet – linked to some research from secondary sources to detail the identification of the rock, and link to how they were formed. The teacher can choose to demonstrate how geological processes work, for example, by conducting an experiment with water, sand, and a gutter to explain the layer-on-layer features of sedimentary rocks. This activity will aim to encourage pupils to use observation, argumentation, and inscription in ways that are increasingly consistent with disciplinary practice.
Key questions	What similarities and differences do you notice about the rocks? Can you describe what the rock(s) look like? What feature is the most important in distinguishing between the rocks and why? How do you think the rocks have been made? Why do you think that? Have they all been made in the same way? Explain your answer? What other information would we need to be able to identify the rock clearly?
Assessment suggestions	Using the observation framework below – the teacher can assess the pupils' observational progression. This will then give a good starting point for future observations and how the pupils can move forward. Correct application of a classification key, posing own questions to ask in this, and noticing additional features that could be used to identify and sort. Note pupils who begin to offer plausible suggestions as to how the rocks may have been formed differently and why this affects their appearance/physical properties. A sample of rocks such as granite, basalt, marble, slate, sandstone, chalk, limestone, or oxford clay.

<table>
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<td>Resources</td>
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The teacher is encouraged to use an observation framework as a learning progression/assessment of rock identification (adapted from Remmen & Frøyland, 2020, p. 126)
<table>
<tr><th>Everyday observation</th><th>Transitional</th><th>Scientific/transitional</th><th>Scientific observation</th></tr>
<tr>
<td>i. Notice more irrelevant than relevant features of rocks
ii. Name specimens at a specific level without justification or relation to major rock categories (‘name dropping’ based on memorisation)</td>
<td>i. Notice more relevant features and use them to classify specimens into the major rock categories
ii. Name specimens at a specific level and classify the specimen into a major group</td>
<td>i. Notice relevant features and use them to classify specimens into the major rock categories
ii. Notice features, stimulating related knowledge and experience with rocks that are used to classify specimens
iii. Infer rock formation processes based on features</td>
<td>i. Notice and describe relevant features and use them to classify specimens into the major rock categories
ii. Classification and naming fits specimens on a more specific level than the major rock categories (e.g. three types of magmatic rocks)
iii. Infer rock formation processes based on features</td>
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<td>H&S considerations</td>
<td>
Make sure pupils do not drop or throw rocks at peers. They must be observed at all times when handling the rocks.

When undertaking fieldwork, the teacher in charge must be experienced in the nature area and in leading groups. The geographical area to be used for fieldwork activities must be researched and physically explored prior to the fieldwork’s commencement, to make sure significant hazards (cliffs, water hazards, quarries etc.) are avoided or carefully assessed. The weather forecast must be obtained, and conditions monitored; the route should be changed if necessary.

The teacher must ensure that all activities are carried out in a safe and calm manner. The school’s health and safety protocols must be followed. Please discuss health and safety with your mentor.
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Research Summary

Seed Dispersal
Using authentic experiences to teach about the life cycle of flowering plants
Pupils should be taught to: explore the part that flowers play in the life cycle of flowering plants, including pollination, seed formation and seed dispersal.
Science – KS2 (Year 3)

Statement of issue

Pupils understanding of plants is limited (McNair & Stein, 2001; Osborne & Freyberg, 1985). Typically, teaching adopts a checklist approach – asking pupils to categorise plants and non-plants, identify what plants need, and correctly label parts of flowers (Anderson et al., 2014). For example, teachers typically point to a picture of a plant using a checklist approach and ask, "is a plant a living thing?" all pupils respond yes. We are also familiar with growing seeds and putting them in different conditions within the classroom, for example, no water or no light, checking off that pupils can identify the soil, seed and stem (Villarroel et al., 2018). However, a checklist approach creates more opportunities for pupils to develop erroneous categorisations, for example, wrongly categorising a seed as a plant, or disagreeing that a tree is a plant and claiming that plants need humans to provide water and light (Anderson et al., 2014; Barman et al., 2006). Instead, researchers suggest we create more authentic experiences to enhance pupils' scientific learning (Chinn & Malhotra, 2001; White & Frederiksen, 1998).

Main findings from the research

Authentic Experiences
Literature suggests that authentic experiences for learning science can be gained using outdoor learning (Rickinson, 2004; Waite, 2011). Researchers have shown that taking part in hands-on activities in the real world better inspire the construction of schemas about the nature of these events (DeMarie et al., 2000; Hudson et al., 1995). The UK Government promotes outdoor learning in its Learning Outside the Classroom Manifesto (DfES, 2006), which sets out the policy for learning outside the classroom. The manifesto recommends that all pupils experience the real world beyond the classroom as part of their learning and personal development. Indeed, research has shown that outdoor learning experiences help to develop cognitive skills that enhance class-based learning (Dillon et al., 2006; Eaton, 2000). Research demonstrates that outdoor learning experiences can benefit pupils both academically and personally, for example, by improving pupil's academic knowledge (Samarapungavan et al., 2008) and improving environmental attitudes (Cheng & Monroe, 2010).

What the research shows: Authentic experiences if there is a school garden
Samarapungavan et al. (2008) explored the impact of using authentic pedagogies to enhance science learning with 65 Year 3 pupils in the United States focused on teaching about life cycles. They followed the life cycle of a monarch butterfly; watching larvae in the classroom, finding caterpillars/chrysalis in the school garden, and seeing adult butterflies emerge from their chrysalis. Through this approach, the pupils experienced authentic learning. A control group of 35 pupils did not have these dedicated science lessons because of an additional focus on literacy and numeracy state tests. The study found that pupils who had the authentic experience (experimental group) learned statistically significantly more science content than the control group.

Caballero and Dashoush (2017) collaborated with the arboretum at Harvard University and designed outdoor learning activities aligned to their state science educational framework. Adopting an ethnographic approach (meaning embedded within the culture of outdoor learning at the arboretum), Caballero used outdoor learning and described observations of pupils (Year 3 and younger) that took part in the arboretum's education programme. Exposing pupils to a variety of plants and asking them to search for a seedling, then find the seedling's parent tree helped rectify the misconception that a tree was not a plant. This helped the pupils to make the connection between the seedling and its subsequent growth into a tree. Other researchers have found that the best way to address pupils' misconceptions is to provide experiences that challenge these (Carey & Sarnecka, 2006; Trundle et al., 2008).

Carrier et al. (2014) measured the impact of outdoor science learning on 30 Year 5 pupils at two schools in the United States. Over a year, four topics were taught - ecosystems, weather, landforms, and forces and motion – all using authentic experiences. They found statistically significant improvements in science knowledge overall. In support of this, Miczajka et al. (2015) showed that pupils gain more in-depth knowledge about habitats by studying them outside. Their study, compared whether primary pupils could conduct an ecological experiment, counting seeds and estimating vegetation cover. Ten schools took part with a total of 302 pupils from Years 5 and 6 and they found that the seed count was the same as that carried out by scientists, although estimated vegetation cover differed as pupils had not yet been taught about percentages. In the study, pupils spent 4 out of 12 lessons outside in their school garden, finding and counting seeds or measuring vegetation cover. They found that pupils demonstrated a more in-depth insight into the ecological background of the native habitats and plant-animal interactions using this approach.

Authentic experiences can be gained with limited time away from the classroom.

There is a trend in urban areas of decreasing opportunities for contact with nature (Louv, 2005). Ju & Kim (2011) provided an alternative to outdoor education but managed to retain authenticity in a classroom setting. They worked with two urban Korean schools and aimed to provide pupils with an authentic first-hand activity. The research focused on teaching the life cycle of flowering plants, and they included 99 Year 5 pupils, 65 of who were assigned to the authentic experience using soil seed banks. Soil seed banks are the name for the natural storage of seeds, which are often dormant within most ecosystems' soil. Pupils collected soil from their school garden, placed them in trays with bedding soil, and laid the soil sample at 1cm thick across the top. Pupils were encouraged to check the soil seed bank trays for seedlings 2-3 times a week and identify the plants using a reference book. Traditionally, in Korea, life cycles are taught through a textbook-based curriculum, although pupils can observe a lima bean growing in the classroom. They found that the pupils who experienced the soil seed banks had statistically significantly higher content and plant ecology knowledge than the pupils who followed the traditional learning approach.

Preparatory work and language

Research shows it is essential before going outside that teachers conduct preparatory work with pupils. Ballantyne and Packer (2002) examined the difference between pupils who took part in preparatory work before fieldwork and those who did not and found statistically significant differences between pupils who took part in preparatory work and those who did not. Those who took part in preparatory work looked forward to their outdoor lessons and reported higher enjoyment of the lesson. Preparatory work can also help introduce pupils to cognitive aspects of outdoor learning (Orion & Hofstein, 1994).

However, it is important to be aware that inappropriate language use can result in pupils attributing anthropomorphic characteristics to plants (such as breathing, drinking or eating), but this can be corrected in an outdoor learning environment. For example, pupils' misconception concerning pollination whereby they believe that a bee delivers honey from flower to flower (Barman et al., 2006). It is the teacher's role to support pupils' observations of the natural world (make things visible that are difficult) to reveal and address the misconception.

Authentic outdoor learning is instrumental in addressing misconceptions as teachers can guide pupils towards the evidence. Giving pupils opportunities to experience nature first-hand encourages learning about diverse species (Lindemann-Mathies, 2006) and variation. For example, using the idea of finding the perfect leaf allows pupils to create meaningful new knowledge that leaves vary and will have holes, tears, and discolouration (Caballero & Dashoush, 2017). There is supporting evidence that young pupils (2-4 years) can correct misconceptions in the face of new evidence (Carey, 2004; Carey & Sarnecka, 2006; Gopnik et al., 2004; Metz, 2004). Research repeatedly shows that authentic outdoor learning increases pupils' scientific knowledge, creates more positive attitudes towards the environment, and addresses misconceptions.

Therefore, a lesson was produced using authentic experiences to teach seed dispersal.

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Lesson Plan

Seed dispersal

Using authentic experiences to teach about the life cycle of flowering plants

Pupils should be taught to: explore the part that flowers play in the life cycle of flowering plants, including pollination, seed formation and seed dispersal.

Science – KS2 (Year 3)

Research recommendation(s) and rationale	Pupils erroneous categorisations and misconceptions about life cycles are allowed to flourish when using a checklist approach to teaching (Anderson et al., 2014). A checklist approach is where pupils are asked to categorise plants or grow seeds in different conditions (Villarroel et al., 2018). However, research suggests that if pupils are given authentic outdoor experiences, they can use evidence from their local environment to correct their erroneous understanding or misconceptions (Caballero & Dashoush, 2017; Carrier et al., 2014; Miczajka et al., 2015; Samarapungavan et al., 2008).
Lesson aim	To understand the processes of seed dispersal through the use of outdoor learning.
Learning objective	To understand where seed dispersal fits into the life cycle of a plant.
Intended learning outcomes	At the end of the lesson, pupils will be able to: i. Explain how seeds are dispersed. ii. Classify seeds by their dispersal method. iii. Explain where seed dispersal fits into the life cycle of a plant.
Scientific vocabulary	Dispersal – how seeds (in this case) are spread. Germination - Germination is the process by which a plant begins to grow from a seed. Roots form under the soil. The stem, leaves and flower emerge above the soil. Life cycle (of plants) – A plant starts life as a seed, which germinates and grows into a plant. The mature plant produces flowers, which are fertilised and produce seeds in a fruit or seedpod. The seeds then germinate to produce new plants.
Suggested lesson sequence and activities	Activities have been adapted from Caballero and Dashoush (2017), who trialled several authentic outdoor experiences for the life cycle topic. As suggested by Ballantyne and Packer (2002), pupils are given a preparatory activity before going outdoors: • Recap the parts of the plant (Year 2 prior knowledge but emphasise where the seeds on different plants can be found). • Recap on what a life cycle is. • Recap on the life cycle of a plant. • Introduce some key vocabulary from above and explain to pupils so that they are able to use it when outdoors completing the activities. • BBC Bitesize KS1 and KS2 website has some great videos for helping with the explanation of the above.

	Outdoor Activity: Squirrel game demonstrates animal seed dispersal. Tell pupils that they are going to be squirrels. Outline an activity area for pupils to use to “bury” their sultana (representing a nut, sultanas biodegrade quickly). You will need two bags of sultanas: one for pupils to hide and one for pupils to eat when they find the sultanas. Give each pupil a sultana to hide where they want. Occupy pupils with a different activity for at least half an hour away from the activity area (see below). Now allow pupils 5 minutes to find their sultanas [warn pupils not to eat this sultana and have back-up sultanas]. Several pupils will not be able to find them. Ask the pupils why, if animals cannot find their store of seeds, this might be important to a plant. This will be a good opportunity to talk about dispersal of seeds through animals and how now that the seed has been buried it can germinate as long as the conditions are suitable for the seed. Interim activity ideas: • Pupils to collect dandelions at different stages in the life cycle; flowering and covered in seeds. Use this to explain the life cycle of the dandelion and then pupils to blow the seeds from the dandelion as another example of seed dispersal. • Pupils to take pictures of plants in the different stages of the life cycle and use software to create a life cycle of a certain plant. **Outdoor Activity: Squirrels collection box** Encourage pupils to collect different types of seeds. This might not be a realistic option depending on the school’s location so perhaps different seeds might need to be ‘placed’ by the teacher for the pupils to find. **Indoor Finishing Activity: Alternative Dispersal activity (links to squirrel’s collection box)** Using the collected seeds from the outdoor activity. Ask pupils to observe and draw the seeds and ask them to pick out the different features. Ask them to think how the seeds might be spread. For example, (a) seeds that are dispersed by wind will have parachutes or wings to help them float on the air; (b) seeds that animals disperse may have burrs that help them attach to fur; (c) seed dispersed by birds may be contained within fruit that is brightly coloured, shiny, or juicy to make it appealing to eat.
Key questions	• What will happen to the squirrels (or other animal) seeds that are buried if they are not found again? • What are the different ways for seeds to be dispersed? • Can you name a seed which is dispersed using animals? • Can you name a seed which is dispersed in the wind? • How do some seeds appeal to birds? • Why do seeds need to be dispersed? • What are the stages of the life cycle for a plant?
Assessment suggestions	• Formative assessment will be key when pupils are working outdoors and completing the activities. Use the questions in the section above to help direct children’s thinking. This will be a great opportunity to encourage pupils to use scientific vocabulary. • Sorting activity: provide pupils with either pictures of seeds or actual seeds and children to put into groups based on how they are dispersed.

	• Pupils to create an explanation text about how seeds are dispersed including examples. • Pupils could write a story as if they are a seed and the journey it goes through in its life cycle (seed, germination, buds and leaves, flowering, seeds, seed dispersal).
Resources **H&S considerations**	• Suitable scene-setting story • Squirrels collection box: small tray/cardboard box for each pupil • Hand lenses • Squirrel game: sultanas Check and follow school policy regarding outdoor/offsite activity.

Research Summary

States of matter
Using inquiry instruction with multiple representations (IIMR) to teach about states of matter
Pupils should be taught to: compare and group materials together, according to whether they are solids, liquids or gases
Science – Key stage 2 (Year 4)

Statement of issue

Primary school pupils are expected to understand that matter is comprised of tiny, invisible particles called atoms, as well as molecules that are in constant motion (Adadan & Ataman, 2020; Pozo & Gómez-Crespo, 2005). However, pupils find it hard to understand states of matter, including the movement and arrangement of particles in three physical states – solid, liquid and gas – and the empty space between particles (Nakhleh et al., 2005; Yaseen, 2018).

Research has shown that although pupils' understanding of states of matter progresses from macro continuous to microparticulate as they move from primary to secondary school (see Boz 2006; Liu & Lesniak 2006), the majority of pupils do not maintain this approach equally across the three physical states (Boz 2006; Johnson, 1998; Nakhleh & Samarapungavan 1999; Nakhleh et al., 2005; Pozo & Gómez-Crespo, 2005; Samarapungavan et al., 2017). The majority of pupils presume the existence of some sort of material in between the particles, usually air or another substance, when they initially develop states of matter ideas (Talanquer, 2009). In particular, studies have reported that pupils commonly understand that particles of gases are in constant movement, inferring this from the analogical interpretation of natural phenomena, but they wrongly understand that particles of solids stay still (Johnson, 1998; Pozo & Gómez-Crespo, 2005).

In summary, pupils' conceptions of matter can be grouped into two main categories: (i) conceptions about the states of matter (including conceptions about atoms, molecules and particle systems), and (ii) everyday conceptions about matter and its transformations (including conceptions about chemical reactions, physical states and their changes, and the conservation of matter (Andersson, 1990).

Main findings from the research

Previous research into pupils' misconceptions in science calls for instructional interventions that can change the construction of their scientific views surrounding natural phenomena (Duit & Treagust, 2003). To promote a change in pupils' conceptions of the states of matter, Adadan et al. (2009) reported that researchers have designed teaching pedagogies such as project-based learning, discrepant events, socially enriched learning contexts, analogies and role-modelling, concrete models and multimedia/multiple representations.

Pupils simulate scientific inquiry processes in the classroom by utilising methods similar to practising scientists, as well as developing well-established conceptual understandings in inquiry-based instruction, to understand various phenomena (Bell et al., 2005; Cairns, 2019). Inquiry-based instruction can be enriched with multiple representations to support pupils' understanding of abstract scientific concepts and to help them develop scientific practices such as manipulating variables, arranging experimental setups, and collecting and interpreting data (Bridle & Yezierski, 2012; Cairns, 2019; Stern et al., 2008). Therefore, inquiry instruction with multiple representations (IIMR) can provide pupils with opportunities to explore the actual phenomenon (macroscopic), develop their own particles representations based on their own observations, as well as to view the dynamic particle representations of phenomena in three physical states (submicroscopic) (Adadan, 2020; Johnson, 1998; Talanquer, 2011).

In a recent study, Adadan and Ataman (2020) examined the effect of inquiry instruction with multiple representations (IIMR) as compared to regular instruction, in terms of promoting a change of conceptual understanding regarding the nature of matter, with 112 primary school pupils. The findings from the study indicated that prior to the instruction, almost none of the pupils were aware of the fact that there exists a vacuum (nothing) between particles of matter; however, more than 90% of pupils believed in the existence of something between the particles. Following the teaching intervention of inquiry instruction with multiple representations (IIMR), about 85% of pupils understood that there is a vacuum between particles.

Adadan and Ataman's (2020) study claimed that the learning gains of inquiry instruction with multiple representations (IIMR) exceeded the learning gains reported for other studies conducted with primary school pupils, which utilised inquiry or multiple representations alone as an instructional approach (see Mamombe et al., 2020; Özmen 2011; Stern et al., 2008). Out of the pupils who participated in the inquiry instruction with multiple representations (IIMR), 67% gained an understanding of the states of matter, from pre to post instruction. In contrast, in other studies, only 48% (Özmen, 2011), 47% (Mamombe et al., 2020) and 30% (Stern et al., 2008) of pupils respectively gained this knowledge.

In an earlier study, Adadan et al. (2009) investigated the impacts of multi-representational instruction on 42 secondary school pupils' conceptual understandings of the states of matter. The findings of the study indicated that prior to instruction all pupils held a range of misconceptions about aspects of the states of matter. The post-instruction findings indicate that multi-representational instruction was more efficacious in promoting a scientific understanding of the states of matter than instruction without multiple representations (Adadan et al., 2009). The study suggests that using multiple modes of representation (a mixed set of oral, textual, and visual approaches — for example, pupils' pictorial drawings, static/animated models) may have been a crucial component of the radical conceptual changes identified, as pupils moved beyond deeply entrenched misconceptions surrounding the states of matter (Adadan et al., 2009).

The main findings of the above research drew attention to the crucial role of inquiry instruction with multiple representations in teaching and learning about the states of matter (Adadan et al., 2009; Adadan & Ataman, 2020). Thus, teachers may consider creating similar learning environments for their pupils when teaching with the aim of conceptual change. The essential role of written communication (activity sheets, drawings, journal entries) in science teaching and learning should be recognised (Adadan, 2020). Dynamic particles representations (animations) are also potentially invaluable for developing pupils' understanding of dynamic phenomena, such as the movement of particles (Adadan & Ataman, 2020).

Therefore, a lesson was produced to incorporate inquiry instruction with multiple representations (IIMR) into states of matter teaching.

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Lesson Plan

States of matter
Using inquiry instruction with multiple representations (IIMR) to teach about states of matter
Pupils should be taught to: compare and group materials together, according to whether they are solids, liquids or gases
Science – Key stage 2 (Year 4)

Research recommendation(s) and rationale	Research has shown that inquiry instruction with multiple representations (IIMR) enables primary school pupils to gain better conceptual understandings of the states of matter (Adadan & Ataman, 2020), compared to utilising inquiry or multiple representations alone as an instructional approach (Mamombe et al., 2020; Özmen 2011; Stern et al., 2008). Inquiry instruction with multiple representations (IIMR) provides pupils with opportunities to explore a phenomenon (macroscopic), develop their own particles representations based on their observations, and to view the dynamic particles representations of a phenomenon in three physical states (sub microscopic) (Adadan & Ataman, 2020; Johnson, 1998; Talanquer, 2011).
Lesson aim	To use inquiry instruction with multiple representations (IIMR) to teach about the states of matter.
Learning objective	To understand that gases, liquids and solids are all made up of tiny particles, that there is a vacuum between particles, and that there are different arrangements of and distances between particles in the three phases.
Intended learning outcomes	At the end of the lesson, pupils will be able to: i. Explain substances as being made up of particles that are too small to be seen without magnification. ii. Describe the existence of a vacuum between the particles, and the arrangement and movement of particles in the solid, liquid and gas states.
Scientific vocabulary	**Particle** – A tiny piece of matter – everything is made of particles. **Solid** – The particles in a solid are very close together, have a very small amount of energy and can only vibrate. **Liquid** – The particles in a liquid are very close together, can vibrate and can change places. **Gas** – The particles in a gas are far apart, have a large amount of energy and move rapidly. **Evaporation** – The process of changing a liquid into a gas. **Condensation** – The process of changing a gas into a liquid. **Freezing** – The process of changing a liquid into a solid. **Melting** – The process of changing a solid into a liquid. **Macroscopic** – Visible to the naked eye *(Atoms are the smallest pieces of matter; they are made of particles (protons and electrons). When atoms are grouped together, these groups are called molecules (the smallest pieces of compounds).)*
Suggested lesson sequence and activities	Inquiry instruction with multiple representations (Adadan & Ataman, 2020) is based on a Predict-Observe-Explain approach (adopted from Bell et al., 2005).

	This lesson will need to fit into a sequence of lessons, after pupils have a solid understanding of solid, liquid, gas and can also represent these simply with 2D particulate drawings. Without this prior knowledge – pupils will not be able to make accurate predictions on the IIMR models below. upils should also have been taught and understand the basic principles surrounding the properties of solids, liquids and gases: [What are the states of matter? - BBC Bitesize]() upils will also need to understand the basic principles of the atoms in a solid, liquid and gas, how they behave and why, and how this looks in the changes of state from Solid to liquid to gas etc. and why this results in the materials acting like they do to the naked eye. *(Note: Class teacher will need to spend some time familiarising themselves with the dynamic particulate representations on the below weblink, before sharing with pupils).* • Pupils will carefully observe the macroscopic phenomenon, and then will verbally explain and pictorially draw particles representations based on their observations. • Pupils will view the dynamic particulate representations of matter for almost all observed phenomena (example resources can be found at: http://mw.concord.org/nextgen/), so that they can compare their pictorial particulate representations with the scientifically accepted dynamic representations and can discuss the differences between the two with their peers in class. • Pupils will write their verbal explanations and draw their pictorial particulate representations on the activity sheets. • Pupils will write a one-page handwritten journal entry. Journal writings allow pupil engagement in thinking processes, where they will compare and contrast their current ideas with their initial ideas. This will offer them an opportunity to increase their awareness about their own ideas. g. Melting of Ice on Hand: Show pupils the ice cube and ask them to identify what state of matter it is currently in. (upils should identify this is a solid). Discuss the 2D particulate drawing of a solid (pupils should know from previous learning). Discuss with pupils what they think will happen physically (macroscopic). (Ice will melt forming a change of state from a solid to a liquid). Ask pupils to represent this as a 2D particulate drawing. upils can then discuss their drawing and explain to a peer what they have drawn and why. Observe the ice melting and discuss the change in state. Watch the dynamic particulate representation and discuss as a class. upils can then draw the “official” representation on their scaffolded sheet Working with a partner, the pupils write up an explanation of what has occurred, using their previous knowledge of changes in state, atom/molecule movement due to energy increase/decrease etc. and compare their original thoughts to the scientifically accepted ones. Depending on ability group of pupils – this may require adult support.

	Repeat the process by observing the boiling of water in a beaker. To extend thinking (this may only be suitable for certain groups of pupils) next look at the diffusion of ink in water. Show pupils the ink and show pupils the water. Ask them to draw a 2D particulate picture of the 2 liquids. (They may wish to represent the ink as a different colour). (This will allow the correct representations of a liquid to be assessed.) Ask pupils to draw, again using 2D particulate representations what they think will happen when one drop of ink is added to the water. Repeat steps 4-7 from previous method. Repeat this process for IIMR instruction, Compression of gas in syringe and mixing of alcohol and water. (These concepts are harder than the previous ones so may require more explanation/modelling from the class teacher).

Core concepts	IIMR Instruction
• States of matter • Existence of a vacuum between particles	*Mixing of alcohol and water* • Predicting, observing, and explaining the phenomenon • Viewing particles representations of liquids • Discussing what exists between particles of matter • Journal writing
• States of matter • Existence of a vacuum between particles • Arrangement of and distances between particles	*Compression of solids, liquids, and gases by using syringes* • Predicting, observing, and explaining the phenomenon • Drawing pictorial particles representations • Observing dynamic particle animations • Journal Writing
• Movement of particles E • existence of a vacuum between particles	*Diffusion of ink in water* • Predicting, observing and explaining the phenomenon • Drawing pictorial particles representations • Observing dynamic particle animations • Journal Writing
• Movement of particles • Arrangement of and distances between particles	*Melting of ice on hand* • Predicting, observing, and explaining the phenomenon • Drawing pictorial particles representations • Observing dynamic particle animations • Journal Writing
• Movement of particles	*Boiling of water in a beaker*

	- Arrangement of and distances between particles — - Predicting, observing, and explaining the phenomenon - Drawing pictorial particles representations - Observing dynamic particle animations - Journal Writing
Resources **H&S considerations**	*Visual, Interactive Simulations of States of Matter* The Concord Consortium. (n.d.). *Molecular Workbench*. Retrieve February 12, 2021 http://mw.concord.org/nextgen/ Recording scaffold to allow prediction drawing, dynamic particulate drawing and explanations written underneath. Syringes (with a stopper) Beakers for boiling the water Ice Ink Pipettes Alcohol (ethanol) The teacher must ensure that all activities are carried out in a safe and calm manner. The school's health and safety protocols must be followed. Please discuss health and safety with your mentor.
Questions	What can you remember about the properties of a solid, liquid, gas? Can you draw a 2D particulate representation in each of these states? Can you explain how the atoms move when they are a solid, liquid, gas? How do we know this/prove this?
Assessment	Listening to pupils discussions as well as looking at their drawings will be key: Can they represent a solid, liquid, gas correctly as a 2D particulate drawing? Can they describe the simple properties of each state of matter? Have pupils shown clear thinking in their explanations, before and after they have seen the dynamic particulate representations? Can pupils begin to talk about "movement" of atoms in these states – expressing an understanding that atoms in solids are still "moving" (vibrating) they just have much less freedom than atoms in gases or liquids? When compressing the gas – do pupils talk about the reason why they cannot push any further once the gas is completely compressed? And understand that the molecules are the reason they cannot push down any more?

Research Summary

Evaporation

Using multiple representations to teach about phases of boiling water

Pupils should be taught to: (i) identify the part played by evaporation, and (ii) condensation in the water cycle and associate the rate of evaporation with temperature

Science – KS2 (Year 4)

Statement of issue

The topics, *evaporation* and *condensation* are conceptually demanding topics (Bar & Travis, 1991), and a large amount of research has explored the misconceptions (e.g. Chang, 1999; Costu et al, 2010; Hälland, 2010; Lemma, 2013; Osborne & Cosgrove, 1983; Tytler, 2000). Research commonly finds that pupils find it challenging to define the phases of change in boiling water, e.g. pupils struggle to tell the difference between steam, smoke and mist (Härmälä-Braskén et al., 2020; Pine et al, 2001).

Main findings from the research

Many researchers who identified the challenges within the topic area of evaporation and condensation also explored how to teach these concepts effectively. The ll s led to the tri lling of many frameworks, pedagogies, and lesson strategies; from story-telling (Banister & Ryan, 2001), to virtual laboratori s or software (Bogusevschi & Muntean, 2020; Papageorgiou et al., 2008).

One strategy that is well researched and proven effective in facilitating pupils' learning about phase in boiling water is multiple representations (Prain et al., 2009; Tytler, 2000; Tytler & Peterson, 2004; Tytler & Peterson, 2005; Tyler et al., 2006; Tyler et al., 2007).

What are multiple representations in science education?

Increasingly science education research acknowledges that we use a mix of languages and many different forms of representation in science, including speech, numbers, tables, figures to explain the complex scientific phenomenon. Simply, multiple representations mean, talking about a scientific concept in different ways using different modes (i.e. demonstrating experiments, drawing explanations, role-playing actions).

There have been extensive investigations into primary pupils' misconceptions of evaporation and condensation, and how best to support pupils' scientific concept development and retention of this topic. They focused their research on evaporation and condensation. They carried out their research on Australian primary pupils aged between 5 and 11 years old, using many classes, and pupils with a school within Melbourne – a case study approach was adopted. For ten years findings were published on the use of representation in science education (examples include: Prain et al., 2009; Tytler, 2000; Tytler & Peterson, 2004; Tytler & Peterson, 2005, Tyler et al., 2006; Tyler et al., 2007).

Identifying the problem:

To begin the research team focused on establishing primary pupils' prior knowledge and comparing whether there was a difference between age groups (Tytler, 2000). Finding both Year 1 and Year 6 students hold similar scientific conceptions and structure their explanations about evaporation and condensation in similar ways. The critical difference was that older pupils were more confident with the concept of air and how to use evidence to construct explanations. The researchers believe that this may explain why more of the older pupils mastered the scientific conception of change in water than the younger pupils. Twelve of these pupils took part in a four-year follow-up study to explore pupils' changing views of evaporation and condensation (Tytler & Peterson, 2004). Demonstrating pupils' understanding of evaporation depended on their personal narratives, i.e. using different contexts to support their understanding (rather than age). Therefore, despite previous research arguing that u pupils cognitively unable to grasp the scientific concept of evaporation or condensation as it was to complex (Bar & Travis, 1991 – using Piaget's Cognitive Development theory).

In the subsequent studies, researchers explored these personal narratives and how these could be co-created in the classroom.

Representations

Tytler et al. (2006) first trialled, using representations to teach, the concept of evaporation (with 3 classes of pupils aged 11 years old; Year 6), focusing on providing different representations to the pupils and asking pupils to complete a drawing explaining what happened. Finding that pupils responded differently to the representations, so it is helpful to consider them as tools for thinking, rather than activities to achieve. The researchers recommend that creating a classroom that is rich with representations of the scientific concept.

Tytler et al. (2007) explored the impact of creating a representational rich classroom using different modes (focused on 9 pupils within a context of 3 classes of pupils aged 11 years old; Year 6). Modes are generally agreed in primary science to be either *descriptive, experimental, mathematical*, *figurative*, or *gestural*. Humans frequently communicate using representations; for example, childhood games use modes of representations, particularly gestures, in the game Charades. Players use the shared representational gestures to guess a book or a film. In Charades, players are limited to one mode, gestures. The research suggests it is useful to incorporate several different classroom activities to allow each pupil to strengthen their personal narrative around the scientific concept, and therefore their understanding.

Representations seem like models (modelling in science education), how are representations different from models?

A model is a type of visual representation. Models can help support and enable visualisation of a scientific concept, for example, particle theory (Papageorgiou et al. 2008). However, at Key Stage 1, the introduction of particle theory is considered inappropriate. Although some researchers argue that to satisfactorily explain the phenomenon of water boiling without particle theory is impossible (Papageorgiou & Johnson, 2005). It may be more appropriate to build an understanding of the concept within Key Stage 2 (Tyler & Peterson, 2000) and when the topic is re-introduced in Key Stage 3 to continue the use of representations and then incorporate models as a form of representation to support pupils' understanding of particle theory and build upon previous learning.

In the 2006 study, Tytler et al. trailed the 5E's sequence (Engage, Engage, Elaborate, Explore, Explain, and Evaluate) and found that this had *no* impact pupils' understanding of the scientific concepts. In total, the activities designed by Tytler and colleagues offered the opportunity for each pupil to apply the concept of evaporation using different modes (e.g. practical, drawing, discussion) 13 times. Activities can be individual, pair (small-group) or class. They can last a lesson or for a couple of weeks (i.e. make a puddle in the playground and observe evaporation). It is essential to consider that the research highlighted in the first paragraph adopts multiple representations, although this is not by design, and this may be the reason for the effectiveness of their methods. For example, story-telling supports the development of pupils' personal narratives by reframing their original understanding of concepts and widening others (Banister & Ryan, 2001), and virtual laboratories allow for several different activities using different modes to be carried out by the pupils to support the development of their understanding of the scientific concept (Bogusevschi & Muntean, 2020; Papageorgiou et al., 2008).

The research's key message is that it is important to offer pupils a classroom rich with representations using a range of different *modes* rather than relying on one mode when teaching evaporation and condensation.

Therefore, a lesson plan was produced that incorporated multiple representations into teaching the phases of boiling water.

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Lesson Plan

Evaporation

Using multiple representations to teach about phases of boiling water

Pupils should be taught to: (i) identify the part played by evaporation and condensation in the water cycle, (ii) and associate the rate of evaporation with temperature

Science – KS2 (Year 4)

Research recommendation(s) and rationale	Research suggests that pupils struggle to define the changes of state that happen when water boils (Härmälä-Braskén et al., 2020; Pine et al., 2001). In answer to this, a programme of research by Tytler et al. (2006, 2007), suggests that pupils' scientific conceptual understanding of evaporation and condensation is best supported by offering a classroom rich with multiple representations to support pupils' understanding.
Lesson aim	To create a classroom environment with different examples of evaporation and condensation of water.
Learning objective	To understand that when water boils and then condenses again this involves a change of state.
Intended learning outcomes	At the end of the lesson, pupils will be able to: i. Identify when water is in its liquid and gaseous states. ii. Explain what can cause water to change state during the evaporation and condensation processes.
Scientific vocabulary	Condensation – when a gas (or vapour) changes state to become a liquid. Evaporation – when a liquid changes state to become a gas (or vapour). Water cycle – is the continuous movement of water around the Earth - liquid water evaporates into water vapour, condenses to form clouds, and then falls back to Earth as rain or snow. Water vapour – water in the gaseous state.
Suggested lesson sequence and activities	The aim is to create a variety of experiences for the pupils such as practical activities, discussions, drawing and annotating diagrams. Examples of evaporation (could be drawn, annotated, discussed) • Why does water in a fish tank go down over time? • What happens to water in a puddle on a sunny day? • Why might water appear on the side of a can with ice put in it? • Why do clothes dry in the sun?

	i l l ss s i s • Show a frying pan of water coming to the boil. • Watch steam from a kettle and then hold a metal tray above it to show the water condensing. • Make a puddle of water in the playground, draw round it with chalk and observe how it changes over time. Potential Activities (can be done alone, in small groups, or as a class – ask pupils to observe and explain the concept, either verbal or written) • Water level going down in a cup/jug • Leave wet clay to dry • Put ice in a closed aluminium can (to show the condensation on the outside of the can) • Disappearing handprint – ask the pupils to wet their hands, make a handprint outside (or on a chalkboard) and ask the pupils to draw around their handprint. Explore what is happening with the pupil as the water evaporates. • Investigate the speed of drying of different fabrics (and in different conditions). *Try to include some activities that last over a full week or longer.
Key questions	As suggested in the lesson plan above; pupil explanations can be given verbally or written down. It is important to encourage pupils to think about the processes that they are seeing as they happen; using the correct vocabulary. Questions could include: - What state of matter is water in at the moment? Before heating the water ask the pupils to say what state it is in. - As you begin heating the water, ask the pupils what they can you see happening. - Ask the pupils what they think is causing the change. - Ask the pupils to explain why droplets of water form on the metal tray that is held above the boiling water. - Ask the pupils why they think condensation forms on bathroom windows. - How does temperature impact on the condensation and evaporation? - What causes something to dry quicker? What is the scientific process here?
Assessment suggestions	1) Formative assessment can be carried out whilst pupils are completing the activities using the questions above. This will ensure pupils have considered the basic processes of evaporation and condensation in relation to states of matter. 2) Provide pupils with a range of scenarios linked to experiments they have completed/discussed previously and choose whether the process is evaporation or condensation. Pupils could be given pictures of each activity and then move the pictures into the two headings. This will assess whether pupils are able to apply their knowledge to real-life scenarios. 3) For a more formal explanation, provide pupils with the questions from the start of the lesson plan: Why does water in a fish tank go down over time?

	What happens to water in a puddle? Why might water appear on the side of a can with ice put in it? Why do clothes dry in the sun? Pupils can then explain the process which happens in each. Encourage use of correct vocabulary; drawings and annotated diagrams to support their explanation. This will ensure pupils are able to understand and apply their knowledge of condensation and evaporation. As with the activities themselves, all of these assessment strategies can be completed either individually, in pairs or in groups. The formative assessment verbal questions will be completed within the lesson. The second assessment suggestion would be most suitably done at the end of the lesson or unit of work because it links back to the activities carried out by the pupils. The third suggestion could be used at the end of the unit of work.
Resources **H&S considerations**	Pupils will need access to water, ice and drying facilities for many of these activities. Activity choice can be dependent on resources available. Hazards: boiling water. Ensure that all activities are carried out safely and calmly and take extra care when boiling water. Follow all your school's health and safety protocols. Please discuss health and safety with your mentor.

Research Summary

The Water Cycle

Supporting pupil's development of model-based explanations to teach about the water cycle

Pupils should be taught to: identify the part played by evaporation and condensation in the water cycle and associate the rate of evaporation with temperature

Science – KS2 (Year 4)

Statement of issue

The water cycle is one of the earliest abstract concepts taught to KS2 pupils (Vinisha & Ramadas, 2013). Research suggests that primary pupils do not think about water dynamically or cyclically (Ben-Zvi Assaraf & Orion, 2010), which leads to struggles in making connections between water in one location and water in another location. In 2013 the water cycle was added to the Year 4 Science curriculum, although the water cycle is included in geography throughout KS2 it is *not* statutory (Savva, 2014).

When learning abstract concepts, pupils take their everyday knowledge and incorporate their scientific knowledge, forming synthetic concepts (Vosniadou, 2014; i.e. the stage between everyday knowledge developing into scientific knowledge.) Many pupils' misconceptions about the water cycle are synthetic concepts, for example, when learning about the water cycle, rain clouds may be focused on, pupils learn to wrongly believe that rain clouds are special and no other clouds are included in the water cycle (Malleus et al., 2016; Taiwo et al., 1999); or pupils focus only on atmospheric cycling ignoring components of the water cycle that happen on the ground (Ben-Zvi Assaraf & Orion, 2010). Another common pupil misconception is the belief that all clouds are made of water vapour (gaseous phase of water; Malleus et al., 2016; Villarroel & Ros, 2013), or that clouds are made of soft fluffy things (Savva, 2014). Clouds are made when water vapour condenses into water droplets (or ice crystals), and a cloud is a large group of floating water droplets. When explaining rain, Year 3 pupils tend not to include evaporation or condensation, and Year 5 pupils tend to include the concept of evaporation, however, they exclude condensation (Savva, 2014), suggesting that these are challenging topics.

Main findings from the research

Model-based explanations

This a supportive process where pupils can develop their synthetic understanding of concepts into a scientific understanding of concepts. Model-based explanations rely on mechanism-based perspectives of scientific explanation (i.e. the process of evaporation where water changes state) and require repeated adjustment (Zangori et al., 2015). Therefore, modelling acts as a bridge between observations and theory (Akerson et al., 2009). Pupils start by developing an initial model based on their prior knowledge (everyday understanding); as pupils build new understanding about water and the changes of state, they evaluate and revise their initial model to align with their new understanding (synthetic understanding), and the more iterations the model goes through, the more scientific conceptual understanding is developed (Vosniadou, 2014).

What the research shows

As part of a 5-year project, Zangori et al., (2017), Baumfalk et al., (2017), and Vo et al., (2015) examined a model-based explanation of the water cycle intervention for Year 4 pupils, they examined 5 American classes and studied 110 Year 4 pupils. This involved repeated rounds of data collection (there was no follow-up), but '*new*' pupils in Year 4 were studied in each round.

Zangori et al., (2017) examined the difference between modelling and enhanced-modelling of the water cycle. In the first year of the study modelling was implemented and measured (referred to as traditional modelling classes), in the second year of an enhanced version of modelling was implemented (referred to as enhanced-modelling classes). Teaching for both modelling classes (traditional modelling and enhanced-modelling classes) were structured around four modelling exercises, pupils modelled water on a slope, evaporation, condensation and water in earth materials (i.e. groundwater in the water cycle). In the enhanced-modelling class pupils were also given explicit opportunities to develop, use, evaluate and revise their models of the water cycle, and each investigation used hands-on water activities. For example, pupils investigated what happens when they exposed water to different temperatures after pupils were asked to draw arrows on the condensation chamber model and show how and why water moves in different temperatures. At the end of the four modelled exercises, pupils reflected on and evaluated their first attempt at modelling and updated their first drawing of their water cycle model. Pupils were also encouraged to discuss their models with their peers and given the opportunity to revise their models. Pupils' understanding was assessed at the end of the unit by their final drawing of the water cycle. Lessons were taped and observed by the researchers, and the teachers were interviewed. A sub-set of the sample of 50 pupils also took part in pre-and-post interviews to explore their model-based explanations.

Zangori et al., (2017) found statistically significant gains in pupils' model-based explanations (in 2 of the 5 classrooms) on the topic of the water cycle, this was attributed to the teachers leveraging specific modelling practices (e.g. supporting pupils by showing them how to pull the separate components of the models together). Qualitative exploration demonstrated that when pupils received the traditional modelling classes pupils relied on plants survival to explain the water cycle, whereas pupils in the enhanced-modelling classes additionally drew on hidden sub-surface elements for how water flows underground—suggesting that supporting pupils in developing model-based explanations of the water cycle components then pulling them together is an effective pedagogy.

Vo et al., (2015) qualitatively analysed the teacher interviews from Zangori et al., (2017) data collection. Although modelling is effective in primary pupils (Forbes et al., 2015; Manz, 2012; Schwarz et al., 2009), opportunities for developing model-based explanations are not typically offered. They found that it is essential for teachers to know, understand, and incorporate scientific modelling into the learning environment for the water cycle. This can be done by using scientific models as flexible reasoning tools to support pupils' interpreting observations and formulating claims (Windschitl et al., 2008). To find out more about the how and why of model-based explanations in the water cycle, visit *http://www.corytforbes.com/projects/mohses* and look at the *supplementary teacher materials.*

Baumfalk et al., (2017) built on Vo et al., (2015) and Zangori et al., (2017) work by comparing pupil outcomes from the same enhanced-modelling classes and traditional modelling classes with the same 110 Year 4 pupils. Finding that pupils' models of the water cycle were equally complex at prior to the teaching intervention were equally complex in both the traditional and enhanced modelling classes, containing rain, clouds, sunshine, puddles, and people. Also, both groups showed an improvement in the number of components included in their final water cycle model. However, the enhanced-modelling group demonstrated greater gains in their understanding of components, processes, and explanations. These gains include emphasizing the non-visible components of the water cycle (i.e. groundwater), adding more written description to their models, drawing more complex models (as measured by the number of processes such as evaporation that they outlined in their drawing), and providing fuller explanations of the water cycle. Therefore, teaching that emphases model-based explanations can support pupils in developing a good understanding of the water cycle's different elements.

Collaboration

In the three studies above, collaboration has been mentioned as part of the pedagogy. Investigating this further with older pupils, Marinopoulos and Stavridou (2002) show how collaboration is important when teaching the water cycle. They tested the impact of collaborative learning, with 238 Greek Year 5 and 6 pupils, as pupils were older, they were learning about acid rain formation within the water cycle. In the experimental class 110 pupils worked collaboratively in small groups (3-5 pupils) using worksheets and hands-on activities. Pupils were encouraged to talk in their small groups about their ideas and drawing conclusions. The 128 pupils in the control class were taught through a lecture and did not collaborate. They found that pupils who worked collaboratively substantially improved their acid rain answers compared to their pre-test answers and the control group. These pupils also produced more developed drawings showing their model-based explanations of how acid rain is produced, compared to the control group (who did not understand how acid rain was produced at the end of the lesson). This study demonstrates the importance of using a collaborative learning strategy when developing model-based explanations of the water cycle.

For model-based teaching to be effective, research suggests:

- Support the connection pupils make between observation and theory by asking 'how' and 'why' questions about the model.
- Provide feedback on models and support pupils in clarifying how their thinking is changing when evaluating and revising models.
- Provide opportunities to work collaboratively on their models.
- Provide challenges to misconceptions, and support pupils' sense-making.

(Baumfalk et al., 2017; Gilbert, 2004; Halloun, 2007; Vo et al., 2015; Zangori et al., 2015; Zangori et al., 2017).

Therefore, a lesson was produced to incorporate multiple opportunities for pupils to develop model-based explanations about the water cycle.

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Lesson Plan

The Water Cycle

Supporting pupil's development of model-based explanations to teach about the water cycle

Pupils should be taught to: identify the part played by evaporation and condensation in the water cycle and associate the rate of evaporation with temperature

Science – KS2 (Year 4)

Research recommendation(s) and rationale	The water cycle is one of the earliest abstract concepts taught to KS2 pupils (Vinisha & Ramadas, 2013). Research suggests that primary pupils do not think about water dynamically or cyclically (Ben-Zvi Assaraf & Orion, 2010), which leads to struggles in making connections between water in one location and water in another location. In 2013 the water cycle was added to the Year 4 Science curriculum, although the water cycle is included in geography throughout KS2 it is not statutory (Savva, 2014). Research suggests that it is important to: - Support the connection pupils make between observation and theory by asking 'how' and 'why' questions about the model. - Provide feedback on models and support pupils in clarifying how their thinking is changing when evaluating and revising models. - Provide opportunities to work collaboratively on their models. - Provide challenges to misconceptions, and support pupils' sense-making.
Lesson aim	Supporting pupils' development of model-based explanations to teach about the water cycle
Learning objective	To understand and explain a model-based water cycle.
Intended learning outcomes	At the end of the lesson, pupils will be able to: i. present an initial model based on their prior knowledge (everyday understanding). ii. be able to verbally evaluate and revise their initial model to align with their new understanding (synthetic understanding).
Scientific vocabulary	**Precipitation –** rain, snow, sleet, dew, formed by condensation of water vapour in the atmosphere **Water vapour -** water in the gaseous state **Evaporation -** when a liquid changes to a vapor, caused by an increase in temperature. **Condensation –** small drops of water which form when warm water vapour or steam touches a cold surface or cools. **Clouds -** made when water vapour condenses into water droplets (or ice crystals). A cloud is a large group of floating water droplets. **Ground Water -** the water that flows beneath the surface of the ground, consisting largely of surface water that has infiltrated (seeped) down: the source of water in springs and wells. **Infiltration -** is the movement of water into the ground from the surface. **Surface flow -** water running off the land surface.
Common misconceptions	• Rain clouds are special, and no other clouds are included in the water cycle (Malleus et al., 2016; Taiwo et al., 1999). • Pupils focus only on atmospheric cycling ignoring components of the water cycle that happen on the ground (Ben-Zvi Assaraf & Orion, 2010).

	• The belief that all clouds are made of water vapour (gaseous phase of water; Malleus et al., 2016; Villarroel & Ros, 2013), or that clouds are made of soft fluffy things (Savva, 2014). • Evaporating or boiling water makes it vanish • Evaporation is when the Sun sucks up the water, or when water is absorbed into a surface/material. • Water in different forms – steam, water, ice – are all different substances.
Suggested lesson sequence and activities	**Note**: in order to fit this into one lesson, you will need to set up the evaporation experiment a week in advance OR allow pupils to set it up this lesson and look at the results in a subsequent lesson. 1. Pupils are encouraged to create their own models of the water cycle based on their prior knowledge (everyday understanding). Ask the key question: How is rain (or all precipitation) linked to rivers, seas, lakes, clouds? Explain the term **precipitation** at this point. Display these key words and check understanding. Explain that a **scientific model** is used to explain scientific concepts for example a food chain shows a simplified model of energy transfer in real life. A **scientific model** will show: • A simplified version of something in real life and • How and why something works as it does. *Photo or video prompt* Time lapse video of a puddle drying up: https://www.youtube.com/watch?v=k8SLCKJ2BPc (If time, take a photo of the school playground in the rain and in dry conditions. Ask: where does the water go?) Tell the pupils it is their job to explain where the water goes. Give pupils time to create their own model. Give pupils time to explain their model to a partner and develop their model if necessary. Take feedback from pairs and collaboratively create a class model of the water cycle (this may well be incorrect and based on misconceptions)they will return to this model later to re-evaluate and improve it. 2. Pupils are exposed to experiences which help them question, explore and develop a deeper understanding of specific aspects of the water cycle.

	2a. Evaporation • Ideally pupils should be given time a week before to design their own fair test to compare evaporation in different locations around the school (indoors and outdoors) • To make the test fair, pupils should consider standardising the volume of water, the size and shape of the container and whether the container has a lid. • If you do not have time for pupils to set this up in advance, then use the same size and shape container, the same volume of water in various locations around the school. • You may also want to place an identical container with the same volume of water but with clingfilm covering it next to each container in the various locations. • Tell pupils the initial volume of water, then ask them to accurately measure and record the new volume for each location. • Can they see a pattern or suggest explanations for the different amounts of evaporation e.g. temperature? ***2b. Condensing into clouds*** • Ideally pupils should have time to set up this experiment themselves a week in advance though if this is not possible, the pupils need to know exactly how the apparatus was set up (through photographs or videos) so that they can observe changes over time. • Set up: o Large plastic bowl. o Measuring jug. o Clingfilm o Elastic band to secure the clingfilm o A mug or heavy cup. o Identify a suitable location for your bowl. Place the mug the right way up in the bowl. Pour 500ml of water into the bowl, around the mug, being careful not to splash any water into the mug (it should be empty). Then cover the opening of the bowl with clingfilm and secure in place. • Pupils should make observations about (and possibly draw)where they can see water before disturbing the bowl. Next pupils should remove the clingfilm and measure the volume of water in the mug. Then measure the volume of water in the bowl. What do they notice (the volume of mug and bowl combined should equal the original volume in the bowl)? • Pupils should now draw a diagram of the bowl experiment which shows their thinking on how the water got into the mug. Note – they may also have noticed condensation on the underside of the clingfilm and they should incorporate this into their drawings / explanations. ***2c. Water on a slope***

	• Pupils should design an experiment that compares how water travels down different slopes (different angles). • Pupils should make predictions, compare their results, and draw conclusions based on their findings. Can they link their findings to their scientific understanding? i.e. That gravity causes water to flow downwards. ***2d. Groundwater*** • Ideally pupils should be given time a week before to design their own fair test to compare how quickly water travels through different earth materials. However, if this is not possible, provide the pupils with the following equipment and instructions. • 9 x 50cm lengths of drainpipes. Over one end of each pipe secure muslin cloth. Fill three drainpipes with sand, three with gravel and three with soil (possible extension task – use more pipes and different types of soil). Place each pipe over a measuring jug. • Pupils should pour the same amount of water (e.g. 500ml) into the top of each pipe. Time how long it takes for 200 ml of water to pass through. • Compare their findings. Split the class into 4 groups. Each group will explore one of the above practical experiences and will then think about how this plays a part in the water cycle. 3. Each group feeds back to the class on their findings. As each group presents their findings, use questioning to help pupils incorporate their knowledge into the model, readjusting as necessary.
Key questions	How ….? Why…….? How is rain (or any precipitation) linked to rivers, seas, lakes, clouds? How did you arrive at that conclusion? Why do you think that? How would you design your experiment? What would your experiment tell you? Does your water cycle model show ……………………………. like you observed in the experiment? How does what you've observed fit into your water cycle model?
Assessment suggestions	Pupils create their own drawing of the water cycle with detailed annotation (Pupils who struggle with written work could explain their diagrams verbally)
Resources	Identical containers, ideally measuring cylinders Clingfilm Mugs Water

H&S considerations	Drainpipe cut into 50cm lengths Muslin cloth Sand, gravel, and soil – enough to fill three drainpipes of each Elastic bands (to secure clingfilm and muslin cloth in place) Measuring jugs/cylinders. Please follow your school health and safety guidance and consult with your mentor.

Research Summary

Sound

Using creative drama to demonstrate how sound travels across different mediums

Pupils should be taught to: (i) identify how sounds are made, associating some of them with something vibrating, and (ii) recognise that vibrations from sounds travel through a medium to the ear

Science – Key stage 2 (Year 4)

Statement of issue

Research has indicated that primary school pupils sometimes have different understandings of sound than those espoused within the scientific model (Allen, 2014; Asoko et al., 1992; Chang et al., 2007; Viennot, 2001). Some pupils believe that a sound such as a ringing telephone is only present inside their ears and do not appreciate that sound is a wave that travels from one place to another (Allen, 2014).

A group of Taiwanese researchers conducted a four-year research study with 3,639 primary school pupils, to investigate pupils' misconceptions about physics topics (Chang et al., 2007). The pupils' misconceptions included that a sound could penetrate the wall of a container (10%), that it was blocked by the sealed container (24%), and that it could be heard because it was carried through the air and could penetrate through tiny holes in the container (5%). The participating pupils insisted that the sound could still be heard when it was blocked by the wall and very few pupils validly employed the conception of vibrations to explain the cause of the sound.

In general, researchers have found that pupils do not regard sound as a form of energy but rather as composed of particles (Chang et al., 2007). Similarly, Viennot (2001) found that pupils did not take the medium into consideration when determining whether a sound can be transmitted or not. Driver et al. (1994) showed that pupils usually think of sound transmission as similar to a leakage through holes or gaps.

Main findings from the research

Research has suggested that pupils have not developed a generalised theory of sound production, transferable across contexts. Therefore, teachers should plan to offer pupils experiences of sound production in less obvious contexts, as well as in contexts where vibrations are clear (Asoko et al., 1992; Viennot, 2001). It may be useful to allow pupils to experiment with applying vibration ideas developed in obvious contexts to less obvious contexts with a view to developing a generalised theory (Asoko et al., 1992). One of the ways of achieving this, as identified in previous research, is to use creative drama to help pupils to learn about difficult scientific concepts related to sound (Hendrix et al., 2012).

Creative drama is a holistic activity that can engage all pupils, as knowledge is acquired by participating in activities that spur their deepest interests and creative imagination (Ward, 1957). When applied to science teaching, creative drama can foster the learning process by adapting and applying acquired knowledge from hands-on lab experiences to new problems and settings (Ariel, 2007). Creative drama helps pupils to clarify and monitor their science learning through discourse and feedback because pupils are actively evaluating their understandings, and seeking clarification and feedback from the teacher and each other, as they engage in creating the science drama (Ariel, 2007).

Research has highlighted the value of two main activities associated with creative drama: pantomime and improvisation (Hendrix & Eick, 2014; Hendrix et al., 2012). Pantomime and improvisation allow pupils to develop a deeper understanding of concepts by creating a transactional learning pathway. Shared meanings can be enhanced, which are grounded in prior knowledge. As part of the creative process, the teacher seeks to help pupils to gain a deeper understanding of concepts, while clarifying alternative conceptions in science (Hendrix et al., 2012). Pantomime and improvisation utilise kinaesthetic awareness to better understand disciplinary content, an approach that is not normally used in schools (Osmond, 2007; Wee, 2009).

Rebecca Hendrix, a science teacher in a primary school located in a small town in the south-eastern region of the United States, conducted an action research study with other researchers with 22 pupils aged 9-10 (Hendrix et al., 2012). She implemented creative drama activities to teach about sound using Glasson's (1993) learning cycle. Her primary task was to ensure that the creative drama activities, notably role-play scenarios, were connected to scientific concepts related to sound. The teacher used the "drama coach as facilitator approach". In this method, pupils wrote skits and improvised songs, which led to the development of an original puppet play on how vibrations or sound waves need a medium through which to travel (Hendrix et al., 2012).

The findings from the study indicated that learning outcomes support the use of creative drama as an effective strategy when appropriately implemented and integrated within Glasson's learning cycle (Hendrix et al., 2012). The study's data analysis identified significant effects related to grade level and time. Pupils in the treatment group had a significantly greater learning outcome than pupils in the control group (Hendrix et al., 2012). Pupils who participated in the teaching intervention also significantly increased their learning over time. Hendrix et al. (2012) found that a significant increase in learning over time was attained in the drama treatment classes, as compared to the non-drama classes.

In another study, Metcalfe et al. (1984) reported that lower achieving pupils who participated in creative drama as an alternative science learning strategy developed a deeper scientific understanding. Pupils in the study were able to relate ideas to previous knowledge and experience through creative role-playing, by relinquishing an egocentric viewpoint. The study concluded that deeper meaningful learning, as opposed to surface learning, had occurred, as demonstrated by pupils' explanations of evidence and conclusions, while relating the ideas to previous knowledge and experience.

Therefore, a lesson plan was produced to incorporate creative drama to teach about how sound travels across different mediums.

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Lesson Plan

Sound

Using creative drama to demonstrate how sound travels across different mediums

Pupils should be taught to: (i) identify how sounds are made, associating some of them with something vibrating, and (ii) recognise that vibrations from sounds travel through a medium to the ear

Science – Key stage 2 (Year 4)

Research recommendation(s) and rationale	Research has shown that primary school pupils hold various misconceptions about sound, notably related to how sounds are produced and how sounds travel (Allen, 2014; Asoko et al., 1992; Chang et al., 2007; Viennot, 2001). A number of researchers have suggested that creative drama is an effective strategy to encourage primary school pupils to develop a deeper scientific understanding, which can be achieved by relinquishing an egocentric viewpoint (Hendrix et al., 2012; Metcalfe et al., 1984). The suggested lesson sequences and activities in this lesson are based on the work of Hendrix et al. (2012) and Hendrix and Eick (2014), and supported by Glasson's (1993) learning cycle.
Lesson aim	To use creative drama to teach about how sound travels across different mediums.
Learning objective	To understand that sounds are produced by vibrations and sound waves travel through a medium by vibrating the molecules in the matter.
Intended learning outcomes	At the end of the lesson, pupils will be able to: i. Describe how sounds are made, associating some of them with a vibrating entity. ii. Explain that vibrations from sounds travel through different mediums to the ear.
Scientific vocabulary	Sound – Is a wave that moves through substances like solids, liquids, and gases and that we hear when the waves enter our ears. Vibration – Quickly moving back and forth (or up and down) from a point of equilibrium. (from a single point) Waves – A kind of vibration (disturbance) that travels through space and matter. Wave motions transfer energy from one place to another Particle – Tiny bits of matter that make up everything in the universe.
Suggested lesson sequence and activities	Common misconceptions: Sound is only heard by the listener Sound only travels in one direction from the source Sound can't travel through solids and liquids High sounds are loud and low sounds are quiet. This lesson assumes that pupils have already covered the unit States of Matter which explores the properties of particles in solids, liquids and gases.

	Throughout the lesson it would be ideal to create a series of explanatory videos (TikTok style would work well) and use these as a record of pupil learning. Pupils could later add their voice overs / captions to reinforce their understanding as alternative to drawing diagrams. **Recap prior knowledge:** Pupils recap the properties of particles in solids (touching, not moving around freely), liquid (able to move past each other, some gaps between particles) and gas (more movement of particles including filling the entire space available, greater distances between particles) by acting these out. Each pupil takes the role of a single particle and they collectively act out each state of matter. The teacher should use questioning to encourage pupils to assess their own drama sequence and how this does / does not accurately represent particle behaviour. Remind pupils that particles move because they have varying amounts of energy. Recap that the reason that a solid changes into a liquid is because the particles gain more energy (from heating) and this allows the particles to begin to move more. Pupils should act out this change from solid to liquid as particles are given heat energy. This will reinforce the understanding that *energy* causes particle movement. **Pantomime** – groups perform as a solid, liquid or gas for other groups to guess. After groups guess, pupils answer with **personification** e.g. "I am a particle in a solid, I am touching other particles and I do nt ohave enough energy to move around." **New learning:** sound is another type of energy that causes particles to vibrate. Now introduce the idea that sound is a type of energy caused by something vibrating. This is easy to show by plucking a guitar string or hitting the surface of a drum. Explain that this vibration causes the particles to move. Ask pupils to act out being air particles in a given space but remaining in one place (keep their feet on one spot). Place a sound source (e.g. an alarm clock) in the centre of the space. When the sound starts ask pupils to demonstrate how they think the vibration will travel through the particles. Use questioning to help pupils critique and adapt their model to produce a good representation of the behaviour of the particles i.e. that the vibration will travel from the source in an outward direction, moving the closest particles first. Reinforce the idea that the sound travelling is the vibration causing the particles to move and pass this vibration on to particles next to them because sound is a form of energy. The pupils (particles) themselves should not move outwards they should simply pass the vibration on in all directions outwards and away from the source.

	Do not worry at this stage about the accurate representation of the sound wave in terms of rarefactions and compressions, just focus on the sound moving outwards from the source and causing particles to vibrate. Another demonstration here would be to take a container of water with a large surface area. Off centre, very carefully place a floating object e.g. a small rubber duck and wait for the water to be still again. Then drop a stone into the centre of the container. Observe how the ripples spread out from the centre to the edge. The duck will bob up and down (showing that the particles under it vibrate) but will not move to the outside of the container. This is an important demonstration to reinforce that it is the vibration that is passed along but that the particles themselves do not move outwards away from the source. It would be good to film this and play it back in slow motion. Now, state that while sound travels outwards from the source in all directions (note that this would be in 3D not just the 2D representation suggested by the surface of the water demo) it is easier to concentrate on a single sound wave in a line away from the source. So, ask the pupils to create a line of particles side by side. Allow a small equal space between the pupils (particles) to represent air particles. Now place the sound source at one end of the line. Say that when you start the sound the vibration needs to be passed along the line. We need to act this out in slow motion. Film if possible so you can all watch the effect afterwards. The first 'particle' in the line would be pushed by the sound vibration and lean away from the sound towards the person next to them (keep their feet firmly in one place and act out only in slow motion).As they get close to the second 'particle' this represents a compression. The second person in the line then leans away towards the third person in the line (a compression again) while the first person returns to their upright position. This causes a compression between 'particles' 2 and 3 but a bigger gap between particle 1 (who is now upright again) and particle 2 who is still leaning away towards particle 3. This bigger gap between particles is a rarefaction. If possible, film this passing of the vibration along the line and then play back adding labels which identify the contractions and rarefactions between the particles as the sound energy passes along them. This can be further demonstrated by getting pupils to stretch out a slinky spring. Create a pulse in the spring at one end which travels along the spring. Pupils will see that as the vibration travels the loops of the spring get compressed and then spread further apart before returning to their initial position. Reinforce again that it is the vibration that travels not the particles themselves. Other questions to explore: Q: What happens when the vibrations stop at the source? (the energy stops passing from particle to particle so the sound stops)

	Q: Is the sound still there if I ca not hear it / if I am not listening? (The sound is there as long as the sound energy is causing them to vibrate. We can hear a sound if it causes our ear drum to vibrate which in turn causes the bones in the inner ear to vibrate and activate nerves which send messages to the brain about the sound). Can sound travel through solids and liquids? Now ask pupils to model the particles (in a line) of solid i.e. they will reduce the gaps between each other so they are now touching shoulder to shoulder. Will a sound vibration still be able to travel along the line? Yes! In fact, it will travel easily because the particles can easily pass the vibration along. Real life examples: sound travels along a metal pipe line. What about in a liquid? Yes, the sound can still be passed from particle to particle. Real life example: whales can hear each other hundreds of miles apart. Why do sounds appear quieter when we are further away from the source? Explain this in terms of the energy decreasing. As energy is used to make the next particle vibrate slightly less energy is passed on each time meaning the vibration reduces. A big vibration at the source creates a louder sound (it would be good to link this to the height of waves on a sound wave diagram) so will travel further before running out of energy than a small vibration at the source. Remember to use the terms louder and quieter. Further challenge. This would probably come up in subsequent lessons, but you may want to explore what happens when sound travelling through air particles reaches a solid. Ask some pupils to model a line of air particles then a few pupils in the line be solid particles (shoulders touching) then on the other side of the solid have more air particles (not touching). This could represent air outside, a solid window (glass) then the air inside the room. Ask pupils to model how the vibration would pass along the line. Would it pass through the solid? Yes. So would we hear the sound from outside if we were inside the room? Yes, if it was loud enough to keep vibrating the particles. Ask pupils to model a quiet sound from the source (particles only move a little and quickly run out of energy) and a louder sound (where particles move more and the vibration travels further). Encourage pupils to adapt their performance to more accurately represent the sound wave and to use personification to explain their actions. This could then be reinforced by having someone go outside with a whistle. Do we hear it from indoors if they blow it quietly vs loudly? Note: This idea could be revisited in later lessons when exploring how to sound proof something. That by adding layers it means the sound vibrations run out of energy before they pass through. Further note: explain that as the energy is used to make the next particle in the line vibrate slightly less is passed on each time to the next particle in line. This could be demonstrated by passing on a box of

something to represent energy and each child in the line removes one small item and so less energy is passed on each time. A packet of small sweets would work well!

What happens when the vibrations reach a solid? (they cause the particles in the solid to start vibrating)

Glasson's (1993) learning cycle

	Teacher Activity	Pupil Activity
Preliminary	• Explore pupil views on how sound is produced through creative dramas. • Provide the motivational experience of integrating music and creative body movement into teaching and learning related to scientific concepts. • Coach pupils to visualize the rapid back-and-forth movement of a sound vibration.	• Engage in a creative movement activity to mimic the wave motion of a sound vibration. • Use music and movement to learn about air particles, sound vibration, sound transfer, and sound mediums.
Focus	• Teach the tools of creative drama to act out scientific models of molecular motion. • Guide pupils by asking open-ended questions about the effect of sound vibrations on particles.	• Use improvisation and pantomime to explore molecular motion. • Use literary personification to understand molecular motion. • Record ideas in a science journal.
Challenge	• Introduce Compression and Rarefaction Guides the exchange of views. • Check to ensure that all views are considered in relation to air particles in a sound wave. • Keep discussion open. • Present the evidence from the accepted scientific point of view.	• Seek the validity of concepts on how sound travels through additional reading of science texts related to compression and rarefaction in sound waves. • Compare the accepted scientific view with the view of other pupils. • Evaluate one's own view. • Cite evidence of view based on scientific readings.
Application	• Assist the pupils to clarify views and to understand concepts from reading and investigations. • Help the pupils to apply the scientific concepts to build accurate models of sound science	• Discuss and debate the best approach to present the group model of compression and rarefaction. • Solve problems in model construction with the collaboration of peers.

<table>
<tr><td></td><td><table><tr><td></td><td>through dramatic improvisation, pantomime and literary personification.</td><td>Present solutions as to the best way to construct the scientific model of compression and rarefaction in a sound wave.
Present models to the class.
Engage in the evaluation of models.</td></tr></table></td></tr>
<tr><td>Key questions</td><td>How does a sound wave start?

How does sound travel? (Understanding where it starts from or travels to)

What happens when the vibrations stop at the source? (the energy stops passing from particle to particle so the sound stops)

Is the sound still there if I ca not hear it / if I am not listening? (The sound is there as long as the sound energy is causing them to vibrate. We can hear a sound if it causes our ear drum to vibrate which in turn causes the bones in the inner ear to vibrate and activate nerves which send messages to the brain about the sound).

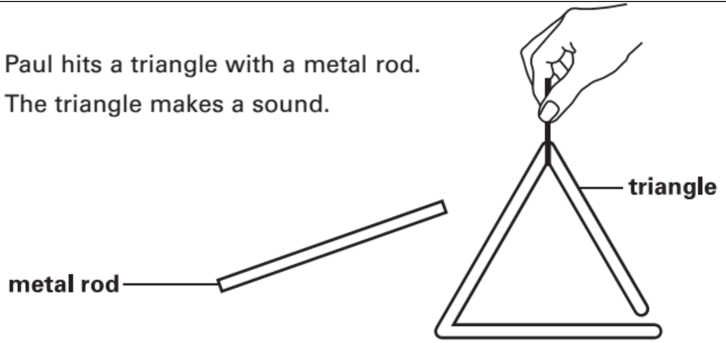
Can sound travel through solids and liquids?

Why do sounds appear quieter when we are further away from the source?</td></tr>
<tr><td>Resources

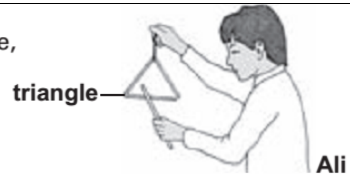
H&S considerations</td><td>Abrahams, I., & Braund, M. (2012). Performing science: Teaching chemistry, physics and biology through drama. Continuum.

Take care with silliness and pushing while pupils are moving around.

The teacher must ensure that all activities are carried out in a safe and calm manner. The school’s health and safety protocols must be followed. Please discuss health and safety with your mentor.</td></tr>
</table>

Assessment Opportunities **(SATs papers)**	Paul hits a triangle with a metal rod. The triangle makes a sound.  What happens to the triangle for Paul to hear a sound when it is hit? ....

Each time Polly appears on stage,
Ali hits a triangle.



(i) What happens to the triangle for it to make a noise when it is hit?

....

(ii) What does the sound travel through to reach Emma's ears?

....

There are lots of people watching the play. Some people are close to the stage. Some people are further away.

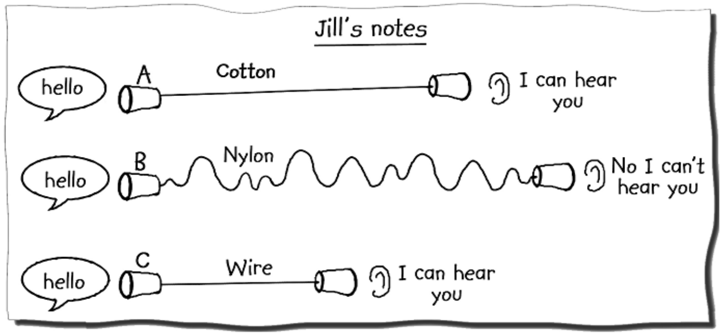
Describe how the **distance** the people are from the triangle affects the **volume** of the sound they hear.

....

....

Jill investigated whether or not sound travelled through different materials.

She made three telephones using plastic cups.
She used different materials to connect the cups.
One child talked through the telephone
and Jill listened.



Look at Jill's notes of her investigation.

How many different materials did Jill test?

....

What was the factor Jill observed or measured to collect her results?

....

Jill changed three factors at the same time.

Complete the list to show the **THREE** factors Jill changed in this investigation.

The first one has been done for you.

1. The tightness of the line ....

2. ....

3. ....

Why is it important to change only **ONE** factor at a time in an investigation?

....

Jill carried out her investigation of sound travelling through different materials again. She made sure only one factor was changed.

Jill described her conclusion.

Jill's teacher said this was **not** a useful science conclusion for her investigation.

Why was Jill's conclusion **not** a useful science conclusion?

....

....

Research Summary

Floating and Sinking

Using a structured constructivist approach to teach about floating and sinking

Pupils should be taught to compare and group together everyday materials on the basis of their properties, including their hardness, solubility, transparency, conductivity (electrical and thermal), and response to magnets

Science – Key stage 2 (Year 5)

Statement of issue

The topics of density and buoyancy forces are introduced in the secondary curriculum because pupils need to grasp scientific formulas such as proportions (Hardy et al., 2006). Typically, in the primary science curriculum, pupils are introduced to a basic concept of a material kind: the realisation that solid objects of the same material behave the same way when immersed in water (Leuchter et al., 2014). Biddulph and Osborne's (1984) investigation of pupils' (Year 3 to 9) understanding of floating and sinking found that they offered many unrelated factors such as mass and weight, as if they determined whether an object sank or floated. Research has shown that if pupils are introduced to explanations for the behaviour of different materials in water, they thus gain the opportunity to revise misconceptions early on. Therefore, there is good reason to expect that they will be able to profit more from the formulas of density and buoyancy force in secondary school (Hardy et al., 2006; Leuchter et al., 2014).

Main findings from the research

What is a constructivist approach?

Constructivism is an educational theory that assumes pupils make (i.e., *construct*) their knowledge. Constructivism assumes that a pupil's knowledge and understanding is based on their prior experience. The original scholars of cognitive constructivism (Piaget, 1954) and social constructivism (Vygotsky, 1978) emphasised that actively processing new information and integrating this with existing knowledge will promote deep understanding.

Research has suggested that pupils participating in science learning underpinned by the doctrines of the constructivist approach achieve a higher degree of conceptual understanding in science than pupils participating in direct instruction (Christianson & Fisher, 1999; Staub & Stern, 2002; Tynjälä, 1999). The concept of scaffolding, originally outlined by Wood et al. (1976) and Vygotsky (1978), has been revisited in its application within complex science learning (Davis & Miyake, 2004; Hogan & Pressley, 1997). The two critical elements of a structured constructivist approach based on scaffolding are structuring tasks to allow pupils to remain focused on important aspects and the support of pupils' reflection on their insights within a larger context of scientific reasoning (Hardy et al., 2006).

Instructional activities in science should facilitate pupils to move along a sequence of conceptual development, during which they can actively discover the possible inadequacies of the initial conceptions, as well as encounter convincing new explanations (Hardy et al., 2006). Leuchter et al. (2014) propose two main foci for designing activities for primary science, intended to support conceptual restructuring by means of scaffolding pupil learning in an inquiry-based setting. The first focus is using structured task features to support reasoning in relation to the targeted concepts. The second focus should be on embedding scientific reasoning through a three-step process of inquiry that allows the pupils to increasingly take responsibility for their own learning (Leuchter et al., 2014). The two case studies presented below are drawn from Hardy et al.'s (2006) and Leuchter et al.'s (2014) work on the use of a structured constructivist approach to teach about floating and sinking in primary science.

Case study 1

Leuchter et al. (2014) developed and implemented a science learning environment for pupils (Year 0, Reception to Year 5), which contained structured learning materials. The central goal was to support conceptual change concerning the understanding of the floating and sinking of objects, and to foster pupils' scientific reasoning skills. The study was conducted with 15 classes of a total of 244 pupils.

The teachers provided pupils with learning materials, consisting of four workstations and a water tub. The four sequences of learning activities were organised according to a presumed conceptual progression of three steps. In the first step, the pupils' most frequent naïve concepts related to predicting floating and sinking, such as weight, volume, and shape, were elicited. In the second step, the aim was to stimulate conceptual restructuring, to enable the inclusion of different kinds of material in pupils' prediction of an object's floating or sinking. The last step was to restructure the concept of a material type, to work towards an initial idea of buoyancy in the pupils' explanations of floating and sinking. In all the learning activities, scientific reasoning was promoted by contrasting materials of different shapes, weights, or sizes, thus prompting processes of comparison. In these activities, the type of material held constant, while the pupils could systematically explore whether an object's size or shape would influence its water behaviour.

The findings of the study suggested that the structured learning environment promoted conceptual development in the domain of floating and sinking. The study found a high increase in pupils' correct classifications of solid bodies as floating or sinking. There was also a learning gain on the level of explicit reasons given by the pupils when justifying their classifications of solid bodies. Before the study took place, reasons were predominantly based on weight, volume, or shape; after the implementation, however, pupils predominantly referred to the type of material and neglected the other dimensions. Pupils also displayed a transition concerning a flexible concept of type of material, taking into account aspects of shape (and thus implicitly buoyancy), in their predictions of the floating behaviour of an object. This is a strong learning gain for pupils, in terms of their classifications and justifications.

Case study 2

In an earlier study, Hardy et al. (2006) investigated the effects of different instructional support degrees within constructivist learning environments, with particular regards to pupils' (Year 4) conceptual understanding of floating and sinking. The researchers developed two instructional units based on constructivist principles of learning, which varied in the degree of instructional support (low and high) provided to pupils.

In the low instructional support group, the pupils were allowed to design their own experiments individually, or within groups. They worked with different shapes and sizes of material, as well as everyday objects. During class discussions, the pupils were free to initiate topics and the teacher kept the conversation going. In the high instructional support group, the learning sequenced into eight consecutive units. In each lesson, pupils only investigated one subtopic with differently shaped and sized materials and everyday objects. During class discussions, the pupils mainly reacted to the teacher's statements and they were free to react to other pupils. The discussions were teacher-directed, with structuring comments and topics that focused on the content of each lesson.

The study results showed that pupils in the group of high instructional support developed a more coherent understanding of why some objects float in water while others sink than the pupils in the low instructional support group. The study suggests that primary school pupils' conceptual understanding of floating and sinking can be optimised through the instructional support provided via the teacher's sequencing of instructional content and the frequency of cognitively structuring statements.

In both the case studies presented above, a structured constructivist approach was used to enhance teaching and learning about floating and sinking. Although different activities were implemented in both studies, the learning was highly scaffolded, resulting in good learning outcomes for pupils in the short and long term.

Therefore, a lesson plan was produced to incorporate a structured constructivist approach to teach about floating and sinking.

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Lesson Plan

Floating and Sinking
Using a structured constructivist approach to teach about floating and sinking
Pupils should be taught to compare and group together everyday materials on the basis of their properties, including their hardness, solubility, transparency, conductivity (electrical and thermal), and response to magnets
Science – Key stage 2 (Year 5)

Research recommendation(s) and rationale	Research has suggested that pupils participating in science learning underpinned by the doctrines of the constructivist approach achieve a higher degree of conceptual understanding in science than pupils participating in direct instruction (Christianson & Fisher, 1999; Staub and Stern, 2002; Tynjälä, 1999). The concept of scaffolding, originally outlined by Wood et al. (1976) and Vygotsky (1978), has been revisited in its application within complex science learning (Davis & Miyake, 2004; Hogan & Pressley, 1997). The two critical elements of a structured constructivist approach based on scaffolding are structuring tasks to allow pupils to remain focused on important aspects and the support of pupils' reflection on their insights within a larger context of scientific reasoning (Hardy et al., 2006).
Lesson aim	To improve pupils understanding of floating and sinking through practical, adult led activities which encourage conceptual understanding.
Learning objective	To understand what impacts an object to float and sink.
Intended learning outcomes	At the end of the lesson, pupils will be able to: - Identify and name those materials that float and those that sink. - Label a diagram of an object floating in water with correct forces (weight, upthrust). - Conduct an experiment to identify objects which are buoyant and those which are not. - Identify the factor influencing a material's ability to float (shape and size etc).
Scientific vocabulary	Floating – when an object rests on the surface of a liquid. Sinking – when an object does not rest on the surface of a liquid. Buoyancy – the term used to describe where something floats or sinks. If the weight is equal to or less than the upthrust, then it floats. If the weight is greater than the upthrust, it sinks. Forces – pushes and pulls in a particular direction. Upthrust – the force that pushes an object up. Weight – how hard the gravity pulls an object down. Shape – the form an object takes. Volume – the amount of space a certain 3D object takes up.

Suggested lesson sequence and activities	To ensure pupils have a higher degree of understanding, they should participate in a sequence of activities that are scaffolded to encourage pupils to remain focussed on the important aspects as well as reflect on their insights within a larger context of scientific reasoning (Hardy et al., 2006). Activity 1 – Sort pupils into small groups and provide them with a water tub and a range of objects (some which float and some which sink). Begin by asking for pupils' predictions as to which objects they think will float and which will sink. Give pupils the opportunity to test the items in the water tub and then record which floated and which sank. Teacher/adults to question pupils as they test the objects and ensure they are recording their results. This first step is designed to draw out pupils' most frequent naïve concepts relating to weight, volume and shape. At this stage also encourage pupils consider the materials which the objects are made from. Bring the class together to discuss what they found out from the short starter experiment. Activity 2 – Show pupils some images of boats (find images of huge cargo boats as well as small wooden rowing boats) and ask them questions about what they can observe (questions 1 and 2). From the discussion, pupils should begin to realise that the materials are characteristically heavy which make a boat, yet they still float (question 3). See if pupils can give some good explanations in response to the questions. Explain to the pupils that it is due to the shape of the boat, which determine whether the boat will float. Show the videos below, to aid with pupils' understanding of forces in action as well as introducing them to the principle of buoyancy. https://www.bbc.co.uk/bitesize/topics/zc89k7h/articles/zytqj6f https://www.youtube.com/watch?v=2dyCe1GPagE Activity 3 – Now the science has been demonstrated and explained to the pupils, encourage them to use the key vocabulary above when talking through the next activity. Provide pupils with a 'boat structure' (use a material which you know to float and has the capacity for weight to be added). Keep the pupils working in small groups and give each group a boat, made of the same material but in different sizes and weights. Allow pupils time to measure and find the mass of the boat and record this. Pupils to then add more mass to the structures they have as it floats. Pupils to keep a cumulative record of the mass added to then determine when the weight becomes greater than the upthrust and the boat sinks. Rotate the boats around the groups and allow pupils to compare the size and shape of the boats and how these impacts on the mass it can carry before sinking (see questions below). Pupils to discuss their findings as a class and this will lead them to classify the different boats based on their shape, size and weight and ability to float successfully when mass is added.
Key questions	Activity 1: 1) Which object(s) do you think will float and which will sink? 2) Which objects have sunk? Why do you think this has happened? Activity 2: 1) What material are the boats made from? 2) How would you describe the materials? Light, heavy? 3) Why/how do boats float?

	Activity 3: 1) What forces are keeping the boat buoyant? 2) What can affect the buoyancy of the boat? 3) Which force becomes greater causing the boat to sink?
Assessment suggestions	Formative assessment will come through the questioning above and allows for misconceptions to be addressed as they arise. At the end of the lesson, pupils could write a conclusion of their findings – challenge them to include the key vocabulary from the lesson. Provide pupils with pictures of the boats used in the lesson and pupils to sort them into most buoyant and least, when mass added. Provide pupils with an image of a water tub containing lots of objects (some floating and others sunk), pupils to draw arrows on the objects showing the forces in action. A sunken object will have a larger arrow pointing down showing the weight force and smaller upthrust arrow going up because they are not equal*. *some teacher input may be required here to guide pupils with drawing the arrows. Arrows should point in the direction a force is acting and then increase/decrease in size dependent on the stronger force.
Resources **H&S considerations**	Water tubs Solid objects 'Boat structure' – something which floats and can have objects added to it. Water safety: Not near electrical items/sockets. Wet surfaces and potential spills on the floor – be wary of slippery surfaces.

Research Summary

Friction
Using practical activities complemented by virtual simulations to teach about friction
Pupils should be taught to: identify the effects of air resistance, water resistance and friction, that act between moving surfaces
Science – Key Stage 2 (Year 5)

RESEARCH
TEACHING

Statement of issue

In science education, forces are considered one of the most problematic areas. A large body of research (Brown & Clement, 1989; Driver et al., 1994; Kruger et al., 1990; Tao & Gunstone, 2000) confirms that forces are an inherently difficult topic for pupils. Heywood and Parker (2001) summarise that the counterintuitive development of (i) abstract ideas about the Newtonian view of force and motion which are opposition to (ii) pupils' everyday experience, as the core problem that make the topic of forces difficult for pupils.

For example, if we think about a ball rolling in the playground, it will slowly come to a stop. If we think that the ball needs a force to make it move, it makes sense to think that it stops because it has run out of force. A more scientific explanation would be that the ball stops because the forces acting on it cause it to slow down. However, the scientific explanation is counter intuitive to pupils' everyday experience (Heywood & Parker, 2001).

Main findings from the research

Scientific concepts such as friction can be counter-intuitive, so research suggests that the best way to support pupils' understanding is to complement practical activities with virtual simulations (Annetta et al., 2009; Evangelou & Kotsis, 2019; Merkouris et al., 2019).

The abstract nature of friction means that lessons can benefit from the inclusion of simulations using digital technology (Evangelou & Kotsis, 2019), particularly since some phenomena are difficult to reproduce. For example, non-frictional states (Sullivan et al., 2017). Simulations may have an advantage over real-world experiments because (i) pupils can perform experiments and solve problems quickly (in one lesson) as feedback is immediate, (ii) repeat the experiment as many times as needed for their understanding, (iii) and using different representations to encourage understanding within different contexts (Jimoyiannis & Komis, 2001).

There is a division within the research community on the benefits of virtually simulated experiments, with some studies confirming their effectiveness (Finkelstein et al., 2005; Annetta et al., 2009; Evangelou & Kotsis, 2019). However, others have found no learning gains compared to using real-world physics experiments (Klahr et al., 2007; Zacharia, 2007; Zacharia & Constantitinou, 2008; Zacharia & Olympoiu, 2011). The critical condition appears to be that virtual simulations are used to complement physical learning material during practical activities (Evangelous & Kotsis, 2019).

What the research shows
Critically, virtual simulations of real-world experiments do not provide pupils with more conceptual gains (Evangelou & Kotsis, 2019). Instead, there is no difference between using real-world experiments or virtual simulations in promoting pupils' conceptual gains in friction (Evangelou & Kotsis, 2019). In comparison, Chini et al. (2012) and Evangelous and Kotsis (2019) compared pupils conceptual understanding of frictional force when using virtual simulations vs real-world experiments. They found no straightforward answer, neither virtual simulations nor real-world is better than the other, rather they should be used to complement each other to support pupils' learning. This notion is found repeatedly throughout the literature; for example, Kocijancic and O'Sullivan (2004) integrated activities that involved data collection with computer simulations. They found that integrating virtual simulations and practical activities supports pupils' learning—suggesting that real-world experiments and virtual experiments

can be used together to encourage pupils' development of scientific concepts. Sullivan et al. (2017) also highlight other benefits such as using virtual experiments when pupil engagement is low, when there is limited lesson time, and when data collection might be messy.

Merkouris et al. (2019) tested the benefit of adapting a virtual physics experiment on friction and making certain elements physical to examine how to combine real and virtual approaches. A group of 56 Year 6 pupils in Greece were randomly assigned to either virtual or physical practical conditions. In the *virtual* condition, pupils controlled a virtual robot, in the *real* condition pupils controlled a *real* robot virtually (*Ollie Sphero Robot).* They found a statistically significant increase in pupils' knowledge about friction when using a physical robot compared to virtual simulation alone. However, Merkouris et al. (2019) acknowledge that the physical vs simulated experiments were not comparable, since the virtual condition was oversimplified compared to the physical condition. This suggests that using a physical approach might better support the pupils in experiencing a broader range of experimental conditions to develop their knowledge and understanding.

Annetta et al. (2009) explored the educational gains of a multiplayer educational computer game *Dr Friction*, on 74 Year 6 pupils in the United States. Before playing *Dr Friction*, pupils took part in a 3-week unit on forces and motion, focusing on theory and activities aimed at exploring forces, such as building rubber-band cars. Pupils were tested pre-and post-engagement with *Dr Friction* to see if there were any learning gains. They found that there was a statistically significant overall gain in knowledge after using *Dr Friction*. However, some pupils performed worse in the post-test, and it was observed that they struggled to engage with the new learning. The researchers suggested that this may be because some pupils need additional support when using computers. Annetta et al. (2009) also suggested that males may be more confident in their use of computers through their experience of video game playing, and their use of computers outside of school (Colley & Comber, 2003). Therefore, including elements that appeal to both males (e.g. 'a guide' character) and females (e.g. collaboration and chat functions) may help to address this.

Several experiments have been carried out with older pupils, looking at the impact of using augmented reality to support pupils' understanding of friction. For example, Sotiriou and Bogner (2008) compared hands-on activities plus augmented reality with hands-on activities alone for 119 Year 11 pupils. They found the pupils that experienced hands-on activities *plus* augmented reality statistically significantly outperformed the hands-on only group. The augmented reality supported pupils in correcting common misconceptions about friction. Although this study uses secondary pupils, it demonstrates an important point about how combining the hands-on activities together with virtual activities can be beneficial for pupils.

A word of caution

There is the temptation for "*activitymania*" within the topic of friction (Moscovici, & Holdlund-Nelson, 1998); as there are many different activities that could be offered to pupils. Recent research by Wilcox et al. (2019) drew attention to the need to support pupils in seeing the connection between the activity and the science content. Wilcox et al. (2019) found their Year 4 pupils responded by saying that they "learned how to make a bridge" or "how to make a good parachute" rather than showing a deep understanding of the scientific concept, because the focus had become about completing the activity. Therefore, Wilcox et al. (2019) suggest:

- asking explicit questions about the science concepts and how these connect to the activity (and to plan these to ensure they are effective),
- use pupils' ideas to develop the discussion further;
- create a pupil-centred environment (What decisions could the pupils make?; What do they want to find out?),
- structure the task into segments, so pupils are not overwhelmed;
- make sure pupils understand that it is ok to make mistakes and adjust the activity;
- remind pupils that the process is more important than the final product.

Therefore, a lesson was produced to incorporate complementary virtual simulations into a lesson about friction.

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Lesson Plan

Friction

Using practical activities complemented by virtual simulations to teach about friction

Pupils should be taught to: identify the effects of air resistance, water resistance and friction, that act between moving surfaces

Science – KS2 (Year 5)

Research recommendation(s) and rationale	Force can be a problematic conceptual area for pupils (Brown & Clement, 1989; Tao & Gunstone, 2000), because of a potential conflict between abstract concepts common in forces topics and pupils' everyday experiences (Heywood & Parker, 2001). Research suggests that to teach friction effectively, practical activities should be combined with virtual simulations (Merkouris et al., 2018; Sotiriou & Bogner, 2008). However, Wilcox et al. (2019) research warns against "*activitymania*" and the importance of helping the pupils to see the link between the activities and the science concepts being investigated.
Lesson aim	To use virtual simulations together with practical activities to teach friction.
Learning objective	To know that friction is a type of force that slows moving objects down.
Intended learning outcomes	At the end of the lesson, pupils will know that: i. Friction is caused when two surfaces move against each other ii. Friction always slows a moving object down iii. The amount of friction depends on the materials from which the surfaces are made.
Scientific vocabulary	**Force**: a force is a push or a pull **friction, n**: a force that occurs between the surfaces of two objects that are touching **oppose, v**: to work against **Lubricant:** a substance that reduces friction between objects in contact Expose students to key vocabulary throughout the session, particulary during the'real world activity' section where the key terms will be pre-taught. As a follow up to the lesson ensure that students revisit these key word flashcards on a regular basis until they are secure, possibly using the Leitner 3 box system (https://www.youtube.com/watch?v=C20EvKtdJwQ&safe=active)
Suggested lesson sequence and activities	*Demonstration activity – Friction and heat* **Real-world activity:** Start by asking a question about the everyday phenomenon of friction to establish a sense of familiarity, such as the following: How many of you have ever been skiing, ice skating, or sledding? (*Students may raise their hands or tell their stories.*) Was it easy to slide on a smooth surface? (*A smooth surface makes sliding easier.*)

	What happened when you slid on a rougher surface? (*It was harder to slide.*) Did it make you not be able to glide as smoothly? (*Yes, and sometimes a rough surface is too bumpy to slide at all.*) Tell students that friction is a type of force that occurs when the surfaces of two objects are in contact with one another. A lot of friction makes it difficult for an object—like a sled—to move across a surface. Too little friction between surfaces can make it difficult to move too, such as oil on a floor that causes a person to slip and slide. Pupils create friction by rubbing their hands together. Ask them to describe what they feel (i.e. warming). Ask pupils to write down what they think is happening, ask a few pupils to share their thinking as part of a class discussion. **Vocabulary Instruction:** Use vocabulary flash cards to focus on key words that link to today's learning. For each word discuss definitions and offer examples: **Friction:** a force that occurs between the surfaces of two objects that are touching) revisit the definition of *friction*: it is a force that opposes movement when two surfaces are in contact. Friction opposes motion, but it also opposes potential motion—a motion that would occur if friction were not present. Discuss where we can observe evidence of friction in the classroom. For example, a drawer that opens easily may have less friction than a drawer that is hard to open. A floor that is slippery has less friction than a carpeted floor. Ask students to identify, in each case, the two surfaces in contact with each other. **Lubricant:** a substance that reduces friction between objects in contact) Tell students that a lubricant is a substance that reduces friction between objects in contact, such as the oil used on the car engine. A lubricant helps make the surface of something slicker to reduce friction and let objects move more smoothly as they rub against each other. Remind students that *contact* means touching. Objects are in contact if they touch each other. Ask students to identify examples of different kinds of surfaces. **SUPPORT**—Students may think that friction only occurs between solid objects and surfaces. In fact, friction also occurs when liquids or solids rub against each other. This is known as *drag*. Vehicles with smoother surfaces, swim caps on swimmers, and smooth helmets on bike riders are all done to reduce the amount of drag, or friction, between the surface and the air or water.

	Keep and use flashcards to enable students to peer assess each other and develop understanding of these key terms in subsequent lessons, possibly using the Leitner 3 box system. **Virtual simulation:** Use the Friction Simulation (details in the Resources section below). Ask pupils to write observations as the two simulated books rub together. Repeat this several times. The simulation is designed to be controlled by the pupils; there is an opportunity for pupils to use the simulation individually on tablets, or take turns using the smartboard. In a class discussion, pupils reflect on their observations of the simulation compared to the real-world activity, explaining how their thinking has changed. The simulation supports the activity by demonstrating the real-world activity and showing the temperature change. *Investigation Activity – Friction and motion* **Real-world activity:** Investigating how different ramp surfaces affect the motion of an object travelling down it. Use different surfaces, such as a hand towel, corrugated cardboard, felt, tinfoil, an oiled surface, and sandpaper. Using a length of wood (or other suitable material) supported at one end as a ramp, cover the ramp with different materials, and investigate the forces acting on a block of wood (or other suitable object) as it moves down the slope. Bring the class together to discuss the following: Cause-and-effect relationships are routinely identified, tested, and used to explain change in science. Scientists and engineers often look at cause-and-effect relationships like this to construct explanations about why certain things happen. Students experienced examples of cause-and-effect relationships during the activity. Remind students of these changes. The surface materials changed how the block moved down the ramp: Some surface materials caused the block to travel down the ramp quickly. Other surface materials caused the block to travel down much more slowly. Encourage students to practice using the phrase, "The __________ caused__________." For example: The friction between the ramp surface and the block surface was stronger and caused the block to slow down. The lubricant (oil) caused the block to move more easily down the ramp as the force of friction was weaker.
Key questions	**What are the different characteristics of friction?** Real- world activity: - What forces are acting on the block? (gravity and friction)

	- What caused the block to get stuck or move very slowly down the ramp? (the friction between the two surfaces) - Were the forces balanced or unbalanced? Which was the stronger force? (unbalanced - the pull of gravity when the block slid, balanced if the block remained stationary) - What was the result of adding oil, a lubricant, to the ramp? (friction was reduced increasing the speed of the block moving down the ramp) - How did the different surfaces affect the speed of the block moving down the ramp? Describe in terms of strength of forces (the force of friction/gravity was stronger/weaker when…)
Assessment opportunities	During class discussion and whilst moving around the class as students complete investigation, ask them key questions. Allow pupils to test each other on key vocabulary using flashcards made, and use this as an opportunity to guage understanding of key vocabulary. Use cause and effect discussion to gauge students understanding of how and why friction occurs and how different variables can affect the amount of friction created.
Resources **H&S considerations**	Resources: • Friction Simulation: Simulations take time to develop by teachers, and there is a shared resource file of simulations found here https://phet.colorado.edu/en/simulation/friction, register for free. With the friction simulation *note you can't use the books with the mouse, go lower on the screen, and the mouse will change to a hand.* • Investigation: Ramp, surfaces (hand towel, corrugated cardboard, felt, tinfoil, oiled surface, sandpaper), block of wood and robot (Sphero, Dot or similar gyro robot). Hazards: oil used on the ramp, sandpaper and tinfoil (regarding cuts and burns) Ensure that all activities are carried out safely and calmly. Follow all your school's health and safety protocols. Please discuss health and safety with your mentor.

Research Summary

Moon Phases
Using Moon journaling activities to teach about the phases of the moon
Pupils should be taught to: describe the movement of the Moon relative to the Earth
Science – Key stage 2 (Year 5)

Statement of issue and rationale

Research has shown that many fundamental topics in space science are very difficult to understand, as naïve notions are pervasive among pupils. Researchers have reported that primary school pupils hold various misconceptions about the phases of the Moon (Barnett & Moran, 2002; Baxter, 1989; Broadstock, 1992; Schoon, 1988). Some of these misconceptions are influenced by: the Moon going in and out of the Earth's shadow, clouds covering parts of the Moon, and planets casting a shadow on the Moon (Hermann & Lewis, 2003).

Barnett and Moran (2002) found that primary school pupils can develop sophisticated understandings of space concepts. In an earlier study, Jones et al. (1987) summarised five mental models of the Sun–Earth–Moon system, which were: (i) the Earth-centred magic model, (ii) the spinning Earth-centred model, (iii) the Earth-centred model with orbiting Sun and/or Moon, (iv) the Sun-centred model with orbiting Earth and/or Moon, and (v) the Sun-centred model with orbiting Earth and Moon orbiting Earth. Thus, research suggests that pupils' mental models of the day/night cycle can be developed using three phases: an initial mental model, a synthetic mental model and a scientific mental model (Vosniadou & Brewer, 1994).

Previous research has suggested a three-step teaching strategy to address misconceptions: identify the misconception, overturn the misconception, and then replace it with a scientific conception (Posner et al., 1982). In an attempt to address the issues highlighted above, many teaching strategies have been put forward to develop pupils' conceptual understanding of the moon phases. A number of researchers have also suggested that the inclusion of activities that develop and enhance pupils' spatial thinking abilities is highly desirable in the design and production of learning materials, and implementation of teaching strategies for space science (Pasachoff & Percy, 2005).

In the acquisition and construction of spatial knowledge in space science, pupils often need to imagine how objects look from other viewpoints. These activities should be based on direct observation, and spatial training exercises should be included to develop pupil orientation frameworks and to enhance their spatial visualisation of dynamic celestial phenomena (Pasachoff & Percy, 2005). Therefore, pupils need to be given an opportunity to explore the world around them through hands-on, open-ended activities (Chin & Osborne, 2008). When pupils act like scientists, they learn about their work by observing, describing, questioning, and searching for answers.

Research suggests that moon journals provide authentic opportunities for pupils to make observations of the natural world, as well as to reflect on the patterns they observe, their learning, and the questions that still remain (Comstock, 1939; McMillan & Wilhelm, 2007). Moon observation journals, created by pupils, foster a purposeful link between what they can observe about the world around them and the spatial relationships inherent in these observations. Moon journals offer pupils a place to write down their observations as well as their emerging thoughts about what they are observing (Cole et al., 2015). They also provide a place to develop pupils' early understandings and to ask questions for further investigation (Fulwiler, 2007). In response, this study will develop a lesson plan to examine how moon journaling can be utilised by pupils to better understand the moon phases.

Main findings from the research

Cole et al. (2015) investigated the relationship between pupils' performance, as evidenced in their moon journals, and their mental models of moon phases. The research subjects were 333 Grade Six (Year 7) pupils from three south-central US schools, located in an urban setting. Each of the schools followed a project-based curriculum called Realistic Explorations in Astronomical Learning (REAL), focusing on Earth/Space lessons. As part of the curriculum, pupils were asked to keep daily moon observation journals. In these journals, pupils sketched the appearance and recorded the location of the moon daily (azimuth and altitude locations). They were also asked to write about what they observed, in particular noting any emerging patterns and making predictions about the future appearance and location of the moon. Moon journals were kept for an entire moon cycle.

The findings from this study indicated that pupils who made many entries in their moon journals and scored high overall on the journal, also scored well on their mental models of moon phases (Cole et al., 2015). The empirical findings of the study suggest that pupils who put more effort into thinking and writing about what they observed, in addition to recording the appearance and location of the sky, likely gained the most from the moon journals. In particular, pupils who kept a moon journal for at least three weeks, equating to 21 entries in total, tended to score significantly better post-test than pupils who made fewer entries.

Overall, Cole et al. (2015) reported that the teachers and pupils participating in the study benefited from the purposeful use of moon journals in their classrooms. However, they suggested that moon journals alone are not enough. In-class discussions of the moon journals also need to take place by using the moon journals as their daily warm-up activity. These classroom discourses are important as they allow pupils to compare their observations with others and to reach a consensus. In the beginning, pupils need to write in their moon journals to make sense of their observations, but they also need to discuss their observations with peers to learn from each other and rectify differences in their mental models.

In Abell et al.'s (2002) work, 200 pupils engaged in a six-week study of phases of the Moon. The study aimed to help pupils to understand the phases of the Moon and to enhance their understanding of the nature of science. Pupils were asked to observe the Moon for a month and to keep a journal of their observations, ideas, and reflections on learning. In addition to these journals, Abell et al. (2002) also developed a number of instructional strategies to help pupils build their understanding. These activities involved large group data sharing and small group problem solving activities, which reflected on pupils' learning experiences.

The findings from Abell et al.'s (2002) study indicated that most pupils developed accurate concepts about moon phases. The moon journaling activities and other supported instructional strategies challenged pupils' theories about science teaching and learning. Abell et al. (2002) also claimed that the benefits of the long-term moon study were undeniable, as it created a space for pupils to consider various ideas and work on scientific explanations that they had rarely experienced in science classrooms.

In short, moon journaling activities not only enabled pupils to develop a conceptual understanding of the phases of the Moon (Abell et al., 2002; Cole et al., 2015), but also to recognise, revise, and reconcile their beliefs about science teaching and learning (Abell et al., 2002).

Therefore, a lesson was produced using moon journaling activities to teach about the moon phases.

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Lesson Plan

Moon Phases
Using Moon journaling activities to teach about the phases of the moon
Pupils should be taught to: describe the movement of the Moon relative to the Earth
Science – Key stage 2 (Year 5)

Research recommendation(s) and rationale	Research has shown that pupils learn best about space science, and in particular the phases of the Moon based on direct observation, which enhances their spatial visualisation of dynamic celestial phenomena (Pasachoff & Percy, 2005). Thus, moon journaling activities should enable pupils to develop a conceptual understanding of the phases of the Moon (Abell et al., 2002; Cole et al., 2015), and an understanding of the nature, processes and methods of science through different types of scientific inquiry (Abell et al., 2002). The suggested lesson sequence is mainly based on the work of Abell et al., (2002).
Lesson aim	To use moon journaling activities to teach about the phases of the Moon and the nature of science.
Learning objective	To enable pupils to understand that the Moon orbits the Earth, which causes the phases of the Moon.
Intended learning outcomes	At the end of the lesson, pupils will be able to: i. Describe the movement of the Moon around the Earth. ii. Explain why the Moon changes its apparent shape. iii. Name eight phases of the Moon.
Scientific vocabulary	Star – large ball of gas and plasma, such as the sun. Sun – an ordinary star in our galaxy, the Milky Way. Moon – an object that orbits a planet or something else that is not a star. Earth – the third from the Sun. The Earth is the only place in the known universe that supports life. Moon phases - new Moon, waxing crescent, first quarter, waxing gibbous, full Moon, waning gibbous, third quarter and waning crescent.
Suggested lesson sequence and activities	**Individual activity: the Moon journal** As a starting point to their learning, prior to any specific teaching of moon phases and linked vocabulary, pupils will observe the Moon for a month and keep a journal of their observations, ideas, and reflections on learning. The Moon journal assignment requires pupils to observe daily, take notes on their observations, and try to make sense of the data. Thus, pupils will write about what they have observed, noting the day, time, and shape of the Moon. At times, they can mention the weather conditions, their viewing location, and the position of the Moon in the sky. Pupils can also include data they have collected from local news or the Internet. Prior to pupils being assigned their journal homework, begin a KWL chart (i.e. what I know, what I want to know and what I learned) where the teacher will ask pupils to list what they already know and what they want to know about the Moon, which will be revisited weekly as journal entries are shared and discussed.

	Large group data sharing and construction of a class moon calendar For the duration of the moon investigation, each class period will begin with a moon discussion/problem solving session. Pupils will share and compare observations and explain their developing theories with other pupils and the teacher. This activity will provide opportunities for discussions about science. During these discussions introduce the pupils to the key scientific vocabulary as appropriate and as it arises linked to the moon phases observed throughout each week. Ask pupils to create key word flashcards for each throughout these sessions and as a follow up to these sessions ensure that students revisit these key word flashcards on a regular basis until they are secure, possibly using the Leitner 3 box system (https://www.youtube.com/watch?v=C20EvKtdJwQ&safe=active) Consider displaying/developing visual aids to facilitate the discussions, e.g. a moon calendar and the KWL chart. On a class moon calendar, pupils will record sightings made since the last class meeting. **Small group discussion and problem solving linked to observation through moon journal** The teacher will focus teammates on one of the questions that arose naturally during that day's large group discussion. In this way, pupils will be encouraged to refocus, extend, and perhaps bring closure to the large group discussion. Teacher can also choose to structure small group discussions by using questions raised to scaffold pupil knowledge construction. Encourage pupils to make predictions about what they will observe next and explain their predictions. **Drawing conclusions and applying knowledge** On completing the month long moon journal encourage students to look for patterns and notice links. Recap with pupils the phases of the moon (new Moon, waxing crescent, first quarter, waxing gibbous, full Moon, waning gibbous, third quarter and waning crescent), using the key vocabulary flash cards and related images to revisit the vocabulary. Pupils to add correct scientific vocabulary to the images they created in their moon journal. **Possible follow up learning activities:** **Classroom models and simulations** Pupils will be introduced to model-making when they have gathered enough data to see patterns emerge and will begin to pose tentative explanations of moon phases. This activity will offer a way for pupils to enhance their explanations. The model will help pupils to visualise celestial objects and manipulate them according to their moon theories. Suggested models include: two-dimensional paper-pencil diagrams, three-dimensional tactile representations, and computer-generated images and simulations. Pupils to link the correct scientific vocabulary to the models they make.

	Science stories Pupils will initially document their own story about their understanding of moon phases and their earlier experiences learning about the Moon. Both of these writings will serve as comparison pieces for their developing theories about moon phases and science teaching and learning. In this activity, pupils will tell their moon stories in class and write them in their journals, to generate feelings of wonder and intrigue. The teacher will encourage pupils to write various forms of prose and poetry. This activity will make the moon investigation more personal and meaningful for the pupils. Finally, pupils will tell stories of their current understandings of moon phases, as well as their visions for teaching about moon phases in their own classrooms.
Key questions	Why may different pupils have observed the moon differently on the same evening? (timing differences in observation, cloud covering) What are you noticing about the changes in the shape of the moon over the past week? What are you expecting the moon to look like tonight, tomorrow, in a week based on your observations so far? What do you think is causing the appearance of the moon to change?
Assessment suggestions	Can students explain how the apparent shape of the moon is changing and predict how it will change in the coming days? Can students explain what is causing the apparent shape of the moon to change? Can students apply the eight phases of the moon to their models accurately?
Resources **H&S considerations**	Bingham, C. (2008). *First space encyclopedia*. DK Publication. (Includes spectacular illustrations of relative sizes of Earth and Sun: also compares size of the Moon, and planets of the Solar System: details eclipses and phases of the Moon). Kerrod, R. (2000). *Earth and Moon*. Chrysalis Education. (Introduces main features of Earth science and Earth–Moon System: compares the size of the Earth and Moon and explains moon phases). Ensure all activities are carried out in a safe and calm manner, take extra care when doing moon observation outside classroom/home at dusk. Follow all your school's health and safety protocols. Please discuss health and safety with your mentor.

Research Summary

Classification - Plants

Using dichotomous keys in facilitating pupils to observe, compare, classify and identify plants

Pupils should be taught to: (i) describe how living things are classified into broad groups according to common observable characteristics and based on similarities and differences, including micro-organisms, plants and animals, and (ii) give reasons for classifying plants and animals based on specific characteristics.

Science – Key stage 2 (Year 6)

Statement of issue

The classification of plants represents one of the most challenging biological teaching topics. This topic is difficult for pupils to adopt because it requires the integration and application of knowledge in plant morphology, plant identification and plant systematics (Anđić et al., 2020; Maskour et al., 2016). Numerous studies have highlighted that pupils cannot identify the most common plant species in their own environment and do not understand their importance (a phenomenon known as *Plant blindness*) (Pany, 2014; Wandersee & Schussler, 2001). In particular, what makes the plant identification process more difficult is that there are many different plant species, and many are similar to each other (Huang et al., 2010).

Main findings from the research

Simplified biological keys are tools adapted for usage by pupils, by providing more or less detail (higher level information) or by employing simplified language that allows them to get to know organisms more closely through their biological identification (Anđić et al., 2020; Bajd et al., 2002). Research has indicated that dichotomous keys - a method of identification whereby groups of organisms are divided into two categories repeatedly - are suitable for science education because they require fewer decisions in the determination process than a multiple-choice key does (Hagedorn et al., 2010; Krasna, 2010). Dichotomous keys are very effective teaching tools for preparing pupils for competitions (Bajd et al., 2002), improving pupils' skills and abilities in independent work (Bromham & Oprandi, 2006), strengthening pupils' motivation for the acquisition of botanical content (Silva et al., 2011), achieving the scientific principle in science (biology) teaching (Randler & Zehender, 2006), and offering greater opportunities for pupils to learn from their mistakes (Marsh et al., 2012).

The teaching of plant identification includes showing pupils how to use dichotomous keys. Such dichotomous keys represent one way to teach about systematics, with the objective of being able to identify unknown taxonomy (Jacquemart et al., 2016). The pupils make a series of determinations about the characteristics of the unknown species; if the determinations are correct, the key gives them the identity of the organism (Anđić et al., 2019; Jacquemart et al., 2016). Researchers have emphasised that keys for non-experts should not be unnecessarily simplistic or untechnical, since such measures would reduce their educational benefit. Furthermore, keys that are enjoyable to use are proven to be more effective (Stagg & Donkin, 2013; Stagg et al., 2015). The examples of case studies presented below were mainly drawn from Anđić et al.'s (2019; 2020) works, which have extensively researched the contribution of dichotomous keys of plants (both printed and digital) to teaching primary school pupils about plant identification.

Case study 1

Anđić et al. (2019) explored the effect of dichotomous keys on the quality and durability of the knowledge of 180 primary school pupils (aged 13-14 years old) in Montenegro, with regards to the classification of plants (*Bryophyta*, *Pteridophyta*, *Gymnosperms* and *Angiosperms*), as compared to traditional teaching methods. The dichotomous key was made in the form of an A4 brochure with colour photos of the plants. Several of the last pages of the brochure contained the illustrated and descriptive glossary. The dichotomous key began with two statements (e.g. – '*miniature plants on whose stems with seta and capsule formed, or plants with thallus….*' and '*plants with different appearance….*'). These statements referred to the morphological characteristics of plants. When a pupil selected the appropriate statement, they would then be directed to the next number where there were two additional statements, which in the following way would lead pupils first to the class, then to the lower systematic categories and eventually to the name of the plant species.

The study indicated that the application of dichotomous keys – when compared to traditional instructional teaching – developed situational and practical learning skills among pupils, rather than theoretical and verbal learning alone. The researchers reported that the benefits of dichotomous keys in comparison to traditional instructional teaching are that the principles of scientific inquiry are applied to the use of dichotomous keys. Since the activities are selected and created based on the experience and previous knowledge of pupils about plants, dichotomous keys make a greater contribution to the quality and durability of pupils' knowledge when compared to traditional instructional teaching. In the study, the pupils understood and applied their newly acquired knowledge to their previous knowledge in order to be as successful as possible in determining solutions. They adopted the principles of the scientific determination of plants using dichotomous keys, which influenced the quality of their knowledge.

Case study 2

In a recent study, Anđić et al. (2020) examined the contribution of the dichotomous digital key and the dichotomous printed key, to primary school pupils' (aged 13-14 years old) achievements, and the sustainability of biological knowledge about the systematisation and classification of plants at all cognitive levels. The dichotomous digital key was applied using m-learning with a tablet PC. Each plant was presented using text, images and sound. The information needed to determine each plant was obtained by reading, listening and watching. The software led pupils through the process of plant determination in its entirety, enabling pupils to become independent learners in determining the plants in question. In the case of the dichotomous printed key, it was created in the form of a script in A4 format and printed in colour.

The study reported that both the dichotomous digital key and the dichotomous printed key can be used in the constructivist learning of biology in primary school, because they were created on the basis of previous pupils' knowledge and encouraged them to independently explore the determination of plants. However, the dichotomous digital key can be better implemented in the constructivist teaching of biology in primary schools. The study found that those pupils who used the dichotomous digital key achieved more sustainable knowledge and had a more positive opinion than the pupils who used the dichotomous printed key, notably in relation to the contribution of the implemented dichotomous key to their desire to examine plants in their own surroundings and further afield.

Therefore, a lesson was produced to incorporate dichotomous keys in facilitating pupils to observe, compare, classify and identify plants.

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Lesson Plan

Classification - Plants

Using dichotomous keys in facilitating pupils to observe, compare, classify and identify plants

Pupils should be taught to: (i) describe how living things are classified into broad groups according to common observable characteristics and based on similarities and differences, including micro- organisms, plants and animals, and (ii) give reasons for classifying plants and animals based on specific characteristics.

Science – Key Stage 2 (Year 6)

NOTE: This lesson is designed to follow on from the related lesson on classifying and identifying animals.

Research recommendation(s) and rationale	The classification of plants represents one of the most challenging biological teaching topics. This topic is difficult for pupils to adopt because it requires the integration and application of knowledge in plant morphology, plant identification and plant systematics (Anđić et al., 2020; Maskour et al., 2016). Numerous studies have highlighted that pupils cannot identify the most common plant species in their own environment and do not understand their importance (a phenomenon known as Plant blindness) (Pany, 2014; Wandersee & Schussler, 2001). In particular, what makes the plant identification process more difficult is that there are many different plant species, and many are similar to each other (Huang et al., 2010). • Simplified biological keys. • Showing pupils how to use dichotomous keys - because they require fewer decisions in the determination process • keys for non-experts should not be unnecessarily simplistic or untechnical • Keys that are enjoyable to use are proven to be more effective (Stagg & Donkin, 2013; Stagg et al., 2015) Case study 1 Anđić et al. (2019) explored the effect of dichotomous keys on the quality and durability of the knowledge of 180 primary school pupils (aged 13-14 years old) in Montenegro, with regards to the classification of plants (Bryophyta, Pteridophyta, Gymnosperms and Angiosperms), as compared to traditional teaching methods. The dichotomous key was made in the form of an A4 brochure with colour photos of the plants. Several of the last pages of the brochure contained the illustrated and descriptive glossary. The dichotomous key began with two statements (e.g. – 'miniature plants on whose stems with seta and capsule formed, or plants with thallus….' and 'plants with different appearance….'). These statements referred to the morphological characteristics of plants. When a pupil selected the appropriate statement, they would then be directed to the next number where there were two additional statements, which in the following way would lead pupils first to the class, then to the lower systematic categories and eventually to the name of the plant species.
Lesson aim	To use dichotomous keys to help pupils to observe, compare, classify and identify plants
Learning objective	To use dichotomous keys as a way to classify plants.
Intended learning outcomes	At the end of the lesson, pupils will be able to: i. To be able to explain the major groups within the plant kingdom. ii. To use and create dichotomous keys that aid plant identification.

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Lesson aim	To use dichotomous keys to help pupils to observe, compare, classify and identify plants
Learning objective	To use dichotomous keys as a way to classify plants.
Intended learning outcomes	At the end of the lesson, pupils will be able to: i. To be able to explain the major groups within the plant kingdom. ii. To use and create dichotomous keys that aid plant identification.

	iii. To be able to explain why fungi are not plants and in fact belong to a different kingdom of life.
Scientific vocabulary	**Shared characteristics** – something that members of a group all have in common. **Subgroup** – when a group can be split into smaller groups. **Dichotomous** – when a group can be split into two distinct parts because there is an obvious difference between members of the group. **Angiosperms** – plants that have flowers and produce seeds **Gymnosperms** – plants that produce seeds without flowers e.g. conifers **Ferns** – make spores not seeds but do have roots, stem and leaves **Mosses** – make spores not seeds and do not have clear roots, stem, and leaves. **Algae** - a type of plant with no stems or leaves that grows in water or on damp surfaces.
Common Misconceptions	• mushrooms are plants • plants get their food from the soil • plants are flowering plants grown in pots with coloured petals and leaves and a stem • trees are not plants • all leaves are green • all stems are green • a trunk is not a stem • blossom is not a flower • plants and seeds are not alive as they cannot be seen to move • plants that grow from bulbs do not have seeds • all plants have flowers • plants eat food
Suggested lesson sequence and activities	**NOTE: This lesson is designed to follow on from the related lesson on classifying and identifying animals and using dichotomous keys.** Display the terms mammal, amphibian, reptile, fish, and birds on the board. Q: *What do these groups all have in common?* (A: They are all animals and they all have an internal skeleton so are vertebrates). Q: *What term do we use when members of a group have something in common?* (A: Shared characteristic) Now play *What am I?* Read out the key features from the table below and ask pupils to match the features to one of the headings. Then add a photo of a representative species from that group e.g. a salmon. Repeat until pupils have linked all the characteristics to each of the five groups.

Group	Body covering	Warm or cold blooded?	Lungs or gills?	Reproduction	Examples
Fish	Scales	Cold	Gills	Lay soft eggs in water	Sharks, trout, salmon
Amphibians	Moist skin	Cold	Gills then lungs	Lay soft eggs in water.	Frogs and newts
Reptiles	Dry scales	Cold	Lungs	Lay rubbery eggs on land (some live birth)	snakes, lizards, crocodiles
Birds	Feathers	Warm	Lungs	Lay hard shelled eggs on land	penguins, emus, owls
Mammals	Skin, most have hair	Warm	Lungs	Live birth. Feed young on milk.	humans, dogs, dolphins

Now show a picture of an insect or other invertebrate. Ask the pupils *what shared characteristic the invertebrate has with the other animals?* They are all animals. But *what does it not share?* It doesn't have an internal skeleton therefore it is an invertebrate.
Using the dichotomous key created last lesson, add a new question above the first question which asks *Does it have an internal skeleton?*

Now show a picture of a plant. Ask pupils *what shared characteristic does the plant have with the animals?* A: They are all living things. Explain that the plant is different to the animals because it can **photosynthesise** (make its own food from sunlight). Remind pupils of their previous work on food chains – plants are producers at the start of the food chain because they use energy from the sun to photosynthesise their food. Animals are consumers – they have to eat (consume) plants and/or other animals.
Add in a new question above the first question which asks *Does it photosynthesise?* No = Animal branch. Yes = Plants.

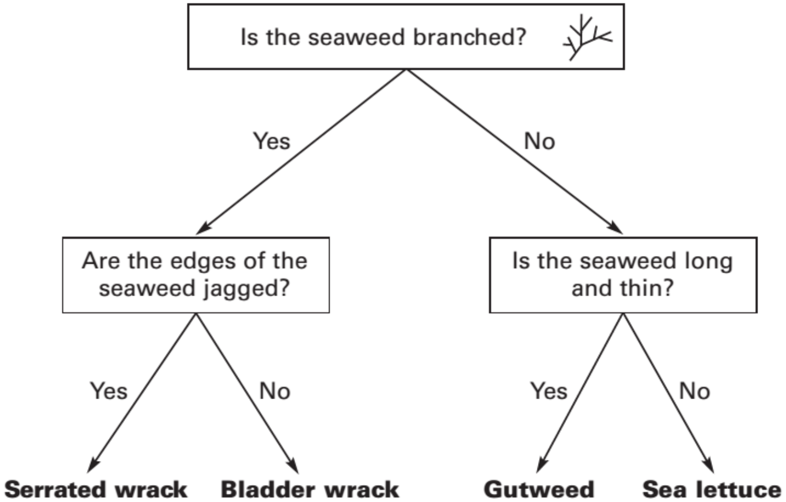
Explain that plants are actually a completely separate kingdom of life to animals. They are all living things or organisms because they can reproduce and they respire (need oxygen). Today we are going to learn about some of the major groups in the plant kingdom.

	Reiterate that the major groups in the animal kingdom are vertebrate and invertebrates. Then within the vertebrate group we had the five subgroups of mammals, reptiles, birds, amphibians and fish. Draw this out or use a visual. Explain that plants also have major subgroups. Give the pupils the plant key in pairs. Ask them to create a question for each dichotomous branching within the key e.g. An appropriate branching for the first split would be "*Does it produce seeds?"* Give pupils time to create the questions for each branching then take feedback of their ideas. Use this as a starting point to discuss the different groups within the plants e.g. **angiosperms** produce seeds and flowers whereas the **gymnosperms** produce seeds but do not have flowers. **Ferns** do not make seeds but they do have roots, stem and leaves whereas **mosses** do not have clear roots, stems and leaves. For examples, carry out an Internet image search using *dichotomous plant key* as the key words. Once you have agreed as a class on the questions on the key and discussed the features of each group, play a game of *What am I?* using species level examples. Support this with pictures e.g. "I have leaves, stem and roots but I don't make seeds, what am I?" A fern. Show pupils an image of a fern e.g. Christmas Fern (Polystichum acrostichoides), again use the Internet for examples of plant images. If possible, have multiple real-life examples (photographs if this is not possible) of flowering plants, gymnosperms (conifers), ferns and mosses for the pupils to explore and examine. Encourage pupils to look at the morphology of each one and to begin to spot the features common to each group but that there is variation in each group still e.g. all the angiosperms have flowers but that the flowers may differ a lot. For greater challenge encourage the pupils to look for similarities and differences between different ferns, noting the shared characteristics of leaves, stem and roots but that the shape of the leaves and size of the plants can vary. If possible, take the pupils out into the outdoor environment and ask them to identify an example of angiosperms, gymnosperms, ferns, and mosses. Once pupils are competent at spotting these major groups, introduce dichotomous keys for identification within a group e.g. for gymnosperms (conifers). Extension task / greater depth: A common misconception among pupils is that mushrooms are a type of plant. Return to the original key produced by the class which shows the separate kingdoms of plants and animals. Point out that mushrooms (fungi) do not photosynthesise and are therefore not part of the plant kingdom. Link this back to their prior knowledge of food chains – fungi are decomposers in the food chain, not producers.
Key questions	What are the shared characteristics within the group? What question could you ask to split the group into two subgroups? What are the shared characteristics of the …………? plant group?

Assessment suggestions	Constant use of verbal questioning throughout the activities to assess pupils’ understanding and scaffold the process of creating their questions. For more formal assessment, use the old SATS questions below.
Resources **H&S considerations**	Variety of plant pictures and plants. Check the pupils do not put any plants or berries in their mouth.

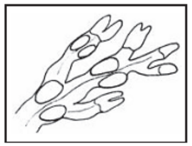
(a) Maria found different types of seaweed on the beach.

Her teacher has a key to identify the seaweeds.



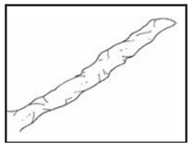
Use the key to identify the different seaweeds below.

Seaweed A has been done for you.



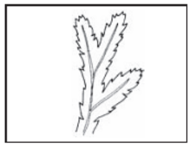
Seaweed A is

Bladder wrack



Seaweed B is ....

Seaweed C is ....



Seaweed D is ....

(1 mark)

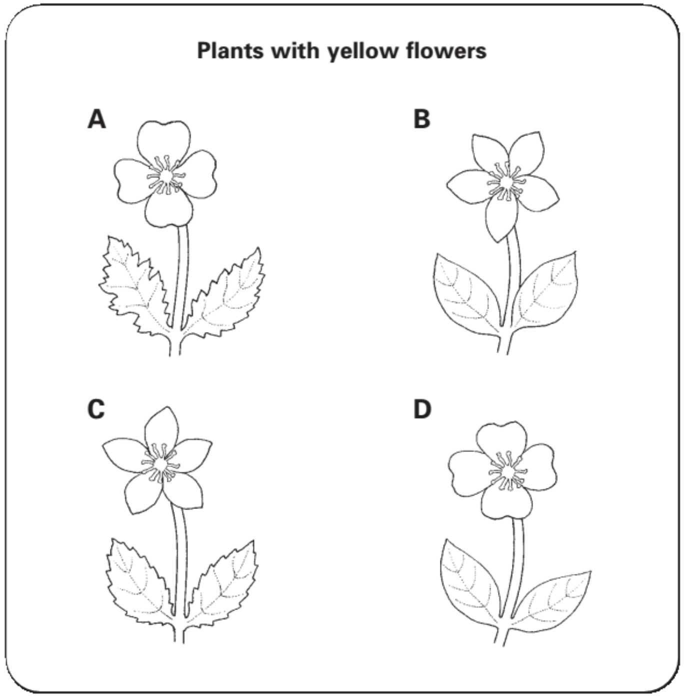
(a) Fiona is in the garden. She wonders how she can find out the names of some of the plants.

Tick **ONE** box to show how Fiona could find out the names of the plants.

Fiona could use a...

food chain.	☐	producer.	☐
fair test.	☐	key.	☐

(b) Fiona sorts the plants into groups to help her find out their names. The plants in one of her groups all have yellow flowers.



Look at the group of plants with yellow flowers.
Fiona needs to sort these plants into two groups.

(i) Suggest a way these plants with yellow flowers could be sorted into two groups.

Group 1: Plants with yellow flowers and ....

....

Group 2: Plants with yellow flowers and ....

....

(ii) Write **A, B, C** or **D** in each box below to show how Fiona should sort the plants with yellow flowers into the two groups you gave above.

Group 1 ☐ ☐ **Group 2** ☐ ☐

3bi 1 mark

3bii 1 mark

(c) Scientists sort plants into groups.
Tick **ONE** box to show why it is a good idea.

- to compare plants with animals ☐
- to see if a plant is a living thing ☐
- in case a plant dies ☐
- because there are many types of plant ☐

3c 1 mark

Research Summary

Classification - Animals

Using dichotomous keys in facilitating pupils to observe, compare, classify and identify animals

Pupils should be taught to: (i) describe how living things are classified into broad groups according to common observable characteristics and based on similarities and differences, including micro- organisms, plants and animals, and (ii) give reasons for classifying plants and animals based on specific characteristics.

Science – Key stage 2 (Year 6)

Statement of issue

Pupils have issues with classifying animals (Bell, 1981). For example, they often incorrectly classify vertebrates as invertebrates (Braund, 1998) or birds as non-bird species (Prokop et al., 2007; Trowbridge & Mintzes, 1988). Species identification may be seen as a classic way of teaching and learning about science, or biology more specifically. However, for a clearer understanding of aspects of the living world (e.g. - genetics, ecology and evolution), and to illustrate the material flow and functioning of ecosystems, this approach needs to discuss discrete species to make the facts more understandable (Randler, 2007; Randler & Bogner, 2002).

Main findings from the research

Dichotomous keys, the method of identification whereby groups of organisms are divided into two categories repeatedly are a widely used tool in science and in the higher education curriculum, since they are harnessed to classify living beings or inert matter, depending on whether or not they possess certain defining features (Cascarosa et al., 2020; Randler, 2007). In an observation exercise presenting several dilemmas, pupils must accept one option and reject the other, which then leads to a new dichotomy to be resolved in exactly the same way, until the specimen is identified (Randler, 2007). By using tools such as dichotomous keys, pupils develop logical-mathematical thinking skills by experimenting, and seeking to understand the changes involved when moving from one dilemma to another. This occurs after making a decision based on observing the element in question (Cascarosa et al., 2020). Within the literature, four studies (see Cascarosa et al., 2020; Prior & Mazas, 2016; Randler, 2007; Randler & Birtel, 2008) emphasise the use of dichotomous keys to teach primary school pupils how to observe, compare, classify and identify animals, as synthesised below.

Case study 1

In their study, Randler and Birtel (2008) designed a '*system of pasta*' to train 104 pupils (Year 6 and Year 7) in developing identification skills. The aim of the study was to enhance pupils' learning and retention when they were working together in small groups on an identification skills training exercise using a dichotomous key for classifying amphibians. In the beginning, the system of pasta was developed and familiarised by the pupils, establishing a dichotomous identification key for different types of pasta, such as lasagne, tortellini, spaghetti, macaroni, and other types. The pupils were then tested to identify and classify eight autochthonous amphibian species that live and reproduce in Saxonia (*Sachsen* in German), where the study was conducted.

The study suggests that an initial training on '*system of pasta*' prior to species identification activities significantly increases pupils' understanding of different characteries of amphibians and their ability to apply classification skills immediately thereafter, even after four weeks have elapsed. The study emphasises the greater impact of using dichotomous identification keys than traditional teaching methods, but only after proper preparation of the pupils' identification and classification skills. The researchers also found that pasta training indeed reduces the extraneous cognitive load and enhances brain capacity, so that pupils are able to focus on the scientific concept at hand – in this case the amphibian identification task.

Case study 2

Prior and Mazas (2016) investigated the use of dichotomous keys with pupils Year 4 and Year 5, using the *Guess Who*? game, to develop their scientific skills such as observation, comparison, classification and identification, when classifying a variety of invertebrate animals. In general, the teacher initially organises, directs and guides the pupils through questions based on the characteristics of the animals that they have to classify. The pupils are then presented with three activities, before having to identify, through questions asked by the teacher, the group of animals to which each key refers. The pupils are given two incomplete dichotomous keys and they have to find out which invertebrate animal they are discussing.

The study reported that most of the pupils were able to complete, develop and manage the dichotomous keys in each of the proposed activities. The degree of motivation and satisfaction found during the activities was also notable. The materials and media used aroused great interest, since the pupils had never before worked on a science unit through dichotomous keys. The study suggests that after the experience, the majority of the pupils understood the concept of dichotomous keys and its use in understanding invertebrate animals, as well as how scientific skills worked in the classroom.

Case study 3

In another study, Randler and Knape (2007) compared the practicability of two different identification keys for animal tracks and signs. The aim of the study was to enhance learning and retention effects when 26 pupils Year 7 were working together in small groups, as part of an identification skills training activity, using original objects and remains (animal signs and tracks), either using a dichotomous or an illustrated key. The identification keys were similar in structure and in the number of solutions offered, but they differed in the method used to reach a correct identification: the illustrated key just contained pictures of the respective tracks, while the dichotomous key started with a decision to be made between two alternatives.

As a result, the pupils using the pictured key perceived a better level of well-being and tended to be less bored. The study found that no differences existed in interest and both groups experienced their task as similarly difficult. Randler and Knape (2007) claimed that although language-based keys indeed seem inferior compared to picture-based keys, his study supported the use of illustrated identification materials for teaching and learning about biodiversity. The study also suggests that the materials used within such group-based, self-determined educational units should now be placed under scrutiny within science instruction, as it seems that these aspects are also a central aspect of improving teaching and learning.

Case study 4

Cascarosa et al.'s (2020) study examined whether or not 23 young pre-school pupils aged 3-4 years old were able to apply scientific tools, including the magnifying glass and dichotomous key, to observe, compare, classify and identify small animals within their surroundings. A didactic sequence was first designed, based on some stages of the scientific method. The teacher guided the observation, based on using the magnifying glass and engaging in description, by encouraging the pupils to count the number of legs and wings of each animal, as well as their colour, before then moving on to identification, by introducing and following a dichotomous key.

The study concluded that the pupils were able to use the magnifying glasses to observe and to compare. By using a magnifying glass, pupils learned to observe and compare small animals in an intentional way, through an examination of their physical characteristics. The comparison criteria they established based on this observation and comparison, were used to classify and identify other animals by using a dichotomous key. However, the results show that the pupils struggled to use keys; thus, help from the teacher was necessary to develop scientific skills for the purpose of observation, comparison, classification and identification.

Therefore, a lesson plan was produced to incorporate dichotomous keys, to facilitate pupils to observe, compare, classify and identify animals.

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Lesson Plan

Classification - Animals

Using dichotomous keys in facilitating pupils to observe, compare, classify and identify animals

Pupils should be taught to: (i) describe how living things are classified into broad groups according to common observable characteristics and based on similarities and differences, including micro- organisms, plants and animals, and (ii) give reasons for classifying plants and animals based on specific characteristics. Science – Key stage 2 (Year 6)

Research recommendation(s) and rationale	Pupils have issues with classifying animals (Bell, 1981). For example, they often incorrectly classify vertebrates as invertebrates (Braund, 1998) or birds as non-bird species (Prokop et al., 2007; Trowbridge & Mintzes, 1988). Species identification may be seen as a classic way of teaching and learning about science, or biology more specifically. However, for a clearer understanding of aspects of the living world (e.g. - genetics, ecology and evolution), and to illustrate the material flow and functioning of ecosystems, this approach needs to discuss discrete species to make the facts more understandable (Randler, 2007; Randler & Bogner, 2002) Dichotomous keys, the method of identification whereby groups of organisms are divided into two categories repeatedly are a widely used tool in science and in the higher education curriculum, since they are harnessed to classify living beings or inert matter, depending on whether or not they possess certain defining features (Cascarosa et al., 2020; Randler, 2007). In an observation exercise presenting several dilemmas, pupils must accept one option and reject the other, which then leads to a new dichotomy to be resolved in exactly the same way, until the specimen is identified (Randler, 2007). By using tools such as dichotomous keys, pupils develop logical-mathematical thinking skills by experimenting, and seeking to understand the changes involved when moving from one dilemma to another. This occurs after making a decision based on observing the element in question (Cascarosa et al., 2020). Within the literature, four studies (see Cascarosa et al., 2020; Prior & Mazas, 2016; Randler, 2007; Randler & Birtel, 2008) emphasise the use of dichotomous keys to teach primary school pupils how to observe, compare, classify and identify animals
Lesson aim	To use dichotomous keys to help pupils observe, compare, classify and identify animals
Learning objective	To use dichotomous keys as a way to classify animals.
Intended learning outcomes	At the end of the lesson, pupils will be able to: i. Explain that species can be grouped based on shared observable characteristics. ii. Use and create dichotomus keys that aid identification based on these observable characteristics.
Scientific vocabulary	**Shared characteristics** – something that members of a group all have in common. **Sub-group** – when a group can be split into smaller groups. **Dichotomous** – when a group can be split into two distinct parts because there is an obvious difference between members of the group.
Common misconceptions	• only four-legged mammals, such as pets, are animals

	• insects are not animals • all ‘bugs’ or ‘creepy crawlies’, such as spiders, are part of the insect group • amphibians and reptiles are the same. • mushrooms are plants. • only birds lay eggs. • snakes are similar to worms, so they must also be invertebrates
Suggested lesson sequence and activities	*Resources – A bag of liquorice allsorts per pair.* Before handing out the llsorts, set clear expectations and rules for the lesson (e.g. the liquorice allsorts are not for eating) Give each pair of pupils a bag of liquorice allsorts. Ask them to sort them into two groups and to justify their groupings. Take feedback from some groups, ideally groups that have sorted them in different ways. There is no right or wrong, but they must be able to explain their grouping. Introduce the term **shared characteristics**. Link this to the reason for grouping e.g. “We had a pile of liquorice allsorts. They have the shared characteristic of being made of liquorice. Then you have split your liquorice allsorts into two groups. The first group have the shared characteristic that they are all round. The other group have the shared characteristic that they are all square.” Now ask the pupils to focus on one of their subgroups e.g. the round ones. Ask them to sort them into *two* new **sub-groups**. Explain that a **sub-group** is a group within a group. For example, they may now split the round liquorice allsorts into those with a black centre and those covered in sprinkles. These are sub groups. They should be able to justify their groupings. Take feedback from some pairs. Now ask all pupils to watch as you model (hands off the liquorice allsorts) Using a large piece of paper, place all the liquorice allsorts at the top. Ask the pupils how did we split the group? What question could you ask? Encourage them to ask questions with yes/no answers that focus on a characteristic e.g. is the Allsort round? Show that the liquorice allsorts now move down the key into two new groups. Write the question on as you ask it. Clearly show how the questions leads to two new groups. Focussing on one sub-group (e.g. the round ones) ask the pupils *How will we split the group? What question could you ask?* Again, encourage them to ask questions with yes/no answers that focus on a characteristic e.g. does the Allsort have a black centre? Show that the liquorice allsorts now move down the key into two new groups. Continue creating the key until the liquorice allsorts are separated into single types (like liquorice allsorts species!). Ask the pupils to now focus on the other sub-group from the first split e.g. the square ones. Can they repeat the process of creating the questions for a **dichotomous key**. Explain that the dichotomous key splits the group into two (dicho- from Greek dikho-, meaning two). Allow pupils time to work in pairs to create their own keys using a set of liquorice allsorts. Swap keys and use peer assessment to check that the keys work. Encourage pupils to re-word their questions where necessary. Questions must focus on a characteristic. Feedback on the questions they produce is essential.

At the end of the lesson, display the terms mammal, amphibian, reptile, fish and birds on the board. Explain that these are all animals and the all have an internal skeleton (i.e. they are vertebrates). These are **shared characteristics** of mammals, amphibians, reptiles, fish and birds. Now play *What am I?* Read out the key features from the table below and ask pupils to match the features to one of the headings. Then add a photo of a representative species from that group e.g. a salmon. Repeat until pupils have linked all the chracteristics to each of the five groups.

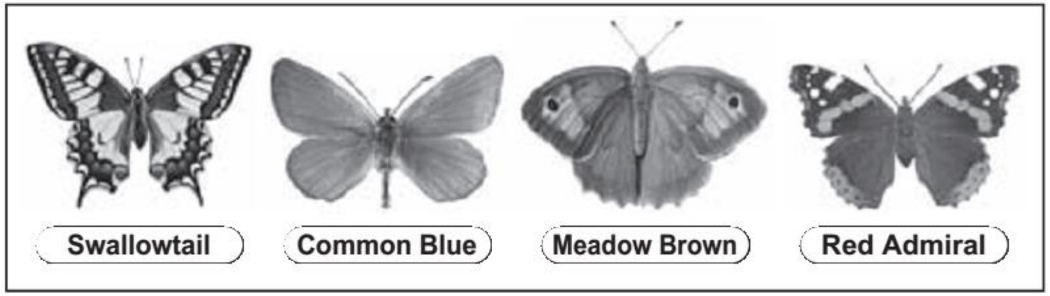
Group	Body covering	Warm or cold blooded?	Lungs or gills?	Reproduction	Examples
Fish	Scales	Cold	Gills	Lay soft eggs in water	Sharks, trout, salmon
Amphibians	Moist skin	Cold	Gills then lungs	Lay soft eggs in water.	Frogs and newts
Reptiles	Dry scales	Cold	Lungs	Lay rubbery eggs on land (some live birth)	snakes, lizards, crocodiles
Birds	Feathers	Warm	Lungs	Lay hard shelled eggs on land	penguins, emus, owls
Mammals	Skin, most have hair	Warm	Lungs	Live birth. Feed young on milk.	humans, dogs, dolphins

Next lesson Recap the key features of each of the five vertebrate groups. Remind pupils that the shared charac eristics are that they are all animals and they all have an internal skeleton (they are vert brates) but we can split them into the sub-groups mammals, amphibians, reptiles, brids and fish based on other shared characteristics. Now, ask pupils to help you think of yes/no questions to split the vertebrates into two groups e.g you might *ask Are they warm blooded?* This would split to two groups: Birds and mammals in one and reptiles, amphibians and fish in the other group. Now, they need to generate a new question to differentiate between mammals and birds e.g. *Does it produce milk?* (or *does it have feathers?)* Repeat with the cold blooded subgroup. E.g. *does it lay eggs in water?*

	is would split the cold blooded group into fish with amphibians and reptiles in the other group. Then demonstrate they need a further question to distinguish between the fish and the amphibians e.g. *does it have moist skin?* Throughout this, model your thinking aloud and provide feedback on the questions they create. They need to master the art of creating useful dichotom us questions which will clearly divide a group into two new subgroups and focus on ch racteristics NOT "is it a fish?" Hand out picture cards of a species from each of the five vertebrate groups. Ask pupils to decide which group they are from and justify their reasoning. Address any misconceptions or incorrect identific tions using questioning to encourage pupils to think about their answers. Now, ask pupils to create their own dichotomous key using the picture cards. Repeat the process as with the liquorice allsorts in the previous lesson. Place all the cards at the top. Create a question. Split the cards into two groups. Now focus on one sub group. Create a new question to split this group into two sub groups until all five cards are separated. Extension task / greater depth: Now produce a new picture card showing an insect e.g. a bee. Remind the pupils that our mammals, amphibians, reptiles, birds and fish had the shared charac eristics of a) all being animals and b) all having an internal skeleton (i.e. being vertebrates). Now ask: *is the bee an animal?* Yes. So it shares that characteristic with the others. Ask: *Does the bee have an internal skeleton?* No, so it is NOT a vertebrate. It is an invertebrate. Show how you could add a question above your first question in your key to distinguish between the vertebrate subgroup and the invertebrates e.g. *does it have an internal skeleton?* Now repeat this process with a plant. Point out that the shared charac istic is that they are all living organisms but the plant is not an animal. You need a question to distinguish between plants and animals such as *does it photosynthesise?* The question should not be "is it a plant?" Link back to your previous questioning . We know the bee and the others are all animals because they are consumers (objective) but the plant is a producers (link back to prior knowledge of food chain from Year 4)
Key questions	*What are the shared characteristics within the group?* *What question could you ask to split the group into two subgroups?* *What are the characteristics of a mammal / fish etc?*
Assessment suggestions	Constant use of verbal questioning throughout the activities to assess pupils' understanding and scaffold the process of creating their questions. For more formal assessment, use the ld SATS questions below.
Resources	Bags of liquorice allsorts, ideally enough for one bag per pair of pupils.

H&S considerations	Set clear boundaries and expectatations so that pupils will not put the liquorice allsorts in their mouths.

(a) Some children visit a butterfly park.
They use the pictures below to identify the butterflies they see.



Sally makes some notes about one butterfly she sees.
Oliver tries to use Sally's notes to identify the butterfly.

Sally's notes:

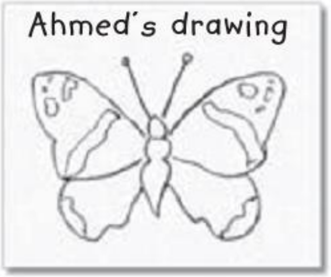
- It has feelers on its head.
- It has wings.

Explain why Oliver **cannot** use Sally's notes to identify the butterfly.

.... (1 mark)

(b) Ahmed drew a butterfly.
It is **not** a Common Blue.

Tick **ONE** feature of **Ahmed's** butterfly and describe how it is different from a Common Blue.



Feature: body ☐ wings ☐

This feature of **Ahmed's** butterfly is different because ....

.... (1 mark) the appropriate statement, they would then be directed to the next number where there were two additional statements, which in the following way would lead pupils first to the class, then to the lower systematic categories and eventually to the name of the plant species.

The study indicated that the application of dichotomous keys – when compared to traditional instructional teaching – developed situational and practical learning skills among pupils, rather than theoretical and verbal learning alone. The researchers reported that the benefits of dichotomous keys in comparison to traditional instructional teaching are that the principles of scientific inquiry are applied to the use of dichotomous keys. Since the activities are selected and created based on the experience and previous knowledge of pupils about plants, dichotomous keys make a greater contribution to the quality and durability of pupils' knowledge when compared to traditional instructional teaching. In the study, the pupils understood and applied their newly acquired knowledge to their previous knowledge in order to be as successful as possible in determining solutions. They adopted the principles of the scientific determination of plants using dichotomous keys, which influenced the quality of their knowledge.

Case study 2

In a recent study, Anđić et al. (2020) examined the contribution of the dichotomous digital key and the dichotomous printed key, to primary school pupils' (aged 13-14 years old) achievements, and the sustainability of biological knowledge about the systematisation and classification of plants at all cognitive levels. The dichotomous digital key was applied using m-learning with a tablet PC. Each plant was presented using text, images and sound. The information needed to determine each plant was obtained by reading, listening and watching. The software led pupils through the process of plant determination in its entirety, enabling pupils to become independent learners in determining the plants in question. In the case of the dichotomous printed key, it was created in the form of a script in A4 format and printed in colour.

The study reported that both the dichotomous digital key and the dichotomous printed key can be used in the constructivist learning of biology in primary school, because they were created on the basis of previous pupils' knowledge and encouraged them to independently explore the determination of plants. However, the dichotomous digital key can be better implemented in the constructivist teaching of biology in primary schools. The study found that those pupils who used the dichotomous digital key achieved more sustainable knowledge and had a more positive opinion than the pupils who used the dichotomous printed key, notably in relation to the contribution of the implemented dichotomous key to their desire to examine plants in their own surroundings and further afield.

Therefore, a lesson was produced to incorporate dichotomous keys in facilitating pupils to observe, compare, classify and identify plants.

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Lesson Plan

Classification - Plants

Using dichotomous keys in facilitating pupils to observe, compare, classify and identify plants

Pupils should be taught to: (i) describe how living things are classified into broad groups according to common observable characteristics and based on similarities and differences, including micro- organisms, plants and animals, and (ii) give reasons for classifying plants and animals based on specific characteristics.

Science – Key Stage 2 (Year 6)

NOTE: This lesson is designed to follow on from the related lesson on classifying and identifying animals.

Research recommendation(s) and rationale	The classification of plants represents one of the most challenging biological teaching topics. This topic is difficult for pupils to adopt because it requires the integration and application of knowledge in plant morphology, plant identification and plant systematics (Anđić et al., 2020; Maskour et al., 2016). Numerous studies have highlighted that pupils cannot identify the most common plant species in their own environment and do not understand their importance (a phenomenon known as Plant blindness) (Pany, 2014; Wandersee & Schussler, 2001). In particular, what makes the plant identification process more difficult is that there are many different plant species, and many are similar to each other (Huang et al., 2010). • Simplified biological keys. • Showing pupils how to use dichotomous keys - because they require fewer decisions in the determination process • keys for non-experts should not be unnecessarily simplistic or untechnical • Keys that are enjoyable to use are proven to be more effective (Stagg & Donkin, 2013; Stagg et al., 2015) Case study 1 Anđić et al. (2019) explored the effect of dichotomous keys on the quality and durability of the knowledge of 180 primary school pupils (aged 13-14 years old) in Montenegro, with regards to the classification of plants (Bryophyta, Pteridophyta, Gymnosperms and Angiosperms), as compared to traditional teaching methods. The dichotomous key was made in the form of an A4 brochure with colour photos of the plants. Several of the last pages of the brochure contained the illustrated and descriptive glossary. The dichotomous key began with two statements (e.g. – 'miniature plants on whose stems with seta and capsule formed, or plants with thallus….' and 'plants with different appearance….'). These statements referred to the morphological characteristics of plants. When a pupil selected the appropriate statement, they would then be directed to the next number where there were two additional statements, which in the following way would lead pupils first to the class, then to the lower systematic categories and eventually to the name of the plant species.
Lesson aim	To use dichotomous keys to help pupils to observe, compare, classify and identify plants
Learning objective	To use dichotomous keys as a way to classify plants.
Intended learning outcomes	At the end of the lesson, pupils will be able to: i. To be able to explain the major groups within the plant kingdom. ii. To use and create dichotomous keys that aid plant identification.

Lesson Plan

Classification - Plants

Using dichotomous keys in facilitating pupils to observe, compare, classify and identify plants

Pupils should be taught to: (i) describe how living things are classified into broad groups according to common observable characteristics and based on similarities and differences, including micro- organisms, plants and animals, and (ii) give reasons for classifying plants and animals based on specific characteristics.

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NOTE: This lesson is designed to follow on from the related lesson on classifying and identifying animals.

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Lesson aim	To use dichotomous keys to help pupils to observe, compare, classify and identify plants
Learning objective	To use dichotomous keys as a way to classify plants.
Intended learning outcomes	At the end of the lesson, pupils will be able to: i. To be able to explain the major groups within the plant kingdom. ii. To use and create dichotomous keys that aid plant identification.

	iii. To be able to explain why fungi are not plants and in fact belong to a different kingdom of life.
Scientific vocabulary	**Shared characteristics** – something that members of a group all have in common. **Subgroup** – when a group can be split into smaller groups. **Dichotomous** – when a group can be split into two distinct parts because there is an obvious difference between members of the group. **Angiosperms** – plants that have flowers and produce seeds **Gymnosperms** – plants that produce seeds without flowers e.g. conifers **Ferns** – make spores not seeds but do have roots, stem and leaves **Mosses** – make spores not seeds and do not have clear roots, stem, and leaves. **Algae** - a type of plant with no stems or leaves that grows in water or on damp surfaces.
Common Misconceptions	• mushrooms are plants • plants get their food from the soil • plants are flowering plants grown in pots with coloured petals and leaves and a stem • trees are not plants • all leaves are green • all stems are green • a trunk is not a stem • blossom is not a flower • plants and seeds are not alive as they cannot be seen to move • plants that grow from bulbs do not have seeds • all plants have flowers • plants eat food
Suggested lesson sequence and activities	**NOTE: This lesson is designed to follow on from the related lesson on classifying and identifying animals and using dichotomous keys.** Display the terms mammal, amphibian, reptile, fish, and birds on the board. Q: *What do these groups all have in common?* (A: They are all animals and they all have an internal skeleton so are vertebrates). Q: *What term do we use when members of a group have something in common?* (A: Shared characteristic) Now play *What am I?* Read out the key features from the table below and ask pupils to match the features to one of the headings. Then add a photo of a representative species from that group e.g. a salmon. Repeat until pupils have linked all the characteristics to each of the five groups.

Group	Body covering	Warm or cold blooded?	Lungs or gills?	Reproduction	Examples
Fish	Scales	Cold	Gills	Lay soft eggs in water	Sharks, trout, salmon
Amphibians	Moist skin	Cold	Gills then lungs	Lay soft eggs in water.	Frogs and newts
Reptiles	Dry scales	Cold	Lungs	Lay rubbery eggs on land (some live birth)	snakes, lizards, crocodiles
Birds	Feathers	Warm	Lungs	Lay hard shelled eggs on land	penguins, emus, owls
Mammals	Skin, most have hair	Warm	Lungs	Live birth. Feed young on milk.	humans, dogs, dolphins

Now show a picture of an insect or other invertebrate. Ask the pupils *what shared characteristic the invertebrate has with the other animals?* They are all animals. But *what does it not share?* It doesn't have an internal skeleton therefore it is an invertebrate.
Using the dichotomous key created last lesson, add a new question above the first question which asks *Does it have an internal skeleton?*

Now show a picture of a plant. Ask pupils *what shared characteristic does the plant have with the animals?* A: They are all living things. Explain that the plant is different to the animals because it can **photosynthesise** (make its own food from sunlight). Remind pupils of their previous work on food chains – plants are producers at the start of the food chain because they use energy from the sun to photosynthesise their food. Animals are consumers – they have to eat (consume) plants and/or other animals.
Add in a new question above the first question which asks *Does it photosynthesise?* No = Animal branch. Yes = Plants.

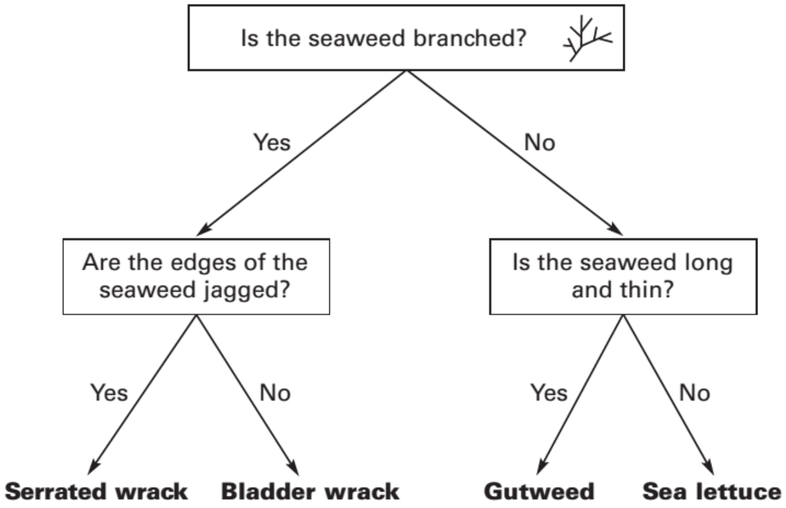
Explain that plants are actually a completely separate kingdom of life to animals. They are all living things or organisms because they can reproduce and they respire (need oxygen). Today we are going to learn about some of the major groups in the plant kingdom.

	Reiterate that the major groups in the animal kingdom are vertebrate and invertebrates. Then within the vertebrate group we had the five subgroups of mammals, reptiles, birds, amphibians and fish. Draw this out or use a visual. Explain that plants also have major subgroups. Give the pupils the plant key in pairs. Ask them to create a question for each dichotomous branching within the key e.g. An appropriate branching for the first split would be "*Does it produce seeds?*" Give pupils time to create the questions for each branching then take feedback of their ideas. Use this as a starting point to discuss the different groups within the plants e.g. **angiosperms** produce seeds and flowers whereas the **gymnosperms** produce seeds but do not have flowers. **Ferns** do not make seeds but they do have roots, stem and leaves whereas **mosses** do not have clear roots, stems and leaves. For examples, carry out an Internet image search using *dichotomous plant key* as the key words. Once you have agreed as a class on the questions on the key and discussed the features of each group, play a game of *What am I?* using species level examples. Support this with pictures e.g. "I have leaves, stem and roots but I don't make seeds, what am I?" A fern. Show pupils an image of a fern e.g. Christmas Fern (Polystichum acrostichoides), again use the Internet for examples of plant images. If possible, have multiple real-life examples (photographs if this is not possible) of flowering plants, gymnosperms (conifers), ferns and mosses for the pupils to explore and examine. Encourage pupils to look at the morphology of each one and to begin to spot the features common to each group but that there is variation in each group still e.g. all the angiosperms have flowers but that the flowers may differ a lot. For greater challenge encourage the pupils to look for similarities and differences between different ferns, noting the shared characteristics of leaves, stem and roots but that the shape of the leaves and size of the plants can vary. If possible, take the pupils out into the outdoor environment and ask them to identify an example of angiosperms, gymnosperms, ferns, and mosses. Once pupils are competent at spotting these major groups, introduce dichotomous keys for identification within a group e.g. for gymnosperms (conifers). Extension task / greater depth: A common misconception among pupils is that mushrooms are a type of plant. Return to the original key produced by the class which shows the separate kingdoms of plants and animals. Point out that mushrooms (fungi) do not photosynthesise and are therefore not part of the plant kingdom. Link this back to their prior knowledge of food chains – fungi are decomposers in the food chain, not producers.
Key questions	What are the shared characteristics within the group? What question could you ask to split the group into two subgroups? What are the shared characteristics of the …………? plant group?

Assessment suggestions	Constant use of verbal questioning throughout the activities to assess pupils' understanding and scaffold the process of creating their questions. For more formal assessment, use the old SATS questions below.
Resources **H&S considerations**	Variety of plant pictures and plants. Check the pupils do not put any plants or berries in their mouth.

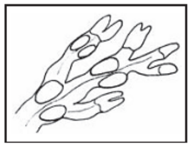
(a) Maria found different types of seaweed on the beach.

Her teacher has a key to identify the seaweeds.



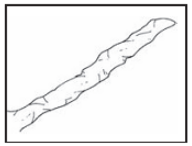
Use the key to identify the different seaweeds below.

Seaweed A has been done for you.



Seaweed A is

Bladder wrack

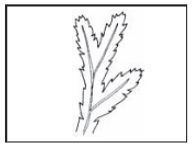


Seaweed B is

....

Seaweed C is

....



Seaweed D is

....

(1 mark)

(a) Fiona is in the garden. She wonders how she can find out the names of some of the plants.

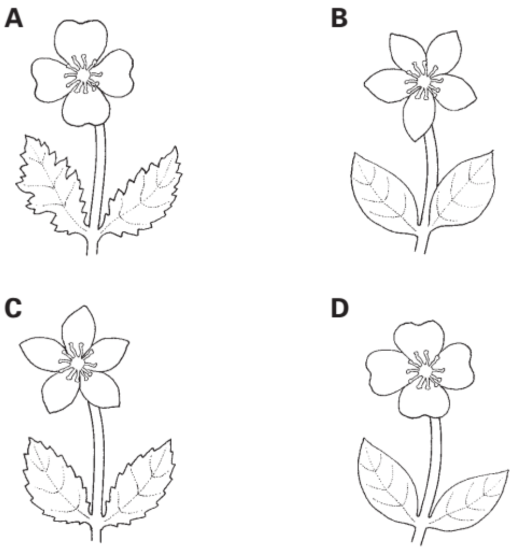
Tick **ONE** box to show how Fiona could find out the names of the plants.

Fiona could use a...

food chain.	☐	producer.	☐
fair test.	☐	key.	☐

(b) Fiona sorts the plants into groups to help her find out their names. The plants in one of her groups all have yellow flowers.

Plants with yellow flowers



Look at the group of plants with yellow flowers.
Fiona needs to sort these plants into two groups.

(i) Suggest a way these plants with yellow flowers could be sorted into two groups.

Group 1: Plants with yellow flowers and ....
....

Group 2: Plants with yellow flowers and ....
....

(ii) Write **A, B, C** or **D** in each box below to show how Fiona should sort the plants with yellow flowers into the two groups you gave above.

3bi 1 mark

Group 1 ☐ ☐

Group 2 ☐ ☐

3bii 1 mark

(c) Scientists sort plants into groups.
Tick **ONE** box to show why it is a good idea.

to compare plants with animals ☐

to see if a plant is a living thing ☐

in case a plant dies ☐

because there are many types of plant ☐

3c 1 mark

	iii. To be able to explain why fungi are not plants and in fact belong to a different kingdom of life.
Scientific vocabulary	**Shared characteristics** – something that members of a group all have in common. **Subgroup** – when a group can be split into smaller groups. **Dichotomous** – when a group can be split into two distinct parts because there is an obvious difference between members of the group. **Angiosperms** – plants that have flowers and produce seeds **Gymnosperms** – plants that produce seeds without flowers e.g. conifers **Ferns** – make spores not seeds but do have roots, stem and leaves **Mosses** – make spores not seeds and do not have clear roots, stem, and leaves. **Algae** - a type of plant with no stems or leaves that grows in water or on damp surfaces.
Common Misconceptions	• mushrooms are plants • plants get their food from the soil • plants are flowering plants grown in pots with coloured petals and leaves and a stem • trees are not plants • all leaves are green • all stems are green • a trunk is not a stem • blossom is not a flower • plants and seeds are not alive as they cannot be seen to move • plants that grow from bulbs do not have seeds • all plants have flowers • plants eat food
Suggested lesson sequence and activities	**NOTE: This lesson is designed to follow on from the related lesson on classifying and identifying animals and using dichotomous keys.** Display the terms mammal, amphibian, reptile, fish, and birds on the board. Q: *What do these groups all have in common?* (A: They are all animals and they all have an internal skeleton so are vertebrates). Q: *What term do we use when members of a group have something in common?* (A: Shared characteristic) Now play *What am I?* Read out the key features from the table below and ask pupils to match the features to one of the headings. Then add a photo of a representative species from that group e.g. a salmon. Repeat until pupils have linked all the characteristics to each of the five groups.

Group	Body covering	Warm or cold blooded?	Lungs or gills?	Reproduction	Examples
Fish	Scales	Cold	Gills	Lay soft eggs in water	Sharks, trout, salmon
Amphibians	Moist skin	Cold	Gills then lungs	Lay soft eggs in water.	Frogs and newts
Reptiles	Dry scales	Cold	Lungs	Lay rubbery eggs on land (some live birth)	snakes, lizards, crocodiles
Birds	Feathers	Warm	Lungs	Lay hard shelled eggs on land	penguins, emus, owls
Mammals	Skin, most have hair	Warm	Lungs	Live birth. Feed young on milk.	humans, dogs, dolphins

Now show a picture of an insect or other invertebrate. Ask the pupils *what shared characteristic the invertebrate has with the other animals?* They are all animals. But *what does it not share?* It doesn't have an internal skeleton therefore it is an invertebrate.
Using the dichotomous key created last lesson, add a new question above the first question which asks *Does it have an internal skeleton?*

Now show a picture of a plant. Ask pupils *what shared characteristic does the plant have with the animals?* A: They are all living things. Explain that the plant is different to the animals because it can **photosynthesise** (make its own food from sunlight). Remind pupils of their previous work on food chains – plants are producers at the start of the food chain because they use energy from the sun to photosynthesise their food. Animals are consumers – they have to eat (consume) plants and/or other animals.
Add in a new question above the first question which asks *Does it photosynthesise?* No = Animal branch. Yes = Plants.

Explain that plants are actually a completely separate kingdom of life to animals. They are all living things or organisms because they can reproduce and they respire (need oxygen). Today we are going to learn about some of the major groups in the plant kingdom.

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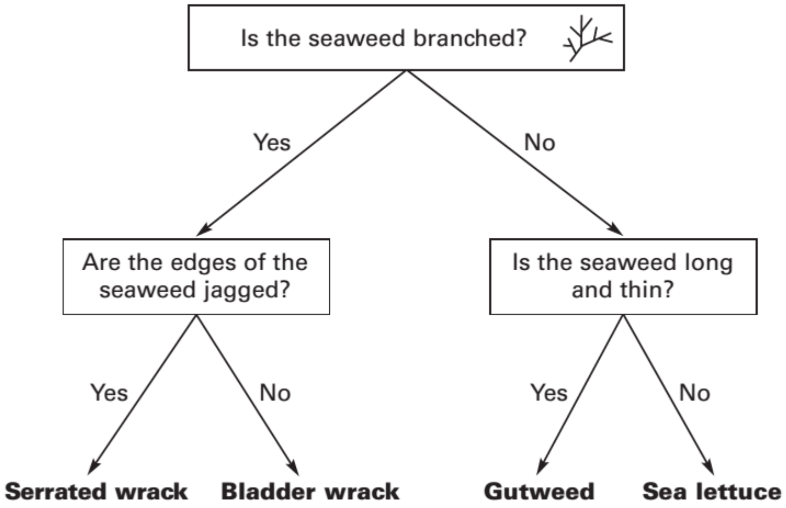

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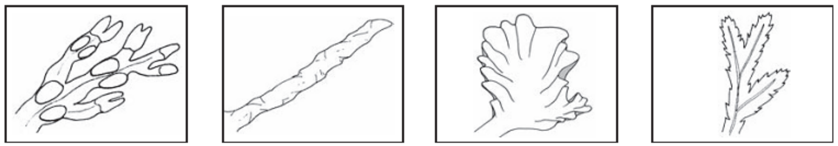


Seaweed A is	**Seaweed B** is	**Seaweed C** is	**Seaweed D** is	
Bladder wrack	....	....	....	(1 mark)

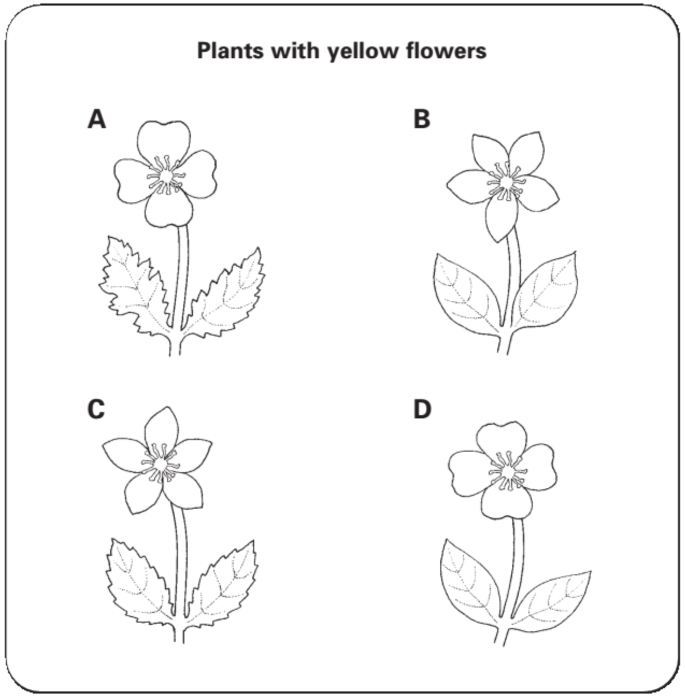
(a) Fiona is in the garden. She wonders how she can find out the names of some of the plants.

Tick **ONE** box to show how Fiona could find out the names of the plants.

Fiona could use a...

food chain.	☐	producer.	☐
fair test.	☐	key.	☐

(b) Fiona sorts the plants into groups to help her find out their names. The plants in one of her groups all have yellow flowers.



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(i) Suggest a way these plants with yellow flowers could be sorted into two groups.

Group 1: Plants with yellow flowers and ....

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Group 2: Plants with yellow flowers and ....

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(ii) Write **A**, **B**, **C** or **D** in each box below to show how Fiona should sort the plants with yellow flowers into the two groups you gave above.

3bi 1 mark

Group 1	Group 2
☐ ☐	☐ ☐

3bii 1 mark

(c) Scientists sort plants into groups.
Tick **ONE** box to show why it is a good idea.

to compare plants with animals ☐

to see if a plant is a living thing ☐

in case a plant dies ☐

because there are many types of plant ☐

3c 1 mark

Research Summary

Evolution

Using storybooks to teach about evolutionary theory

Pupils should be taught to: recognise that living things have changed over time and that fossils provide information about living things that inhabited the Earth millions of years ago

Science – KS2 (Year 6)

Statement of issue

Over 30 years of research shows misconceptions about evolution and natural selection are pervasive across society from primary pupils to adults (Jungwirth, 1975; MacFadden et al., 2007; Prinou et al., 2008). Gregory (2009) proposes two reasons why natural selection is difficult to understand, (i) it requires acceptance of the historical fact of evolution, and (ii) as evolution is a new addition to the curriculum, any prior learning was limited. Supporting Gregory's (2009) proposal, limited knowledge of evolution is commonly reported by non-science specialist teachers and pre-service teachers who say that they would feel more prepared to teach about evolution if they had more knowledge and understanding about it (Borgerding et al., 2015; Kover & Hogge, 2017; Tidon & Lewontin, 2004).

Requests for more knowledge led researchers like Fail (2008) to argue for the inclusion of evolution in the primary science curriculum, as evolutionary theory connects a wide array of science concepts. Hermann (2011) further suggested that learning the fundamental concepts of evolutionary theory, as part of pupils' primary education, would support the teaching of evolution as part of secondary education. Indeed, in 2014 the topic of evolution was included in the primary science curriculum in England.

Main findings from the research

Storybooks are a widely used resource, as they are pupil friendly and support a shared approach to learning (Kelemen et al., 2014). The addition of pictures to enrich the narrative has also been shown to help reduce the cognitive load on pupils (Mayer & Moreno, 2003).

What the research shows

Shtulman et al. (2016) assessed the effectiveness of using a brief 10-minute storybook to teach about evolution. Two groups of pupils took part in the study, 52 Year 1 to Year 3 pupils (who were classified as younger pupils) and 44 Year 5 to Year 7 pupils (who were classified as older pupils). Both groups were taught using a picture storybook, which was written by the researchers and based on best practice. For example, research demonstrates that pupils treat only functional traits as heritable – a functional trait could be the colour of a bird's plumage for camouflage (Springer & Keil, 1989; Ware & Gelman, 2014). The storybook featured pictures of animals and one of their traits with an explanation of the origin of the trait. There were two illustrated examples given for each of the five evolutionary principles: inheritance, differential survival, differential reproduction, population change and variation. The storybook also contained both the pre-test and post-test questions, which presented a picture of an animal, a description of one of its traits, and a prompt for the pupil to explain where the trait came from. To further examine pupils' understanding, the researchers interviewed pupils' explanations of adaptation after hearing the story.

They found all pupils benefited from the storybook lesson, however, the older pupils benefited statistically significantly more than the younger pupils. Analysis revealed that after the storybook lesson, the older pupils were statistically significantly more likely to correctly use all five evolutionary principles in their explanations of evolution. Therefore demonstrating that older pupils can be taught about evolution effectively using a storybook-based lesson.

Browning and Hohenstein (2015) examined the effectiveness of using reading of two different types of text to teach about evolution. They compared the effectiveness of learning from narrative text (story telling) and expository text (facts presented in an authoritative way). Based on previous research by Doyle and Carter (2003), the researchers suggested that learning from narrative text engages pupils' imagination and may better support pupils to understand challenging concepts like variation that make evolution difficult to understand. The narrative text contained cartoon pictures with text explaining the principles of evolution, together with photographs that were integrated within the text. Both texts were created by the researchers and based on the chronology of *how the first humans arrived on Earth.* The text was adapted for reading ability, and a simplified version was used with younger pupils. Three classes took part: 16 Year 1 pupils, 21 Year 2 pupils and 25 Year 3 pupils; half of each class individually read the narrative text and half read the expository text. Due to the age of the pupils, they were not expected to read without help because the main focus was on the content. Pupils' understanding was measured pre-and-post reading with interview-style questions to explore their understanding of evolution from the texts that they read. It was found that the pupils who read the narrative text demonstrated statistically significantly better understanding of evolution than the pupils who read the expository text. Further analysis showed that the pupils who engaged with questions about the narrative text were able to give better-informed and relevant answers to the questions, with a more specific focus on evolutionary principles, than the pupils who read the expository text. The researchers also found that older pupils showed the greatest benefit from reading the narrative text over the expository text. Furthermore, it was found that pre-existing knowledge of evolution did not influence the results which suggests that reading narrative text supports pupils learning about evolutionary theory regardless of their previous levels of knowledge.

Avoid anthropomorphic language

Legare et al. (2013) manipulated the language a storybook used to describe evolutionary change, according to three conditions, (i) needs-based explanations, that reference basic survival needs (e.g. 'some eagles *wanted* to change, and they became a little bit bigger' p.192) (ii) anthropomorphic (i.e. desire-based) explanations, that referenced animals mental state (e.g. 'some eagles *needed* to change so that they were a little bit bigger' p.194) (iii) scientifically accurate natural selection explanations (e.g. 'some eagles *were* a little bit bigger' p.195). Each storybook varied according to the three conditions above, had pictures, and was based on the evolutionary change of three different birds. They interviewed 88 Year 1 to Year 7 pupils pre-and-post listening to a story read by the researcher. They found that pupils showed a statistically significantly greater understanding of evolutionary change when they listened to the story that used either needs-based or natural selection-focused language. Those pupils who listened to the story with anthropomorphic language performed statistically significantly poorer than the pupils who listened to the version of the story that used either the needs-based or natural selection-focused explanations. In common with the Browning and Hohenstein (2015) findings, older pupils performed statistically significantly better than younger pupils. Therefore, it is important when selecting a storybook to *avoid* anthropomorphic language that references animals' mental states, such as 'wanting', 'liking',or 'trying'.

Long-lasting knowledge

Kelemen et al. (2014) explored the effectiveness of a picture storybook (written by the researchers) for young pupils to learn about evolutionary theory and tested pupils' retention of knowledge with a follow-up lesson. The researchers wrote a story about natural selection of a fictional mammalian population, '*the pilosas'*, who were affected by their insect food source moving out of reach deeper underground. The story explored the variability in the pilosas' trunk sizes and how this impacted their survival and reproduction. The book was called *How the piloses evolved skinny noses*. They read the 10-minute story to 61 Year 1 to Year 3 pupils. Pupils understanding was measured pre-and-post listening to the story and then again three months later. They found a statistically significant improvement in all pupils' knowledge of evolutionary theory after listening to the story, with knowledge being retained over time at the same level as the post-test pupils. Therefore, listening to a story about fictional mammals can support pupils in developing long-term knowledge of evolutionary theory.

Research demonstrates that older pupils (Year 6) benefit the most from using narrative text to learn about evolutionary theory (Browning & Hohenstein, 2015; Legare et al., 2013). Fictional and non-fictional narrative texts are effective ways to teach evolutionary theory, and narrative texts are more effective than expository texts (Browning & Hohenstein, 2015). It is important to avoid anthropomorphic language that makes reference to animals' mental states and focus on stories that use either natural selection-focused, or needs-based, language (Legare et al., 2013). Whilst 10 minutes of reading or listening to a story can be effective, research shows that when this is combined with an exploration of pupils' thoughts after reading the story it is even more effective (Browning & Hohenstein, 2015; Shtulman et al., 2016) and supports longer-term retention of knowledge about evolutionary processes (Kelemen et al., 2014).

Therefore, a lesson was produced to incorporate narrative text into teaching about evolution.

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Lesson Plan

Evolution

Using storybooks to teach about evolutionary theory

Pupils should be taught to: recognise that living things have changed over time and that fossils provide information about living things that inhabited the Earth millions of years ago Science – KS2 (Year 6)

Research recommendation(s) and rationale	Research demonstrates that older pupils (Year 6) benefit the most from using narrative text to learn about evolutionary theory (Browning & Hohenstein, 2015; Legare et al., 2013). Fictional and non-fictional narrative texts are effective ways to teach evolutionary theory, and narrative texts are more effective than expository texts (Browning & Hohenstein, 2015). It is important to avoid anthropomorphic language that makes reference to animals' mental states and focus on stories that use either natural selection-focused, or needs-based, language (Legare et al., 2013). Whilst 10 minutes of reading or listening to a story can be effective, research shows that when this is combined with an exploration of pupils' thoughts after reading the story it is even more effective (Browning & Hohenstein, 2015; Shtulman et al., 2016) and supports longer-term retention of knowledge about evolutionary processes (Kelemen et al., 2014).
Lesson aim	To introduce the theory of evolution using a text.
Learning objective	To introduce some of the key vocabulary for this unit. To give pupils an overview of the basics of evolutionary theory. To address some of the common misconceptions around evolution.
Intended learning outcomes	At the end of the lesson, pupils will be able to: i. Explain that **random mutation** causes **variation** in a **population.** ii. Explain that **natural selection** in an environment means some individuals are more likely to **reproduce** than others. iii. Explain that over many generations the effect of natural selection can cause species to change.
Scientific vocabulary	**Random mutuation** – when mistakes in the copying of DNA causes differences in the genetic code. **Genetic code / DNA** – the instructions for how any organism is made. **Organism** – any living thing. **Variation** – when i dividuals in a population are slightly different. **Population** – a group of individuals all living together in one place / area / environment. **Generation** – a group of organisms all born and living in the ame period of time. **Natural selection** – when something about the environment means some individuals are more likely to survive and reproduce than others. **Adaptation** – when a species has a certain behaviour or physical feature that helps it survive in its environment. **Trait** - a particular characteristic, quality, or tendency that someone or something has.
Common Misconceptions	• adaptation occurs during an animal's lifetime: giraffes' necks stretch during their lifetime to reach higher leaves and animals living in cold environments grow thick fur during their life

	• there is always plenty of food for wild animals • humans are not animals • a fossil is an actual piece of the extinct animal or plant • amphibians and reptiles are the same. • an animal's habitat is like its 'home' • offspring most resemble their parents of the same sex, so that sons look like fathers
Suggested lesson sequence and activities	**Discussion Starter (Misconception Identifier!)** Show a picture of any animal or plant which clearly displays an adaptation that makes it suit its environment (e.g. a giraffe eating leaves from the top of a tree). Pose the question "How did giraffes become adapted to eating leaves from the top of the trees?" Key misconceptions to look out for – They needed longer necks so their necks grew. **Starter Activity:** Ask pupils to form one or two long lines, one behind the other (ideally at least 10 pupils per line). Give each person in the line a pencil. Explain that they are going to create a new generation of their organism by copying their genetic code. Give the person at the head of the line a random string of the letters A, T, C and G in any order such as ATCGTAGTCGGTACCGGAT written on the top Post-It note in a pad of Post-Its. When you say go, they have to copy it quickly onto the Post-It below, peel off the top post it and pass the pack to the next person in the line (so that they keep the original Post-It but pass on their copy). The next person then copies the top Post-It onto the Post-It below, peels off and keeps the top one and passes the new one on. This should be done quickly so that the pupils don't have time to copy the code too accurately! **Discussion:** Explain that some organisms, such as bacteria, **reproduce** by creating copies of their genetic code or DNA. Each new copy on a Post-It note represents a new **generation**. Now compare the Post-It notes to the original code. Read out the code and ask pupils to highlight any parts of their code that do not match the original code. Explain that these mistakes are **random mutations** in the DNA. These mistakes mean that these individuals will be slightly different in some way. These slight differences are know as **variation.** So within the Post-It note population, there is variation – some individuals have a slightly different genetic code which means they *may* have slightly different physical **traits** or behavioural **traits**. Introduce the text: *On the Origin of Species* retold and illustrated by Sabina Radeva. Read pages 1, 2 and 3. On page 3 where it mentions Jean-Baptiste Lamarck's theory (a common misconception) link it back to the starter activity with the post its – in any population there will be variation. So in a population of giraffes there will be some variation in neck length. Continue reading to page 8 (variation in rabbits). Highlight that the random mistakes (random mutations) mean the idividuals are slightly different – the variation in the population. Read on to page 17 (finches).

Activity: Tell pupils that the code on their Post-It note is the code for a species of insect. Most of the insects are light green apart from those that have random mutations. Some of these mutations make the insects lighter yellowy-green and some make the insects darker green. Give pupils the appropriate coloured 'insect' (a circle of paper). Now explain that all these insects live on a leaf. Pupils put their insects onto a giant green leaf (which is a close colour to the darker green insects). Reiterate that the random mutation (the copying mistakes) mean there is variation in the population of the insects. One form of variation is their colour. Now explain that a predator that eats the insects is a bird (you may want to use a puppet). Explain that the bird spots the yellow insects very easily but is harder to spot the dark green. It also eats some of the original light green. Remove some insects that get eaten, but more yellow, some light green and not many dark green. Now explain that the surviving insects reproduce. Most of the insects will reproduce offspring like themselves (same colour) but some random mutaions (mistakes in the copying) will mean the offspring are a different colour. Replace each insect on the leaf. Most with the same colour and one or two with a different colour. Explain that there is still variation in this new generation (the different colours). Reintroduce the predator. Reiterate that the yellow are more likely to get eaten, some of the light green and not many of the dark green. Repeat the reproduction process. A new generation. Over many many generations the population of insects will be largely darker green – they have become adapted to their green environment because of natural selection.

Recap the key aspects of the process with the pupils:

- Mistakes is copying the genetic code mean there is **variation** in a **population**
- This may mean some individuals are more suited to their environment
- These individuals are more likely to survive and reproduce – **natural selection**
- Over many generations, the population will change so that more members have the useful **adaptation** – this is **evolution**.

Greater depth – changes to the environment can change the selection pressure e.g. a drought. If yellow insects are better at surviing drought then this new natural selection would favour yellow insects. If the drought continues, over many generations the population would become predominantly yellow.

Independent task: pupils can story board the evolution of the insects (you could take photos of each stage or they could draw it) and add a brief explanation under each picture.

Discussion: Link this back to the original giraffe picture. Where was the variation? (some giraffes had slightly longer necks than others). What was the selection pressure? (being able to reach leaves that others could not was an advantage so they were more likely to survive and reproduce). Each generation there would still be variation in neck length, but if a long neck is always an advantage then over many many generations giraffes adapted and had longer necks than their ancestors.

Useful Links:
This provides a brilliant, clear explanation of Evolution:

	What Is Evolution? What Is Natural Selection? What Is The Evidence For Evolution? This shows how the selection pressure on a population of finches changed the average beak size in the next generation: https://www.youtube.com/watch?v=mcM23M-CCog
Key questions	Why are individuals in a population slightly different to each other? (Because random mutation, small mistakes in the copying process, cause some individuals to be slightly different). Why are some individuals more likely to survive and reproduce? (because natural selection favours some variation e.g. colour more than another) Can organisms choose to adapt? (no, the variation is random, but the selection pressure will mean some have an advantage and are more likely to survive, reproduce and pass on this advantage).
Assessment suggestions	Assess their explanations of the process – these could be written or verbal (possibly use video evidence?)
Resources **H&S considerations**	Yellow, light green and dark green circles of paper. A giant dark green paper leaf. Bird puppet optional. **Book:** *On the Origin of Species* retold and illustrated by Sabina Radeva. ISBN-10: 0141388501; ISBN-13: 978-0141388502 None beyond normal classroom H&S considerations.

Research Summary

Light

Using a constructivist approach to teach how we see things

Pupils should be taught to:

- use the idea that light travels in straight lines to explain that objects are seen because they give out or reflect light into the eye
- explain that we see things because light travels from light sources to our eyes or from light sources to objects and then to our eyes

Science – KS2 (Year 6)

RESEARCH TEACHING

Statement of issue

In primary science, the topic of light is often cited as containing several challenging concepts for pupils to learn (Atwood et al., 2005; Krall et al., 2009; Van Zee et al., 2005). Heywood (2005) examined pre-service primary teachers' knowledge of light, showing that at the core of the topic is the contrast between pupils' personal experience of how they see (i.e. human perception) with the requirement for the topic to be explained through abstract mechanisms in a static or stationary manner. The challenge is how to resolve personal and scientific knowledge.

Main findings from the research

To best address the gap highlighted by between pupils' personal experience of light and vision (i.e. how we see) with the abstract mechanisms for how light travels to the eye, research suggests that the teacher adopt a constructivist approach (Heywood, 2005).

What is a constructivist approach?

Constructivism is an educational theory that assumes pupils construct their knowledge. Constructivism assumes that pupil's knowledge and understanding is based on their prior experiences. This is important within the context of light, as pupils come with their own personal experience and explanations for how we see things.

What does constructivism look like in practice?

The role of the teacher is to support pupils in making their pre-existing conceptions and misconceptions explicit – so to get the learners' ideas *out in the open*. Learners are then prompted to focus on these and helped to correctly build (or rebuild) the correct scientific knowledge and understanding (Thurston et al., 2006).

How best can we support pupils scientific concept development?

1) **Use a constructivist approach.**

Evidence: Thurston et al., (2006) adopted a constructivist approach and explored the topic of light with Y5 pupils in Scotland. The purpose was to establish if a constructivist approach could improve pupils' knowledge of scientific concepts. A combination of building, scaffolding, and practical activities was adopted. Knowledge was measured pre- and post-approach, and a statistically significant improvement in scientific concept knowledge was demonstrated.

2) **Establish pupils' prior knowledge – use this to direct lesson planning.**

Evidence: Preston et al. (2006) encouraged pre-service primary teachers to adopt a constructivist approach to teach primary science and technology topics during their school placements, finding that the lessons were effective in increasing pupil knowledge of the scientific concepts. The key to their success was establishing pupils' prior knowledge and targeting the lesson plan based on this information. It is better to actively engage pupils by eliciting pupils' existing ideas about scientific concepts and helping them to reframe these (Harlen, 1996). Given that primary pupils will have an everyday experience of light and vision, it eliciting their existing ideas and using them as the starting point in lessons is important (Tytler, 2002).

3) Encourage social interaction among pupils.

Evidence: Amin et al., (2014) conducted a review of research looking at the role of social interaction on scientific concept learning. They found that social interaction influences how pupils are able to engage with scientific concepts. For example, Herrenkohl et al. (1999) encouraged pupils to take on roles to help scaffold their scientific inquiries; pre-and post-tests demonstrated improved understanding of the scientific concepts. Hatano & Inagaki (1991) encouraged pupils to discuss their predictions with each other and were better able to explain the concepts. Therefore, it is essential to optimise opportunities for discussion within the class - either whole class or in small groups (Tytler, 2014).

4) Promoting a deep understanding of a scientific concept takes time.

Evidence: One of the key pieces of feedback that researchers receive when teachers (pre-and in-service) adopt a constructivist approach to teach science, is that promoting a deep understanding of a concept takes time (Preston et al., 2006). This can be challenging given the amount of time available for science lessons in schools. However, a constructivist approach can be used to plan connected and meaningful learning experiences.

The problem of multiple understandings

As light is closely linked to human perception (and personal experience), the topic of light lends itself to common sense or everyday explanations that might be flawed. This can be challenging when trying to teach scientific concept as pupils may hold multiple and conflicting understandings (Jenkins, 2000). The persistence of incorrect ideas can be problematic for a constructivist approach and research suggests that the key is to identify the misconceptions and support pupils to construct or reconstruct the correct scientific explanations (Jenkins, 2000; Skamp & Preston, 2017).

In the light topic, it has been shown that primary pupils do not understand how we see objects (Fetherstonhaugh, 1990; Osborne et al., 1990). Therefore, pupils need to be supported in understanding that *light reflects off objects and travels in straight lines into our eyes*. Therefore, when adopting a constructivist approach, it is important to first actively establish pupils' prior knowledge about how they think we see things and then use this as the starting point for encouraging pupil disucussion and giving them time to process new information and think through their ideas.

Therefore, a lesson was produced adopting a constructivist approach for teaching how we see things.

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Lesson Plan

Light

Using a constructivist approach to teach that light travels in straight lines

Pupils should be taught to: recognise that light appears to travel in straight lines

Science – KS2 (Year 6)

Research recommendation(s) and rationale	Research suggests that pupils find light difficult to understand due to the combination of human experiences of vision and abstract mechanisms that we use to explain the science (Heywood, 2005). Pupils struggle to make the connection between the light source, the object and the eye (i.e. light travels in straight lines; Fetherstonhaugh, 1990; Osborne et al., 1990). Research suggests that an effective way to encourage pupils to learn about light is for them to recognise that light appears to travel in straight lines by teachers adopting a constructivist approach (Preston et al., 2006; Thurston et al., 2006). Teachers can do this by first actively establishing pupils' prior knowledge, using this to inform planning (Preston et al., 2006), optimising opportunities for social interaction and discussion (Tytler, 2012), and remembering that a deep understanding of concepts takes time (Preston et al., 2006).
Lesson aim	To use a constructivist approach to learn about how we see things.
Learning objective	To understand that light reflects off objects and travels in straight lines into our eyes.
Intended learning outcomes	At the end of the lesson, pupils will be able to: i. State, when asked, that we see things when light reflects off objects and into our eyes. ii. Explain the connection between the object and the eye (we see things because…).
Scientific vocabulary	Reflection – when light reflects (bounces) off an object. Opaque – a material that does not allow light to pass though it. Translucent – a material that allows some light to pass through but objects cannot be seen clearly through it. Transparent – a material that allows light to pass through and objects can be seen clearly though it.
Suggested lesson sequence and activities	**A. Following the constructivist approach, establish prior knowledge, using an initial assessment activity.** This is to establish what knowledge has been retained from Year 3, and what misconceptions may have developed since then. Research suggests it is important to actively engage pupils (Preston, et al., 2006). Ask pupils to draw a picture of themselves showing how they think we see an object e.g. a book. Look for drawings that show light as coming from the eye to the object – this is a misconception. **B. Help the pupils to know and understand that light travels *from* a light source into our eyes.** Using small torches in a dimly lit area, ask the pupils to compare how well they see when the torch is lit and when it is not. Ask them to draw a picture of what they think is happening when we see the light from the torch and discuss this in small groups. **C. Help the pupils to know and understand that we see things because light reflects off objects into our eyes.** Use pieces of aluminium foil – shiny side up. Ask the pupils to shine the torches onto the foil and explain what they see. Ask them to draw a

	picture of what they think is happening to the light from the torch. Repeat with other coloured, reflective objects e.g. a smooth, plastic object. Encourage the pupils to discuss their ideas in groups. **Common misconceptions** include: • we see objects because light travels from our eyes to the object, (the arrows will come from the eyes not into the eyes). • we can still see even where there is an absence of any light, **Initial assessment:** Give pupils the first diagram (Assessment suggestions) . Ask them to explain how the driver can see the light on the bike - they must include arrows to show the direction the light travels. This will identify what pupils already know and highlight any misconceptions. **Activity 1:** After collecting their responses, make the classroom as dark as possible and turn on a torch. Ask the pupils where they think the light is coming from. Establish with them that the torch is a source of light because it gives out light. Now shine the torch light onto a small mirror and use it to light up an object in a different direction to the original torch beam. Ask the pupils, "Is the mirror the light source?" The answer is no. So, help them to understand that the light from the torch is being reflected by the mirror. **Task 1**: Give pupils a list of different light sources and other objects that reflect light and ask them to sort them. Each group should then present their findings and justify their choices. Be sure to include the Moon in this activity. As pupils present their feedback be sure to use questioning to challenge any misconceptions, particularly around the Moon and Sun. It may help to use a quick simulation of the Sun as a light source (a torch) and the Moon as a surface that reflects light (e.g., a pingpong ball). **Safety note:** do not use a powerful torch. While it will make for a better demonstration, it may accidentally shine into pupils' eyes. You can draw their attention to the reason you are using a weak torch and remind them that we should not shine lights into our eyes or look directly at very bright light sources, especially the Sun. **Activity 2:** How do we see? Reiterate that we have said that the torch is the source of the light so the light is travelling *from* the source. We know that the light hits the mirror and is reflected. So, how do we see it? In the darkened room again, set up the torch shining onto the mirror at an angle so that the light is reflected at an angle, not directly back at the torch. Now, ask one pupil to hold up a large piece of card in front of their face, blocking their view of the torch light. Can they still see the light? No. Can the other pupils see the light shining onto the card (the side away from the pupil)? Yes. So why can the child no longer see the torch? Because we have stopped the light from reaching their eyes. We see because light travels into our eyes.

Key questions	What is the light source? Where is the light coming from? Why can they see the object? Is the light reflecting off anything? Is the mirror/______ a light source? **Further Questions:** What would happen if we switched off the light source and there was no other light source in the room? Would we still see? No, because we need some light to reach our eyes in order to see. What if there is light from the window? Is the window a light source? No, the un outside the window is the light source, but the transparent window is allowing light into the room because light can pass through transparent objects. The card we used earlier was opaque – light cannot pass through it. Some items are translucent - they allow some light to pass through.

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<td>Assessment suggestions</td>
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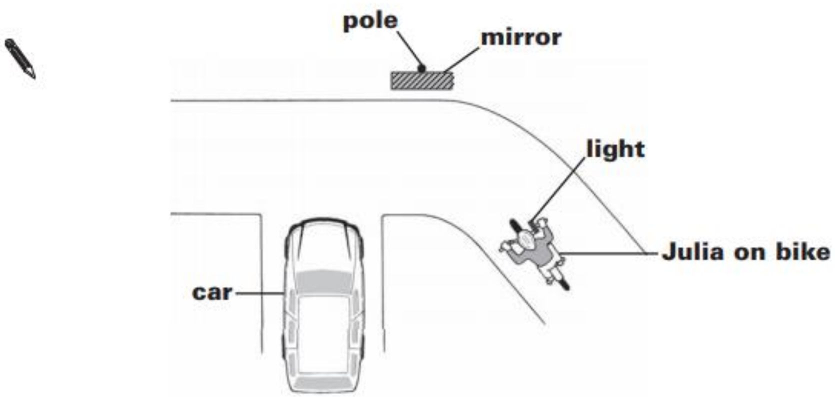
Initial assessment: Give pupils this diagram. Ask them to explain how the driver can see the light on the bike and they must include how the light travels. This will identify what pupils already know and highlight any misconceptions.

Julia's house is near a bend in the road. There is a mirror on a pole so car drivers can see people coming round the bend.

Draw **TWO** arrows on the diagram below to show the direction light travels for the car driver to see the light on Julia's bike.



Now return to the original assessment diagram. Recap our findings: We know light comes from the source. We know light can reflect (bounce) off objects (e.g. the mirror) and we know that light travels into our eyes. Use this to model aloud the process for drawing the correct arrows to show how the object is seen. Be sure to show to explain that light bounces off all objects, not just mirrors.

Present a new and slightly different diagram to complete. This time have a different object and light source in the picture. Ask pupils to discuss in small groups how the person can see the object. Each group should feed back their suggestions and discuss disparities. Be sure to then guide them through the drawing process voicing out loud your thought processes.

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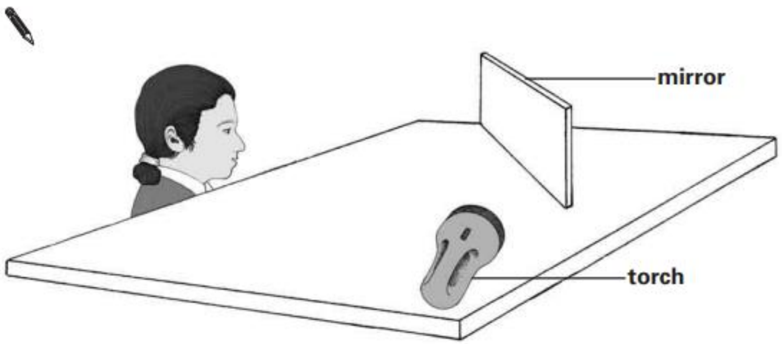
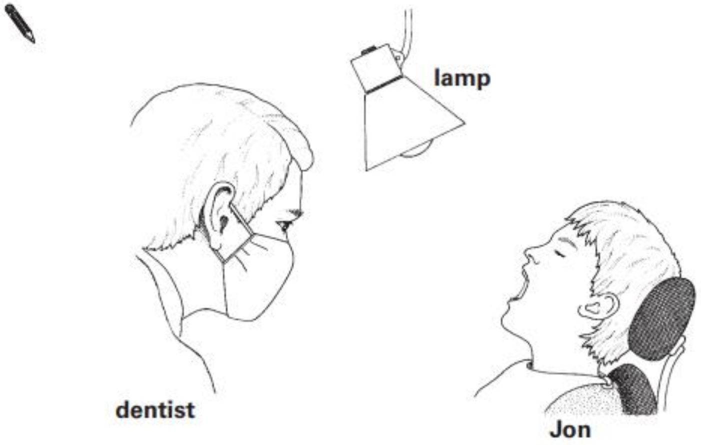
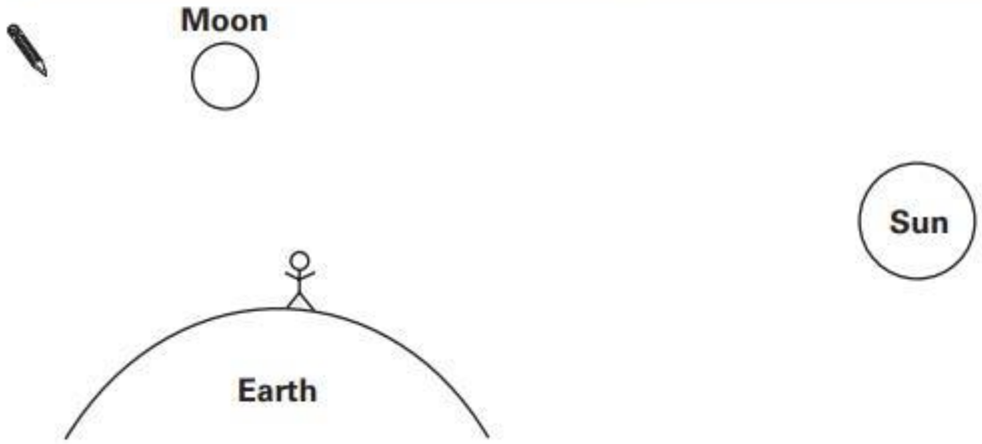
	The picture below shows Sanna looking at the torch light reflected in a mirror. Draw **TWO arrows** to show the direction the light must travel for Sanna to see light from the torch in the mirror. 

	The dentist uses a lamp to see Jon's teeth clearly. Draw **TWO** arrows on the diagram below to show the direction light travels for the dentist to see Jon's teeth. 

	Draw **TWO** arrows on the diagram below to show the direction light travels for the person on the Earth to be able to see the Moon. 
Resources **H&S considerations**	Torches, objects for making shadows. Remember spare batteries for torches, activities will work better with bright torches. Other resources are dependent on pupils' prior knowledge, e.g. ribbon, mirrors, carboard, scissors, cutting board (periscope making), flexible opaque tubes. Hazards: batteries, bright or flashing lights. Ensure all activities are carried out in a safe and calm manner and follow all your school's health and safety protocols. Please discuss health and safety with your mentor.