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| **Unit title: Cells, tissues, organs, organ systems and movement** |
| **Synopsis: *In this section put the why, what and how of the topic.*** | **What the research tells us: *In this section put an overview of what the research from Best Evidence tells us.*** |
| **Why are we teaching this content?** Cells are a fundamental structure in living things. The interactions between cells lead to tissues, organs, organs systems and whole organisms which are studied through different models. The interaction between whole organisms is explored in Interdependence. So, cells are a key step in the theme of scale (from particles to global systems).  Understanding of cells and the structures they form is a threshold topic for multiple other topics. The relationship between particles and cells addresses several misconceptions that often arise. This is explicitly addressed through the structure of the cell and also through organ systems that distribute particles to cells and remove non-living waste products. We introduce the relationship between structure and function / properties. This theme is revisited many times in many contexts.  Using scientific apparatus to see what we cannot see using our eyes is introduced through what we can see with our eyes and what we can see with a **light** microscope. This builds on Particles where macro properties are explained with a model.  **What are we teaching?** **AQA:**Identify the principal features of a onion cells and describe their functions  **Know:** Multicellular organisms are composed of cells which are organised into tissues, organs and systems to carry out life processes. There are many types of cell. Each has a different structure or feature so it can do a specific job. **Facts:** Both plant and animal cells have a cell membrane, nucleus, cytoplasm and mitochondria. Plant cells also have a cell wall, chloroplasts and usually a permanent vacuole.  **Skill:** Use a light microscope to observe and draw cells **Apply:** Explain why multi-cellular organisms need organ systems to keep their cells alive.  Suggest what kind of tissue or organism a cell is part of, based on its features.  Explain how to use a microscope to identify and compare different types of cells.  Explain how uni-cellular organisms are adapted to carry out functions that in multi-cellular organisms are done by different types of cell. Deduce general patterns about how the structure of different cells is related to their function.   **How are we teaching it (broadly)?** Students explore the structure of living things using light microscopes and using slides that they have prepared for themselves and pre-prepared slides (to see the ubiquitous nature of cells). **Writing methods to accompany practicals are modelled here and students make their first attempts at writing methods. The importance of precise and concise scientific methods is explored in the context of the scientific method.**  A model is introduced that relates a cell to a simple factory. This helps students to understand how different organelles are inter-linked and how the living cell relates to the non-living. Models of cells, tissues, organs and organ systems are used to explore the relationship between these structures and particles (e.g. using ice cube bags to represent tissues, layers of ice cube bags for organs etc). This helps to embed the theme of scale and avoids a series of misconceptions.  Different specialised cells are introduced and their structure related to their functions.  Diffusion is revisited in the context of the cell and related to the processes that occur within them; explicit details of reactions are not required although the fact that chemical reactions occur in cells is required.  The need for specialised organs and organ systems is then explained simply in terms of the rate of diffusion. Other factors that make complex systems necessary are also explored. Adaptations of uni-cellular organisms are explored (e.g. in the context of diffusion). Movement is explored in relation to organs and tissues. The importance of bones is studied in relation to why it is necessary in order to maintain life functions.  | **Extracts from Best Evidence:**  **Cell shape and size** Research shows: * Hands-on microscopy of cells, tissues and organisms should be the starting point to build understanding of cell size and what they look like (AAAS Project 2061, 2009; Skinner, 2011) and that they are a common building block (AAAS Project 2061, 2009; Skinner, 2011).
* Students don’t always appreciate the 3D structure of cells (rooted in using 2D images only) (Vijapurkar, Kawalkar and Nambiar, 2014).
* Advocacy for building models to overcome the second point (e.g. Tregidgo and Ratcliffe, 2000; Lazarowitz and Naim, 2014).
* Early use of generalised diagrams blocks development of students understanding of the true nature of cells. Students exposed to a broad range of images (2D, 3D and models) and using these to ‘build’ the generalised structures Clément (2007).
* Students can think that atoms, molecules and cells are the same size (the ‘molecell’) (Arnold, 1983).
* Students can think that everything studied in Biology is alive and molecules only exist in Chemistry and Physics (Dreyfus and Jungwirth, 1988).
* 25% of 11-18 year olds think living things can only contain ‘about 1000’ cells and single-celled organisms don’t exist (AAAS Project 2061).
* Cartoon-like depictions (with faces, arms etc) introduce and reinforce misconceptions.

**Cells and cell structures**  Research shows: * Cell theory1 is a fundamental concept in biology that underpins understanding of other biological concepts. It includes the ideas that organisms are made up of one or more cells; that life depends on the structure, functions and organisation of cells; and that all cells are made from existing cells.
* Pre-KS3 students will have built their own ideas about cells from media and everyday experience (AAAS Project 2061, 2009; Department for Education, 2013).
* Light microscopy and drawing cells can help overcome misunderstandings (Haşiloğlu and Eminoğlu , 2017).
* Many KS4 students struggle to explain how cells carry out life processes even when they could identify organelles.
* Many students thought that cells contain macroscopic organs that carry out life processes. This was associated with students thinking cells eat (nutrition) and breath (respiration) and that they have needs and wants.

Watching videos of cells growing and dividing, taking in substances and changing direction when encountering barriers helps build understanding. Research (e.g. Dreyfus and Jungwirth, 1988; Clément, 2007) has identified a number of misunderstandings that students have about cells, and some common practices that may introduce or reinforce these misunderstandings, including for example:

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| **Misunderstanding**  | **Practices that can introduce** **or reinforce the misunderstanding**  |
| Cells are merely structural units, like ‘bricks in a wall’, but not functional units that carry out life processes.  | Over-reliance on static imagery of cells, including textbook diagrams and photomicrographs that show only structural details of (apparently lifeless) cells.  |
| There are only two kinds of cells, namely animal cells and plant cells (and hence that only animals and plants are made up of cells).  | Limiting students’ experience of cells (e.g. through microscopy and cellular imagery) to just animal and plant cells (e.g. onion cells and cheek cells).  |
| The bodies of humans and other animals *contain* cells, perhaps floating in a ‘soup’ of body fluids, rather than being *made up of* cells.  | Typical textbook depictions of animal cells as round and isolated (in contrast to plant cells, which are usually depicted as polygonal and adjacent to other cells). Over-reliance on blood cells as examples of human cells.  |
| Animistic and anthropomorphic views, such as believing that cells and cell organelles have desires and intentions (e.g. they ‘know’ or ‘want’ to take in and discard particular substances).  | Use of cartoon-like depictions of cells and cell organelles with faces or with speech bubbles in which they describe their own functions.  |

**Diffusion and the cell membrane** *Cells and diffusion* Various researchers (Odom, 1995; Tomažič and Vidic, 2012; Stains and Sevian, 2015; Oztas and Oztas, 2016) have used diagnostic questions to reveal common misunderstandings about diffusion in school children that can persist in students up to university level, including that: * molecules in an area of high concentration want to spread out, or move to seek out an area with more room;
* molecules move only in one direction, from an area of higher concentration to an area of lower concentration (a failure to understand the random movement of particles versus the concept of *net* movement);
* movement of particles stops after the concentration gradient between two areas has been equalised by diffusion (possibly because students interpret “no net movement” to mean “no movement of particles”);
* diffusion of a substance through a solvent requires a chemical reaction, or occurs because the substance splits up into smaller bits that mix with the solvent
* diffusion requires energy from a cell, and would stop if the cell died.

Wilkerson-Jerde, Gravel and Macrander, 2015; Kutzner and Pearson, 2017) have described constructivist approaches that enable students to build their own explanations of diffusion, which may help to develop students’ understanding and overcome misconceptions, including for example: * group discussion, both teacher-led and student-student;
* challenging students to apply concepts they have been taught to make predictions;
* asking students to create and use models to explain diffusion including drawings, animations, simulations, physical models (e.g. sieves and balls), and role-play.

*Particle explanations* Students have various ways of thinking about substances and what they are made up of at the sub-microscopic level, including (Johnson, 1998) * that substances are continuous and are not made up of (or do not contain) particles (incorrect);
* that there are particles *in* the continuous substance – i.e. the substance is between the particles (incorrect);
* that particles *are* the substance – i.e. the substance is made up of particles (correct).

Those students who did talk about particles showed very little appreciation of the intrinsic, random movement of particles.  **Cells, tissues and organ systems** *Cells and organs* * Young children tend to be able to draw randomly placed organs. Correct placement and how they are connected into a system needs to be developed (Reiss et al., 2002; Bartoszeck, Machado and Amann-Gainotti, 2011) .
* Young children tend to think of a body holistically as a single entity but after age 10 they can identify different functional parts that work together.
* Children will need to develop the idea of organisation at different levels and that life is a property of interaction between the different parts (Capra and Luisi, 2014; Skinner 2011).
* Young people (up to age 20) can struggle to identify that bones connect to make a functional skeleton. The functions of the skeleton are generally poorly understood (Guichard, 1995; Tunnicliffe and Reiss, 1999).
* Students struggle to draw muscles passing across a joint (Caravita et al., 1988). Dissecting raw chicken legs and using models can overcome this(Haddad, 1995; Goodwyn and Salm, 2007; Fullick, 2011).
* Bones aren’t recognised as being alive nor made of cells. Some students only think bones are alive when inside the body (Caravita and Falchetti, 2005; Fullick, 2011).
* Students also don’t often muscles recognise muscles other than skeletal muscles; their roles in the digestive, circulatory and respiratory systems are not recognised (Driver et al., 1994).
* Some students think that air is pimped around the body instead of blood.
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| **Threshold concepts: What concepts do student need to have prior knowledge of?**  | **Which topics develop the concepts from this one?**  |
| **Particle theory****Diffusion (physical processes)****Elements and compounds (for knowledge of chemical reactions)****Speed (students need to appreciate that diffusion is very slow)** |  |

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| **Links to KS3 programme of study:** |
| **Cells and organisation**  cells as the fundamental unit of living organisms, including how to observe, interpret and record cell structure using a light microscope  the functions of the cell wall, cell membrane, cytoplasm, nucleus, vacuole, mitochondria and chloroplasts  the similarities and differences between plant and animal cells  the role of diffusion in the movement of materials in and between cells  the structural adaptations of some unicellular organisms  the hierarchical organisation of multicellular organisms: from cells to tissues to organs to systems to organisms.**The skeletal and muscular systems**  the structure and functions of the human skeleton, to include support, protection, movement and making blood cells  biomechanics – the interaction between skeleton and muscles, including the measurement of force exerted by different muscles  the function of muscles and examples of antagonistic muscles. |
| **Links to KS2 programme of study:** | **Links to KS4 programme of study:** |
| Pupils should be taught to: Identify that humans and some other animals have skeletons and muscles for support, protection and movement (year 3)Pupils should be introduced to the relationship between structure and function: the idea that every part has a job to do. They should explore questions that focus on the role of the roots and stem in nutrition and support, leaves for nutrition and flowers for reproduction (year 3)Describe the simple functions of the basic parts of the digestive system in humans (year 4)They might draw and discuss their ideas about the digestive system and compare them with models or images (year 4)Describe the life process of reproduction in some plants and animals (year 5) | **Cell biology** • cells as the basic structural unit of all organisms; adaptations of cells related to their functions; the main sub-cellular structures of eukaryotic and prokaryotic cells • stem cells in animals and meristems in plants • enzymes • factors affecting the rate of enzymatic reactions • the importance of cellular respiration; the processes of aerobic and anaerobic respiration • carbohydrates, proteins, nucleic acids and lipids as key biological molecules.**Transport systems** • the need for transport systems in multicellular organisms, including plants • the relationship between the structure and functions of the human circulatory system.**Coordination and control** • principles of nervous coordination and control in humans • the relationship between the structure and function of the human nervous system • the relationship between structure and function in a reflex arc • principles of hormonal coordination and control in humans • hormones in human reproduction, hormonal and non-hormonal methods of contraception |
| **Cross-curricular links:** | **Wider development:**  |
| **Maths: This can be left for now****English:** | **SMSC:****PLTS:** **SEAL:****Numeracy and literacy: Literacy includes keystone words** |

**Lesson sequence:**

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| **Lesson title** | **Best evidence (diagnostics)** | **Notes** |
| What are living things made of?  | Using a light microscope | MRS NERG / GREN will not be taught as it introduces its own misconceptions (<https://acommonbiologist.wordpress.com/2020/08/30/is-it-time-to-let-mrs-gren-die/#:~:text=Fire%20is%20non%2Dliving%20but,Movement%20%E2%80%93%20fire%20spreads> ). Instead we will work form the premise that all known living things are made of cells.Demonstration of light microscope. Method for use of microscope. Students need to understand that ‘higher’ organisms have organ systems, organs etc and that these parts work together.They then need to be introduced to the microscope and how to use it (so they can see what organs and tissues are made of in higher organisms and also what microorganisms are made of. The former continues the theme of body parts working together).Students will write a plan for the first time. They will need to see good examples and strong modelling will be required.  |
| Observing cells (use of microscope) | Too small to see; seeing cells; what’s the magnification; made of cells | Students need exposure to a wide range of cells including those of micro-organisms, so they understand the generic diagram is a simplified average cell. |
| The cell as a living unit: Atoms, biological molecules and organelles. | Atoms, biological molecules and organelles; the unit of life; organ or organelle? ; a single cell can; cell needs | Organelles common to the vast majority of cells need to be identified and roles discussed (cell membrane, cytoplasm, nucleus, mitochondria). Students need to appreciate that the cytoplasm contains molecules involved in chemical reactions. Reactants and products move through the cytoplasm. The cell membrane allows certain molecules to enter and leave the cell. Organelles have specialised roles; they contain the molecules needed to perform those roles.Good opportunity to use a model to explain roles of organelles (e.g. factory model – although choose the example carefully as several on the internet contain poor science) |
| The cell membrane and the cytoplasm – a closer look | The cell membrane; the right structure for the job; cytoplasm – a particle model; cell needs; Across the membrane; deodorant; in and out of a cell; dead cell; cell needs | Scientist Spotlight: CRISPR and its use in editing genetic material in the nucleus.The cytoplasm is described in terms of organic molecules moving randomly within it; the particles take part in chemical reactions. The cell membrane is shown to be partially permeable with particles moving through it via ‘holes’.  |
| The nucleus – the central controller |  | The nucleus controls the reactions within the cytoplasm and through these, many characteristics of the whole organism. However, the mechanism is saved for later.The relatively new technique and its potential uses are explored. Much of this work has been completed by Charpentier and Doudna who received a Nobel Prize for this work. |
| Animal cells and plant cells (that do and do not absorb light).  | Animal or plant cell? | Lots of examples of specialised cells should be included to avoid students overgeneralising. Students need to be able to classify cells from features not generalised shapes and images. Again, a full range of examples should be used. Reinforce the point that organisms are made of one or more cells whose sizes and shapes vary. |
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**Lesson sequence and lesson overviews**

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| Lesson | Title and keywords | Objectives | What students are learning | What students are not learning | Suggested activities |
| 1 | **What are living things made of?** **Keywords:** MicroscopeEyepiece lensObjective lensStageSlideLight / lampFine focus Course focus | **Know the main organ systems and their roles.****Understand how organ systems work together to sustain life.** **Know the parts of a light microscope.** **Know the features of an effective plan for a procedure.** **Able to explain how to use a light microscope to observe samples.** | * Organisms have organ systems and organs that work together to sustain life.
* The parts of a light microscope
* How to use a light microscope
 | * MRS GREN / NERG in isolation (KS3 introduces made of cells as a criteria for living things). Life processes can be taught but in relation to how they occur within cells.
 | **Connect**Identify organs and organ systems in diagrams, the model body or real organs. Discuss their roles in maintaining life (knowledge of life processes is likely to be very low). **(See slide showing organ systems in resources).****Modelling**Discuss the role of organ systems in relation to each other ***(the interaction of organ systems and other layers of organisation (e.g. cells, tissues, organs) result in life).*** E.g. The respiratory system oxygenates blood and the circulatory system circulates it around the body. Similarly, the digestive system moves nutrients into the blood. **Modelling**Show images of small organisms, organs, cells, tissues and dividing cells **(see resources).** Discuss how these images might be obtained.Have students label a diagram of a light microscope **(see resources).****Modelling**Model how to use a light microscope (or use alternative media) properly.Label the parts of a microscope **(see resources).****Application (M.E. Time)**Using WAGOLLs **(see resources)** identify the features of a strong plan **(see resources for criteria).** **Modelling**Model how to write a plan from scratch including verbalising your thought processes (this is particularly important). A suitable method might be making a cup of tea (as it is familiar). **Application (M.E. Time)**Students write their own plan **(see resources for sequencing task).**Applications* Identifying the impact on the body of an organ system not working correctly.
* Identifying the strengths and weaknesses of WAGOLL plans for making a slide and practical work already completed.
* Application of ideas from the above into writing own method.
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| Notes including most common misconceptions |
| **What the research says:** Researchers have acknowledged that the cell is, when first introduced, an abstract concept (Dreyfus and Jungwirth, 1988; 1989). When introducing ideas about cells, several sources advocate starting with hands-on light microscopy of cells from a range of tissues and organisms, to enable students to discover for themselves that cells are the common building blocks of living things and what they look like (AAAS Project 2061, 2009; Skinner, 2011).Haşiloğlu and Eminoğlu (2017) found that light microscopy was effective in helping students to overcome misunderstandings about what cells look like; students’ drawings of cells were much more accurate after light microscopy.The ability to use a light microscope to observe and produce a scientific drawing of a specimen is an assessed practical activity at ages 16 and 18 in England (Department for Education, 2014; 2015). |

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| Lesson | Title and keywords | Objectives | What students are learning | What students are not learning | Suggested activities |
| 2 | **Observing cells (use of microscope)****Keywords:** MagnificationObservationMicroscopeEyepiece lensObjective lensStageSlideLight / lampFine focus Course focusCell | **Able to use a light microscope to observe samples.****Able to record images from a light microscope accurately.** **Able to calculate the magnification provided by a light microscope using the eye piece lens and objective lens.****Know that organisms are composed of one or more cell. Care needs to be taken to represent cells in context (e.g if they form part of a tisuue, a single cell should not be shown).****Know that cells have common features.** | * How to make observations and record them accurately.
* Calculation of magnification using the eyepiece and objective lenses
* Living things are composed of one or more cell.
* All cells have some features in common
 | * Structure-function relationships in specific cell types
* Organelles that can only be seen with an electron microscope
* Details of the organelles (addressed in a later lesson in this sequence).
 | **Connect**Students read a plan for the use of a light microscope and identify errors and improvements **(see resources).****Modelling**Model how to use the light microscope to focus samples on prepared slides (using prepared slides ensures students focus on the use of the microscope and not making slides).Students focus their own microscopes on a slide. **Modelling**Model how to draw the image seen using a microscope **(see resources for success criteria and examples).** Ensure students understand why accurate recording is required in science).**Application (M.E. Time)**Students draw what they see using their microscope. **Modelling**Model how to calculate magnification from the objective and eyepiece lenses. Students complete for their slide **(see resources).****Modelling**Present students with multiple images of cells and tissues from a variety of organisms **(see resources).** Identify common organelles (covered in more detail in next lesson) and classify samples as from unicellular or multicellular organisms. **Application (M.E. Time)**Students classify samples **(see resources)** as unicellular or multicellular with justification.Applications* When presented with micrographs and / or associated drawing, students can identify strong and weak points against given criteria.
* Producing accurate drawings of what they see using a light microscope.
* Classifying samples on slides as unicellular or multicellular.
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| Notes including most common misconceptions |
| Images of cells from a wide range of organisms should be used so students can identify commonalities. Use of generic cell structures at this point are unhelpful as they introduce misconceptions. Time lapse videos of cells dividing, cells in embryos becoming and organism etc should be used to help students appreciate the cell as an active entity that organisms are composed of. **What the research says:** A number of researchers have reported that children aged 11-16 lack an appreciation of size and scale, and that this impacts their understanding of the relative sizes of cells and other biological structures (e.g. Arnold, 1983; Dreyfus and Jungwirth, 1988; Driver et al., 1994).Dreyfus and Jungwirth (1989) acknowledge that the cell is, when first introduced, an abstract concept. When introducing ideas about cells, several sources advocate starting with hands-on light microscopy of cells from a range of tissues and organisms, to enable students to build their own understanding of the size of cells and what they look like (AAAS Project 2061, 2009; Skinner, 2011).Some students at age 16 struggle to name appropriate apparatus that could be used to view structures at cellular level, with incorrect responses including magnifying glass, telescope and the eyes (OCR, 2018).Research has identified a number of misunderstandings that students have about cells, including:* that there are only two kinds of cells, namely animal cells and plant cells, and hence that only animals and plants are made up of cells (Clément, 2007)
* the assumption that molecules and cells are all the same size, a conflation that has been dubbed “the molecell” (Arnold, 1983)
* that everything studied in biology lessons, including biological molecules such as proteins and carbohydrates, is made of cells (Dreyfus and Jungwirth, 1988).
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| Lesson | Title and keywords | Objectives | What students are learning | What students are not learning | Suggested activities |
| 3 | The cell as a living unit: Atoms, biological molecules and organelles.**Keywords:** CytoplasmCell membraneNucleusMitochondriaSubcellularModel | **Know that all living things are composed of cells and that cells are the simplest form of life.** **Know that cells perform life processes (limited to respiration, growth, reproduction, excretion, nutrition)****Know the common parts of an animal cell and what they do.** **Use a model to understand how the organelles relate to one another.** | * Cells contain organelles with specific functions
* Functions of each organelle (expanded in the next lesson)
* Organelles compartmentalise the cell and therefore make it more efficient
* Organelles have specialised roles and contain molecules that enable them to fulfil those roles
* The bank or factory as a model for a cell
 | * Organelles that can not be seen with a light microscope
* Organelles specific to plant cells
* Organelles from prokaryotic cells
* Details of specific chemical processes (e.g. respiration); these are covered later in the course (after threshold concepts have been learnt).
* Generic plant and animal cells.
 | **Connect**Review of scientific drawings of cells **(see resources)**; retrieval from last lesson. Drawings from Best Evidence are in the folder as an alternative **(see resources)**.**Modelling**Provide students with the text **(see resources)**. Read the text together and identify why cells have compartments. Students may need reminding about reading skills **(see resources)**. This is also an opportunity to develop oracy. Slides showing the entymology of subcellular and organelle are given **(see resources)**. Using a range of images of cells and tissues, identify common organelles. Discuss each in turn **(see resources)**.**Application (M.E. Time)**Students identify organelles in a micrograph **(see resources)**. They then link organelles to three life functions **(see resources)**.**Modelling**Model the parts of a cell as a factory / bank that contributes to the whole organism (country). E.g. blood vessels can be considered to be internal transport links **(see resources).** **The Cell Song:** [**https://www.youtube.com/watch?v=rABKB5aS2Zg**](https://www.youtube.com/watch?v=rABKB5aS2Zg)**Application (M.E. Time)**Identify the strengths and weaknesses of the model from the last activity **(see resources).** |
| Notes including most common misconceptions |
| **What the research says:** A single cell can carry out all the processes of life. An organism may be made up of a single cell or many cells working together. This is why scientists think of cells as the basic units of life.Researchers have acknowledged that the cell is, when first introduced, an abstract concept, and that children may never see cells functioning, so the *living* (functional) cell remains an abstract idea even if they have become familiar with the structures of cells through light microscopy and pictures (Dreyfus and Jungwirth, 1988; 1989). A number of researchers have reported that children aged 11-16 lack an appreciation of size and scale, and that this impacts their understanding of the relative sizes of cells and other biological structures (e.g. Arnold, 1983; Dreyfus and Jungwirth, 1988; Driver et al., 1994). A related misunderstanding is that everything studied in biology lessons, including biological molecules such as proteins and carbohydrates, is made of cells and is alive; some children would only apply the term “molecule” to things they had studied in chemistry and physics (Dreyfus and Jungwirth, 1988).Dreyfus and Jungwirth (1988) found that many 16-year-olds struggled to explain how cells carry out life processes. Many of the students thought that cells contain macroscopic organs such as a digestive tract (e.g. for nutrition) or lungs (e.g. for respiration). Even students who could identify the correct cell organelles could not explain how they carry out their functions, especially how the nucleus ‘controls’ the structure and functions of a cell.Researchers (Arnold, 1983; Dreyfus and Jungwirth, 1988; Driver et al., 1994) have reported a number of misunderstandings that students have about cells, including:* poor or no appreciation of size and scale
* animistic and anthropomorphic views, including that cells and cell organelles can have faces, limbs, internal organs or the ability to speak.
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| Lesson | Title and keywords | Objectives | What students are learning | What students are not learning | Suggested activities |
| 4 | The cell membrane and the cytoplasm – a closer lookUltimately you are trying to demonstrate that cells are complicated (the fried egg model is an oversimplification.Students will revisit diffusion; this concept is revisited several times in secondary school and so must be fully understood. **Keywords:** Cell membraneCytoplasmSemi-permeableMoleculesDiffusionConcentration gradientSurface areaThickness | **Know that the contents of cells are very crowded and dynamic.****Know that molecules constantly move into, out of and within cells and that this is essential to the cell remaining alive.** **Know that the cytoplasm is where the majority of chemical reactions occur.** **Know that the cell membrane controls which substances diffuse into and out of the cell** **Able to explain how substances move into and through cells and why this process is very slow.**  | * The cytoplasm as a complex mixture of molecules that move freely throughout.
* The cytoplasm is where most of the chemical reactions in the cell occur. These often involve converting excesses of one molecule into more useful molecules.
* The cell membrane as a semi-permeable membrane that controls which substances enter and leave the cell.
* The structure of the cell membrane including gated holes that enable the membrane to control passage of specific molecules.
* Definition of diffusion (this was studied in the Particles topic)
* Substances diffuse through the cell membrane and through the cytoplasm
* Factors affecting the rate of diffusion into and through cells (surface area; concentration gradient; membrane thickness)
* The rate of diffusion limits cell size
 | * The fluid mosaic model
* The cytosol (terminology introduced much later)
* Analogies between organelles and organs.
* Ficks Law
* Effect of temperature
* Organ systems
 | Topics for Skills Drill (threshold concepts)Substances that our bodies require (KS2)Common organelles in animal cells (this topic)Particle model particularly for liquids (particle model)Diffusion (particle model)**Connect:**Image of Brownian motion. State that this shows a process that all life depends on. Cops and Robbers retrieval activity **(see resources).**Link to mitochondria receiving oxygen and glucose and excretion of carbon dioxide (as an example). **M.E Time**Best Evidence questions (hinge questions) **(see resources).****Modelling**Demonstration of diffusion (natural gas between two gas jars / any coloured substance in water etc) / diffusion through a gel **(see resources - videos).** The difference in rate of diffusion is important. Identify what is happening (diffusion) and the mechanism of diffusion (Brownian motion). Students complete a brain dump (write down what they recall) of what the demonstrations tells them (the state of matter affects the rate of diffusion; this is picked up later in the lesson) **(see resources).****Modelling**Using images and videos **(see resources)** identify the likely state of the cytoplasm and the cell membrane. Explain why the rate of diffusion is low. **Application (M.E. Time)**Best Evidence question plus follow up elaborative question to explore student ideas **(see resources).****Modelling**Adaptations of the cell membrane for increasing the rate of diffusion. A SciTable article is in the resources folder. This can be used as a literacy task **(see resources).****Application (M.E. Time)**Explain why *Valonia ventricose* could not survive using diffusion alone (some information is given). A retrieval practice slide is also supplied as scaffolding **(see resources).**Good opportunity for a question around maximum size of simple undifferentiated organisms: <https://www.youtube.com/watch?v=9SLYdENgsog> Caulerpa (6) uses cytoplasmic streaming not diffusion. Other cells are limited by the rate of diffusion. Also, see <https://sciencenotes.org/what-is-the-largest-unicellular-organism/> .**A folder containing diagnostic questions from Best Evidence has also been included (see resources).** |
| Notes including most common misconceptions |
| Images showing how crowded the contents of cells are at: <https://iubmb.onlinelibrary.wiley.com/doi/pdf/10.1002/bmb.20494> <https://www.the-scientist.com/image-of-the-day/image-of-the-day-crowded-cytoplasm-39602> <https://pdb101.rcsb.org/sci-art/goodsell-gallery/sars-cov-2-fusion> Some are paintings (rooted in real research) by David Goodsell. Short clips showing diffusion in cytoplasm: <https://elifesciences.org/articles/19274/figures> What the research says: Dreyfus and Jungwirth (1988) found that many 16-year-olds struggled to explain how cells and cell structures carry out life processes. Incorrect animistic and anthropomorphic views were commonly expressed, including the belief that cells and organelles have desires and intentions (e.g. that the cell or the cell membrane ‘knows’ or ‘decides’ to take in and discard particular substances).Explaining diffusion requires a secure understanding of concepts from chemistry and physics, including the particulate nature of matter and the behaviour of particles in solutions. Students can struggle to understand and explain diffusion because of the need to visualise and think about the process at the molecular level (Sanger, Brecheisen and Hynek, 2001).Johnson (1998) summarises research in which it was found that even students who appreciate that a substance is made up of particles showed very little appreciation of the intrinsic, random movement of particles. In addition, they commonly had misunderstandings about the spacing between the particles of a substance in the liquid state – typically choosing to depict the particles as too far apart, somewhere between that of the solid and gas states. This misunderstanding could be introduced or reinforced by textbook diagrams in which the spacing is shown incorrectly.Odom (1995) has defined a list of knowledge statements required for understanding diffusion in the context of cells, which begins with the following three ideas:1. All particles are in constant motion.
2. Diffusion involves the movement of particles.
3. Diffusion results from the random motion and/or collisions of particles (ions or molecules).

…as pre-requisites for the development of understanding that diffusion is the net movement of particles as a result of a concentration gradient.Various researchers (e.g. Odom, 1995; Tomažič and Vidic, 2012; Oztas and Oztas, 2016) have described the use of two-tier multiple choice questions to diagnose students’ misconceptions related to diffusion in the context of cells, including a series of questions known as the ‘Diffusion and Osmosis Diagnostic Test’ (DODT), as described by Odom and Barrow (1995).These tests have revealed common misunderstandings about diffusion amongst students, including that:* molecules move only in one direction, from an area of higher concentration to an area of lower concentration (a failure to understand the random movement of particles versus the concept of *net* movement);
* movement of particles stops after the concentration gradient between two areas has been equalised by diffusion (possibly because students interpret “no net movement” to mean “no movement of particles”).

Students can struggle to understand and explain diffusion because of the need to visualise and think about processes at the molecular level (Sanger, Brecheisen and Hynek, 2001).Various researchers (Odom, 1995; Tomažič and Vidic, 2012; Stains and Sevian, 2015; Oztas and Oztas, 2016) have used diagnostic questions to reveal common misunderstandings about diffusion in school children that can persist in students up to university level, including that:* molecules in an area of high concentration want to spread out, or move to seek out an area with more room;
* molecules move only in one direction, from an area of higher concentration to an area of lower concentration (a failure to understand the random movement of particles versus the concept of *net* movement);
* movement of particles stops after the concentration gradient between two areas has been equalised by diffusion (possibly because students interpret “no net movement” to mean “no movement of particles”);
* diffusion of a substance through a solvent requires a chemical reaction, or occurs because the substance splits up into smaller bits that mix with the solvent.

Some students believe that diffusion requires an external force or mechanical event (rather than resulting from the intrinsic movement of particles), a misunderstanding that may be linked to students’ everyday experiences of stirring and dissolving, such as stirring sugar into tea (Çalýk, Ayas and Ebenezer, 2005; Stains and Sevian, 2015).Students can struggle to understand and explain diffusion because of the apparent disconnect between what happens at the macroscopic level and what happens at the particle level – e.g. molecules collide and move in random directions and do not stop, but there is net movement from high concentration to low concentration until equilibrium is reached (AlHarbi et al., 2015; Stains and Sevian, 2015). |

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| Lesson | Title and keywords | Objectives | What students are learning | What students are not learning | Suggested activities |
| 5 | The nucleus – the central controller**Keywords:** NucleusGenetic materialDNAGeneGenome | **Understand the role of the nucleus in the cell. This should include macroscopic features and microscopic (conotrl of chemical reactions).** **Understand the benefits of scientific progress (CRISPR in this case)****Understand that not everybody agrees on whether scientific developments should be allowed to occur** | * The contents of the nucleus
* The nucleus controls the rate of all reactions in the cell
* The nucleus partially determines the features of all living things
* CRISPR – gene editing. Scientist Spotlight: Nobel Prize for Chemistry 2020 went to Emmanuelle Charpentier and Jennifer Doudna for CRISPR.
 | * Protein synthesis and how it moderates rates of chemical reactions; we will cover this later to reduce extraneous cognitive load (KS4 content).
* The structure of DNA.
* Transcription and translation
* Proteomes and transcriptomes
 | Topics for Skills Drill (threshold concepts)Substances that our bodies require (KS2)Common organelles in animal cells (this topic)Functions of the organellesChemical reactions (Element topic)**Useful CRISPR links:** <https://www.newscientist.com/definition/what-is-crispr/> <https://medlineplus.gov/genetics/understanding/genomicresearch/genomeediting/> <https://www.nobelprize.org/prizes/chemistry/2020/press-release/> **Connect:**Images of cells from onion epidermis. Spaced retrieval: Spaced retrieval: identifying organelles and fiunctions; unicellular or multicellular etc. **Modelling:**<https://www.youtube.com/watch?v=hywRdDVR76A> Use the video to show the effect of DNA on a macroscopic level. Additional information is included but the focus needs to remain on DNA / genes dictating species and macroscopic features. They also regulate the rate of reactions in a cell: Brain Dump (retrieval) on the role of the nucleus. Alternative retrieval task given. **(see resources).**http://i.imgur.com/kOoqb.jpg**M.E. Time**Explaining non-identical twins on a cellular level **(see resources).****Modelling:**Literacy task: Students extract the meaning of CRISPR from a given text **(see resources).**Also, the implications if it is allowed to be used uncontrolled. Emphasis is on the role of the community in regulating the implications of current science. Also, the motivations of scientists in completing controversial work and the skillsets they use. **(see resources – CrisPR babies).****Good practice in using reading skills should be modelled. Help students extract information before answering structured questions.** WAGOLLs given for use if the evaluation ME task is used. The writing of these should be modelled so students see the thought process.**Application (M.E. Time)**Students complete a newspaper article on what CRISPR is. A profile of the scientists should be included as should the role of the community. OR: Evaluate the use of CRISPR in humans **(see resources).**  |
| Notes including most common misconceptions |
| None |

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| Lesson | Title and keywords | Objectives | What students are learning | What students are not learning | Suggested activities |
| 6 | Animal cells and plant cells (that do and do not absorb light). **Keywords:** CellNucleusMitochondriaCytoplasmCell membraneCell wallVacuoleChloroplastPhotosynthesisSpecialised  | **Know the organelles that plant and animal cells can have (but don’t always have).****Know some examples of specialised plant and animal cells.****Compare plant and animal cells in terms of the organelles that they can have.****Able to explain why plant cells have additional organelles in terms of the life processes** | * Organelles that are common in animal cells and plant cells
* Examples of plant and animal cells that do not have all of the organelles that plant and animal cells can have.
* Specialised cells only contain the organelles that they require to perform their function (feeds forward into another lesson in this topic)
 | * Organelles other than the nucleus, cell membrane, cytoplasm, mitochondria; chloroplast; permanent vacuole and cell wall.
 | **Connect:**Connect to prior learning. Plants need to make their own food and then transfer energy from that food. Which organelles might they have in common with animal cells? Which functions of a plant can’t animal cell organelles do? **(see resources).****Modelling:**Using multiple images of cells and tissues from animals, identify common features. These should include the nucleus, cell membrane, cytoplasm and mitochondria. Roles should be discussed using the factory model. **This process ought to be teacher led so the teacher can model how to identify relevant organelles.** Students repeat the process for plant cells. The review should identify all common parts of the cell and their roles. **(see resources).****Application (M.E. Time)**Classify plant and animal cells based on their organelles. Students should justify their answers. This should include awkward examples that may not have all common organelles or that have awkward shapes and features. **(see resources).****Modelling:**Supply students with generic cell diagrams. Model identification of similarities and differences. **(see resources).**For cells that were classified earlier, students explain the presence of additional organelles in plant cells in terms of their function and the needs of the plant. **(see resources).****Application (M.E. Time)**Using images / micrographs of amoeba and euglena, identify features that would be expected to be found in plant and animal cells. Identify which organelles are missing that are common in plant and animal cells. **(see resources).****I have included a Best Evidence diagnostic for functions of cell organelles** **(see resources).****A second diagnostic enables students to identify common features of plant / animal cells and then to compare them.**  |
| Notes including most common misconceptions |
| The generic cells should be built up with reference to specialised cells so students appreciate that the meaning of a generic cell (it doesn’t represent all cells)What the research says: Researchers have acknowledged that the cell is, when first introduced, an abstract concept (Dreyfus and Jungwirth, 1988; 1989).Clément (2007) notes that “the cell concept is generally introduced by two juxtaposed drawings, a plant cell and an animal cell” with the common features of animal and plant cells labelled, and that the plant cell is generally polygonal and adjacent to other cells while the animal cell is more rounded in shape and isolated. If students are not presented with a greater variety of images of cells it could introduce or reinforce the misunderstanding that all animals cells and all plants cells have the same shape and structures as these two archetypal depictions; Clément found this misunderstanding persisting in students up to undergraduate level.Clément also noted that the differences between types of animal cells (e.g. epithelium, neuron, sperm cell) may appear to be more pronounced that the differences between an animal cell and a plant cell (e.g. an epithelial cell from a human check and a spongy mesophyll cell from a plant leaf) – especially when depicted using cross-sectional line diagrams.It may be helpful for students to understand that the archetypal, textbook depictions of animal and plant cells are *models*. Not all animal plant and cells have exactly the same shape or structures as those depicted in the models; but the models are a useful description of the common features of animal and plant cells. |

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| Lesson | Title and keywords | Objectives | What students are learning | What students are not learning | Suggested activities |
| **7 MAP** | **MAP****Keywords:** CellNucleusMitochondriaCytoplasmCell membraneCell wallVacuoleChloroplastStructureFunction | **Understand that cells have a three dimensional structure****Able to identify materials that reflect the structure and function of each organelle****Able to describe the strengths and weaknesses of the model cells and the 2D generic model plant and animal cells.** | **MAP****Last minute cramming increases short-term performance (in this MAP) but decreases long-term performance. Preparation for this assessment should be minimal; this will give a truer reflection of each student’s schema and enable more fruitful feedback.**  | **The MAP has several parts and is expected to take most of a lesson.** **If you are concerned about time, pick the sections that you think will allow you to give students the most useful feedback.** | <https://owlcation.com/stem/3d-cell-model#PhotoSwipe1442770069663> **The MAP is expected to take most of the lesson. Limited resources are supplied for the lesson because of this.** **Response tasks from Best Evidence are supplied to support your planning of feedback activities.**  |
| Notes including most common misconceptions |
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| Lesson | Title and keywords | Objectives | What students are learning | What students are not learning | Suggested activities |
| 8 | Specialised cells**Keywords:** Structural adaptationNerve cellRed blood cellSperm cellLeaf cell Root hair cell | **Define ‘specialised’ and ‘differentiated’.****Know the main structural features of each specialised cell studied****Know the main function of each specialised cell studied****Able to explain why each structural feature is essential to the cells function**Able to explain how each specialised cell contributes to life functions.  | * The structure and function of nerve cells, egg cells, sperm cells; red blood cell; root hair cell and leaf cell (palisade mesophyll)
* How structure relates to function.
 | * SA:Volume ratio
* The relationship between structure and function is the priority; complex concepts such as SA : volume are not required.
 | **Connect:**Using an image of a specialised cell, students identify organelles and state functions. **(see resources).**When given extra information about the function of the cell they identify structures that facilitate that function. **Modelling:**Model identification of common features of cells and then linking those features to the cell function **(see resources).**Give students examples of specialised cells with their functions. Have students link cell structures to the function. Use fading (I do, we do, you do) to build expertise and confidence.Compare outcomes to an expert answer **(see resources).**Alternatively give students a sorting task with image, structural features and function. Have them sort the cards and be prepared to discuss answers. **Application (M.E. Time)**Exam style questions  **(see resources).****Modelling:**Model how red blood cells contribute to life functions through linking the circulatory and respiratory systems to chemical processes in cells. If fading is required: Nerve cells carry impulses that are involved in animals responding to the environment. **Application (M.E. Time)**Students complete their own examples.Applications* How specialised cells contribute to life processes at the level of the whole organism **(see resources).**
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| Notes including most common misconceptions |
| What the research says: Various researchers (e.g. Odom, 1995; Tomažič and Vidic, 2012; Oztas and Oztas, 2016) have described the use of two-tier multiple choice questions to diagnose students’ misconceptions related to diffusion in the context of cells. Students can struggle to understand and explain diffusion because of the need to visualise and think about processes at the molecular level (Sanger, Brecheisen and Hynek, 2001).There is very little published research into students’ understanding of the concepts of surface area and surface-area-to-volume ratio and their implications for living and non-living systems (Taylor and Jones, 2013). Various school science curricula recognise size and scale as important crosscutting concepts in science (National Academy of Sciences, 2012; Department for Education, 2015).Data from national examinations in the UK shows that students at age 16 struggle to explain why the shape of a root hair cell enables it to absorb substances from the soil more effectively (OCR, 2018). Commonly seen answers that did not provide sufficient explanation included that it could reach further into the soil and that it would anchor the plant in the soil more effectively. |

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| Lesson | Title and keywords | Objectives | What students are learning | What students are not learning | Suggested activities |
| 9 | Cells, tissues, organs and organ systems**Keywords:** OrganisationCell TissueOrganOrgan systemInteractions | **Know the definitions of tissues, organs and organ systems.****Know examples of tissues, organs and organ systems in plants and animals.** **Able to explain how examples of tissues, organs and organ systems contribute to life processes in cells.** | * Tissues defined as a group of similar cells that have a common function
* Organ defined as two or more types of tissue performing a specific set of functions for the body
* Organ systems defined as many organs working together to accomplish a common purpose
* The hierarchy of organisation
* Examples of tissues and organs in plants and animals
* Organ systems in animals (circulatory; respiratory; reproductive; digestive; muscular skeletal; immune)
* The reproductive system as the only organ system in plants
 | * Details of organ systems (addressed later); the main focus is the hierarchy of organisation
 | **Connect:**Referring back to lesson 1, matching cells to organ systems with justification. Stretch can be to identify how each cell / organ system contributes to life functions **(see resources).****Modelling:**Students find definitions of cells, tissues, organs and organ systems in Activate 1 or KS4 text. This can be clarified using ice cube bags (each cell represents a cell, each bag is a tissue and several layers of bags would be an organ. **Modelling:**Descriptions and images of different cells, tissues, organs and organ systems. **Application (M.E. Time)**Students complete remaining examples with justification and organise into a hierarchy **(see resources).****Modelling (alternative 1):**Fading: Given an organ system / organ / tissue, identify how the organ systems, organs and tissues contribute to cell survival **(see resources).****Application (M.E. Time)**Students complete examples. Applications can include specialised cells and how they contribute to the survival of individual cells **(see resources).****Modelling (alternative 2):**Provide students with labelled diagrams of circulatory and respiratory systems in animals and vascular system in plants. Model how to identify organ systems, organs, tissues and cells that contribute to respiration and photosynthesis. **Application (M.E. Time)**As above but students complete the tasks **(see resources).** |
| Notes including most common misconceptions |
| What the research says: Research (e.g. Dreyfus and Jungwirth, 1988; Clément, 2007) has identified a number of misunderstandings that students have about cells, including that the bodies of humans and other animals *contain* cells, perhaps floating in a ‘soup’ of body fluids, rather than being *made up of* cells. Some common practices that may introduce or reinforce these misunderstandings include overuse of typical textbook depictions of animal cells as circular and isolated (in contrast to plant cells, which are usually depicted as polygonal and adjacent to other cells), and using only blood cells as examples of human cells.Young children may think of the human body holistically as a single entity, but by age 10 they more commonly understand that it has different functional parts that work together to maintain life (Carey, 1985; Driver et al., 1994).From age 11, students could begin to explore some basic ideas that introduce a systems view of life (Capra and Luisi, 2014), including the idea that living systems are organised at different levels (molecules, cells, tissues, organs, organs systems and whole organisms) and that life is a property that emerges from the interactions between the parts that make up these different levels (Skinner, 2011).Researchers have reported the common misunderstanding in children that the bodies of humans and other animals *contain* cells, perhaps floating in a ‘soup’ of body fluids, rather than being *made up of* cells (Clément, 2007). Dreyfus and Jungwirth (1988) found that many 16-year-olds struggled to explain how cells carry out life processes, with many students thinking that cells contain macroscopic organs such as a digestive tract (e.g. for nutrition) or lungs (e.g. for respiration). Cartoon-like depictions of cells with faces, limbs or speech bubbles implying that they are able to speak may introduce or reinforce misunderstandings about the size and scale of cells and organs. |

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| Lesson | Title and keywords | Objectives | What students are learning | What students are not learning | Suggested activities |
| 10 | Why do organisms develop organs and organ systems as they get larger? **Keywords:** Single-celled organismMulti-cellular organismDiffusionRate | **Able to describe the features and associated functions of amoeba and euglena.****Able to explain how the features enable life processes to be fulfilled.****Compare the organ systems of multicellular organisms to the features of unicellular organisms.** **Explain the need for increased complexity in larger organisms in terms of diffusion and life processes.** | Single celled organisms use diffusion. Diffusion is too slow for multi-cellular organisms to survive so they have specialised systems that are cooperative.Amoeba and Euglena as examples of unicellular organisms. To include movement, reproduction and sources of nutrients and oxygen.Comparison of the above to organ systems in multicellular organisms. |  | **Connect:**Image of *Valona ventricosa* (one of the largest single celled organisms). Referring back to lesson 4, students explain why we wouldn’t expect the organism to grow larger. *Caulerpa taxifolia* – from an image students work out why this organism can grow bigger than the previous (length of diffusion pathway and high surface area) **(see resources).** **Modelling:**Using images of amoeba and Euglena, students identify features in common with animal and plant cells (one can be used to model and the second can be the students attempt) **(see resources).****Application (M.E. Time)**Identify features of Euglena and Amoeba that facilitate diffusion of gases into and out of the cell (e.g. short diffusion pathway) **(see resources).****Modelling:**Calculate the surface area and volume of cubes with increasing sizes. This can be done with fading. Demonstrate that increasing size decreases the relative surface area so we could not absorb nutrients / gases to maintain life. Lungs, intestines, gills etc increase the surface area and so enable us to absorb / excrete enough molecules to sustain life **(see resources).****Application (M.E. Time)**Identification of structures in different organisms that increase the surface area in different organisms (e.g. humans, fish, axolotls, tadpoles etc). Why toads adopt a water absorption response when dehydrated. Toads and frogs having poorly developed lungs (relatively low SA) and so absorb oxygen through the skin (the sole mechanism when submerged) **(see resources).**  |
| Notes including most common misconceptions |
| What the research says: Young children may think of the human body holistically as a single entity, but by age 10 they more commonly understand that it has different functional parts that work together to maintain life (Carey, 1985; Driver et al., 1994).From age 11, students could begin to explore some basic ideas that introduce a systems view of life (Capra and Luisi, 2014), including the idea that living systems are organised at different levels (molecules, cells, tissues, organs, organs systems and whole organisms) and that life is a property that emerges from the interactions between the parts that make up these different levels (Skinner, 2011).Researchers have reported the common misunderstanding in children that the bodies of humans and other animals *contain* cells, perhaps floating in a ‘soup’ of body fluids, rather than being *made up of* cells (Clément, 2007). Dreyfus and Jungwirth (1988) found that many 16-year-olds struggled to explain how cells carry out life processes, with many students thinking that cells contain macroscopic organs such as a digestive tract (e.g. for nutrition) or lungs (e.g. for respiration). Cartoon-like depictions of cells with faces, limbs or speech bubbles implying that they are able to speak may introduce or reinforce misunderstandings about the size and scale of cells and organs. |

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| Lesson | Title and keywords | Objectives | What students are learning | What students are not learning | Suggested activities |
| 11 | Movement and the four functions of a skeleton**Keywords:** SkeletonBones | **Know the four functions of the skeletal system.****Able to describe the structure of a bone****Able to explain the importance of the four functions to organisms** | * The four functions of the skeletal system (support the body; protect vital organs; help the body move; make blood cells).
* Skeleton as part of the muscular skeletal system.
* Bones are composed of living cells and extracellular matrix.
 | * Functions of different blood cells.
* Detailed knowledge of the role of muscles in causing movement and providing support.
 | **Connect:** State the function of the heart. Explain why cells and tissues in mammals need the heart to perform life functions. Explain why it is important that the body protects the heart **(see resources).****Or:** Students use post-it notes to identify the bones on a model skeleton (using prior knowledge) **(see resources).****Modelling:** Use fading to identify the main function of different bones in the body. E.g. The skull primarily protects the brain. The femur is primarily concerned with support and movement (and making blood cells in children). Follow up with the structure of a bone and the function of each part **(see resources).****Application (M.E. Time)**Students work through their own examples **(see resources).****Modelling:** Provide students with a list of the life functions and a diagram of the structure of a bone (with functions of parts). Model how to relate the main function of each bone, or parts of a bone, to the life functions. E.g. The bone marrow makes red blood cells. These are oxygenated at the lungs and transfer the oxygen to respiring cells **(see resources).****Application (M.E. Time)**Students complete their own examples.  |
| Notes including most common misconceptions |
| What the research says: Several studies have found that children up to age 20 struggle to appreciate that individual bones are not isolated but are connected to make a functional skeleton (Guichard, 1995; Tunnicliffe and Reiss, 1999). While young children only recognise the supportive and protective (static) functions of the skeleton, older children understand that the skeleton is necessary for movement; however, only one fifth of the older children in one study could draw muscles correctly across a joint (Caravita et al., 1988). Use of real muscles and bones, e.g. raw chicken legs, and models can help children to understand this more effectively, including the idea that muscles can only pull (Haddad, 1995; Goodwyn and Salm, 2007; Fullick, 2011).It is a common misunderstanding amongst people of all ages that bone (even when it is inside a living organism) is dead, perhaps because bones and skeletons are often associated with imagery of death and with specimens in museums etc.; this misunderstanding is reinforced by the fact that bones are usually only seen when they are outside the body, and are usually only alive when they are inside it (Caravita and Falchetti, 2005; Fullick, 2011). Caravita and Falchetti found that growth and movement were the criteria most commonly applied by students to decide whether bones were alive, as well as phenomenological criteria drawn from personal experience such as that bones hurt when injured and repair when broken; few 8-9 years olds mentioned that bones are made of cells, but it was more common in 12-13 year olds. |

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| Lesson | Title and keywords | Objectives | What students are learning | What students are not learning | Suggested activities |
| 12 | The structure and function of joints**Keywords:** SkeletonBonesJointCartilageLigamentsTendonsFluid | **Name three types of joints and give an example of each****Able to classify a joint and justify the reasoning****Able to describe the structure of a joint (including the roles of the different parts)** | * The three types of joints
* Examples of each type of joint
* The structure of joints and the roles of fluid, cartilage and ligaments
 |  | **Connect:** If bones enable large organisms to move, what other structures are also required? Expect answers such as joints, muscles, ligaments and tendons (**see resources).****Modelling:** Using the model skeleton, or own body, model the different types of joint. Demonstrate how to identify the type of joint through the movement it supports.**Application (M.E. Time)**Students identify type of joint present in different locations in the body and explain their answers **(see resources).**Challenge: Identify how an organism would be affected if one type of joint were exchanged for another **(see resources).****Modelling:** Explain the structure of a joint and the function of the component parts. This should include the role of cartilage, fluid, tendons and ligaments. **Application (M.E. Time)**Students identify how worn cartilage and dehydration might affect the function of the joint. * Effect of work cartilage, arthritis, dehydration etc on joint function.
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| Notes including most common misconceptions |
| What the research says:  |

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| Lesson | Title and keywords | Objectives | What students are learning | What students are not learning | Suggested activities |
| 13 | Skeletal muscles **Keywords:** MuscleAntagonisticContractRelax | **Able to identify the function of a specific muscle using a diagram.****Define ‘antagonistic muscles’.****Know examples of antagonistic pairs of muscles.** **Able to describe an experiment o measure muscle strength** | * The major skeletal muscles and their functions.
* The purpose of antagonistic muscles.
* Antagonistic muscles performing opposite roles.
* Predicting outcomes of muscle contraction from diagrams
 | * Other types of muscle are covered in the next lesson.
 | **Connect:** Students identify muscles on a diagram of the musculoskeletal system. Where possible, students should identify the function of each muscle / group of muscles **(see resources).****Modelling:** Model the dissection of a chicken wing. This should include identification of the joint and associated structures. Antagonistic muscles should be identified along with their role **(see resources).****Application (M.E. Time)**Students complete dissection under close supervision. Identify antagonistic muscle pairs on their bodies (or see worksheet in resources). These should include the role of each muscle / group of muscles in a pair (including why one relaxes as the other contracts) **(see resources).**Or: Students build a model of an antagonistic pair of muscles.  |
| Notes including most common misconceptions |
| Use of real muscles and bones, e.g. raw chicken legs, and models can help children to understand this more effectively, including the idea that muscles can only pull (Haddad, 1995; Goodwyn and Salm, 2007; Fullick, 2011). |