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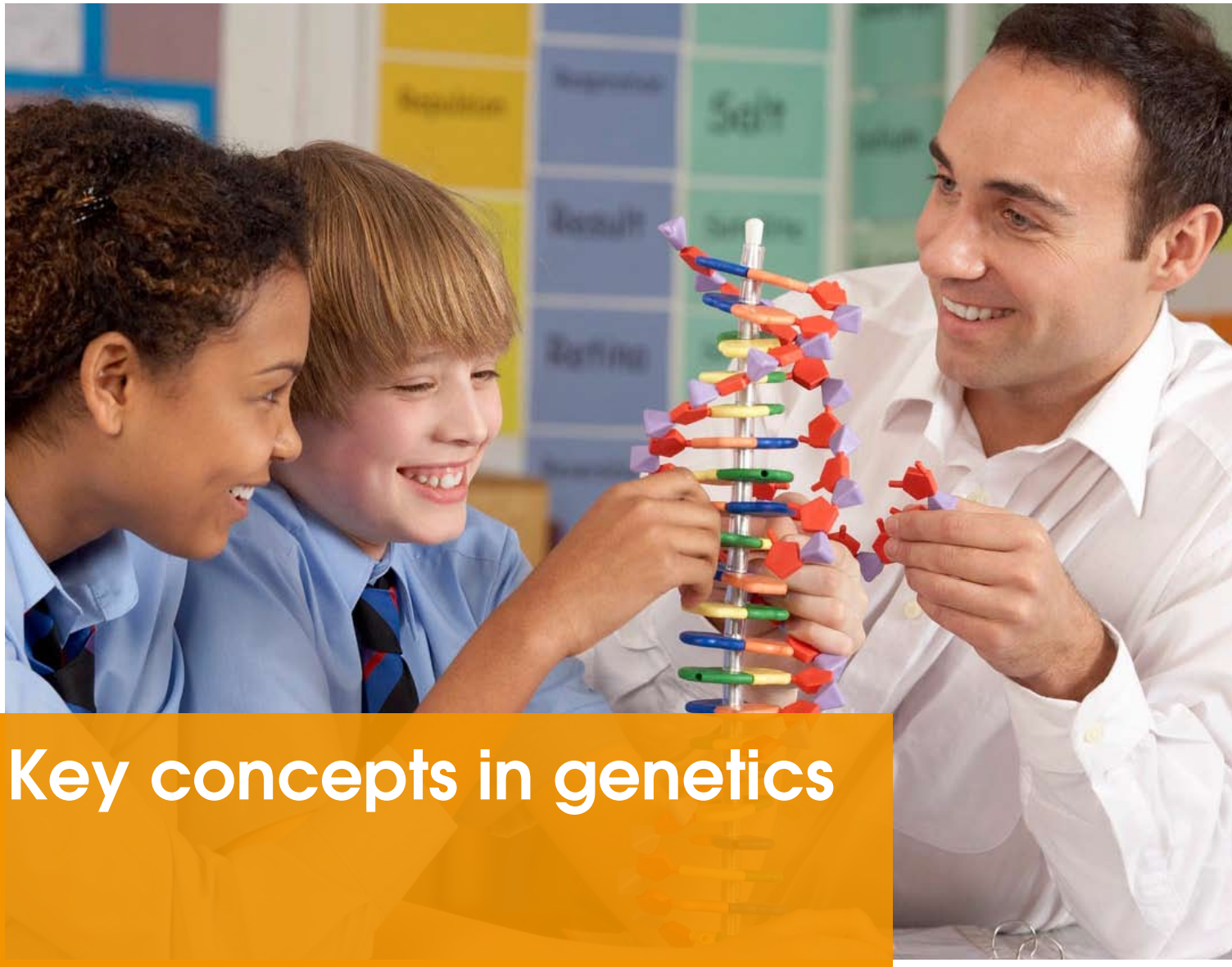

Key concepts in genetics

Science teaching unit

department for
children, schools and families

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Key concepts in genetics

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Contents

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Key concepts in genetics

Background

This teaching sequence is designed for Key Stage 4. It links to the Secondary National Strategy Framework for Science yearly learning objectives and provides coverage of parts of the QCA Programme of Study for Science. The overall aim of the sequence is for pupils to develop a *secure understanding* of basic genetic concepts which they can then apply or build upon as needed. This aim is addressed through *interactive* teaching approaches where links between subject matter are explored and established through appropriate talk between teacher and pupils and amongst pupils. The sequence is set within a real world context with links to 'How science works'.

Teaching design principles

The design of this sequence is based upon a number of key principles. These are listed as follows:

Working on knowledge

Research shows that many pupils at Key Stage 4 find it very difficult to distinguish between chromosomes, genes and alleles – even after teaching. This teaching sequence is specifically designed to make the distinctions very clear and to make the nature of the relationship between chromosomes, genes and alleles very explicit. This is done by focussing on just one aspect of that relationship at a time, rather than teaching everything at the same time. This approach means that the concept of an allele is not introduced until Lesson 4 – the first point at which it is *needed* as part of an explanation. Where the intended explanation varies significantly from the explanation which is usually presented, the key points (together with guidance about the intended purpose), are set out in a box.

The sequence involves:

- setting the sequence in a real world context which acts as a thread running through the sequence and gives meaning to the learning;
- identifying the basic concepts which pupils need to understand, and addressing each in turn:
  - the relationship between structures;
  - the idea that, within an individual organism, all body (somatic) cells carry the same genetic information;
  - the mechanism by which this is achieved (mitosis);

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  - the need for a second type of cell division (meiosis) to produce sex cells (gametes);
  - the implications of meiosis (genetic variation and inheritance);

and within each broad concept:

  - probing, and explicitly working from, pupils' starting ideas;
  - presenting just those science ideas needed to understand the particular concept;
  - applying those ideas in some way;
- building the ideas up into a coherent explanatory framework which can be used to understand a wide range of genetic phenomena;
- engaging in reasoned argument and informed decision making:
  - distinguishing between reasoned argument based on the scientific ideas (the 'facts') and personal opinion which also informs decision-making.

Teaching approach

The sequence involves:

- generating interest and providing a meaningful real life context for the intended learning through a short and structured discussion of a news item (embryo selection); this provides a thread which runs through, and helps to link, the sequence of lessons;
- using diagnostic questions and other Assessment for Learning (AfL) activities to make explicit the differences between pupils' ideas and the scientific explanations to be developed;
- providing pupils with activities which challenge their initial ideas and help them to bridge the gap between these and the scientific explanations;
- making explicit the relationship between genetic structures and the links between concepts;
- prompting pupils to reflect on their learning:
  - revisiting and expanding on questions raised during the initial discussion;
  - using 'thinking files'* to record developing ideas in a temporary form which can be easily revisited;
- expecting pupils to apply their developing knowledge (to related contexts; to gene technology);
- managing small group discussion to encourage *informed* decision making and the development of *reasoned* argument.

*** *thinking file*: personalised A4 envelope or cardboard wallet in which pupils store tentative ideas and reflections which they will revisit and reconsider as they move through the teaching sequence; it is best to collect these in at the end of each lesson (unless needed for homework) to ensure that they are always available when needed.**

Mode of interaction

The sequence has been designed to maximise pupil learning by incorporating lots of interaction between the teacher and pupils. The sequence involves:

- using different *modes of interaction* between teacher and pupils according to different teaching aims;
- providing opportunities for pupil–pupil talk in pairs and small groups.

How science works

This sequence involves developing the skills of reasoned argument and informed decision making.

Pupils' curriculum starting points

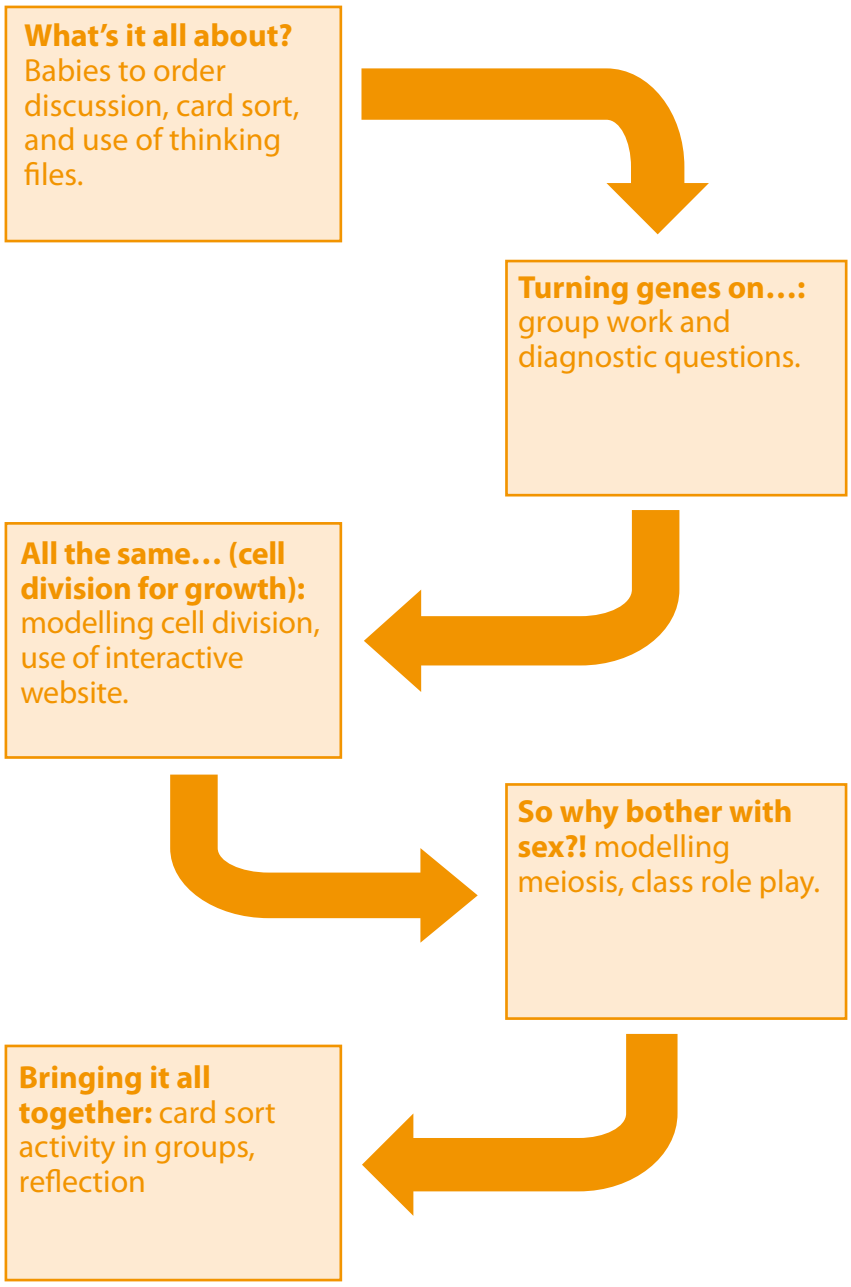
By the time pupils arrive at their science lessons in Key Stage 4, they will have experienced some teaching related to genetics. Most pupils will know that:

1. cells contain a nucleus, which controls what the cell does (and what the cell makes);
2. a cell from a male and a cell from a female fuse to form a fertilised cell and this is the start of a new life;
3. the fertilised cell grows into a new individual through a process of cell division;
4. variation may be inherited or may be caused by the environment;
5. inherited characteristics can be passed on to the next generation (and selective breeding can increase the frequency of these characteristics).

Through everyday experiences they may also be familiar with much of the basic terminology (gene, chromosome, genetic code, DNA, gene modification etc.) but unclear about the meaning of these terms.

What the pupils will NOT have is a clear understanding of basic genetic structures and how they relate to each other or how basic genetic concepts are linked to form a coherent explanatory framework. The overall aim of this sequence of lessons is to develop a coherent explanatory framework for inheritance.

Genetics: Overview



Lesson 1: What's it all about?

Teaching 'story'

The sequence starts with a structured discussion of a news item designed to stimulate pupils' thinking about genetics and its potential impact on our daily lives. Pupils read the article and discuss the questions in small groups before recording their views individually. Pupils' discussion needs to be managed so that the whole activity takes about 20 minutes, including feedback.

Activity 1.1: Babies to order

The article is set out as a newspaper report and is based on a real situation which has been in the news during the last few years.

Teaching objectives

- To interest and motivate pupils, providing a meaningful real life context for the intended learning.
- To start building up information which will inform the decision-making activity in the final lesson.
- To make explicit pupils' existing ideas about inheritance and embryo technology, thus providing baseline data (AfL).
- To provide pupils with an opportunity to reflect on the additional information that they might need before they all begin to arrive at a view about this use of genetics.

Learning outcomes

By the end of this activity, most pupils will be able to:

- recognise their own and others' existing ideas about inheritance;
- identify the sorts of additional information that they might need if they are to arrive at an informed view about this use of embryo technology.

What to prepare

- One copy of the news article per group of 3–4 pupils
- One copy of the questions per pupil
- One 'thinking file' per pupil.

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Mode of interaction

Small group discussion
Groups of 3–4 pupils discuss the questions before recording their ideas individually. The teacher encourages them to explain or justify their thinking.
INTERACTIVE/DIALOGIC

DIALOGIC HOTSPOT

What happens during this activity

After reading the article (either in groups or as a whole class) each group discusses the following questions, trying to agree an answer, before recording their ideas individually in their 'thinking files':

1. 'How is it possible for parents who are unaffected by a genetic disorder to have a child who is affected by that disorder?'
2. 'Any ideas about how an unaffected embryo is identified?'
3. 'Do you think parents should be allowed to do this?' ('yes', 'no' or 'don't know'; reasons …).
4. 'Is there anything that you'd like to know more about before deciding?'

Through brief whole-class feedback the teacher needs to:

- address any major misconceptions about the *social* consequences of the process – for example, any notion that the selected child is kept in hospital and used for spare parts as needed – and respond to requests for additional information which is not *related to the science*;
- encourage and model 'justifying' a view;
- collect/summarise ideas and questions about the science with a non-evaluative (INTERACTIVE-DIALOGIC) approach, noting that there will be an opportunity to revisit these ideas and find out more during this sequence of lessons.

Click here to watch a video clip

Don't forget to collect in the thinking files.

Teaching 'story'

Having begun to explore their understanding of inheritance through the consideration of a real life context pupils now use a card sort activity to draw out and develop their ideas about the genetic basis of inheritance. The activity encourages pupils to recognise and re-organise the knowledge they already have and so start to build up their understanding of the relationship between basic genetic structures.

Activity 1.2: Putting the structures in place

Through small group discussion of a 3-part card sort activity pupils are encouraged to *re-organise* their existing ideas and so develop a better understanding of the relationship between genetic structures. During the initial discussions the role of the teacher is to encourage pupils to think the task through *for themselves* and to *refrain* from telling them the answer.

Teaching objectives

- To explore and make explicit pupils' existing ideas.
- To encourage pupils to think for themselves by prompting them to reorganise their existing ideas.
- To make the different levels of organisation and the relationship between structures (whole organism, cell, nucleus, chromosome, DNA and gene) more explicit during the process.
- To draw on the pupils' ideas when establishing the correct scientific view.

Learning outcomes

By the end of this activity, most pupils will be able to:

- locate genes within the structure of a whole organism;
- distinguish between gene and chromosome;
- understand how basic genetic structures relate to each other and to the organism as a whole.

They will also begin to recognise their capacity to think something through *for themselves*.

What to prepare

Three sets of cards for each group:

- TERMS: gene, DNA, chromosome, nucleus, cell, organism;
- PICTURES: gene, DNA, chromosome, nucleus, cell, organism;
- DEFINITIONS: gene, DNA, chromosome, nucleus, cell, organism.

Mode of interaction

The main focus is on pupil-pupil discussion. The teacher's role is to coordinate the pupils' response into a presentation of the science. The activity moves from DIALOGIC to AUTHORITATIVE as it progresses, but remains INTERACTIVE throughout.

What happens during this activity

The class is organised into small groups (3–4 pupils); each group is given the first set of cards (TERMS) and asked to arrange them in order of size. When the group has agreed this arrangement they take the second set of cards (PICTURES) and match these to the terms. The teacher should *not comment* on the sequence they produce using the TERMS cards but should encourage them to review this sequence once they have matched the pictures to the terms. Once the group has *agreed* the second sort they take the third set of cards (DEFINITIONS), and the process is repeated. Again, they have an opportunity to change the sequence. During feedback the teacher draws on pupils' ideas to present the scientific view to the class. This might be done as an interactive whiteboard activity with individual pupils coming to the front to put a term/picture/definition into a box and the class voting to confirm that it is correct (AfL opportunity for peer and self assessment and oral feedback).

If there is disagreement about the correct order the teacher should encourage pupils to explain their reasoning. The sequence of *whole organism, cell, nucleus, chromosome, gene* is unambiguous but pupils holding scientifically valid ideas about genes and DNA might place DNA in three different positions, depending on their perspective. These are:

- smaller than a gene *because* a gene is made up of DNA;
- larger than a gene *because* a gene is one section of a much longer strand of DNA;
- larger than a chromosome *because* DNA is very tightly coiled and if it was unwound it would be very, very long.

The validity of a pupil's response can be assessed by probing their reasoning. Explanations can also reveal the source of a misconception, for example, that chromosomes are bigger than the nucleus because *'In the book there's a picture of chromosomes in a cell, and you can't see any nucleus'.*

Teaching 'story'

Having established the relationship between different structures, a series of interesting and exciting facts are used to consolidate the learning, demonstrate that the basic system is the same in all organisms, and maintain the 'Wow' factor.

Activity 1.3: Would you believe it!

The teacher presents a series of facts about genes, DNA and chromosomes with reference to a range of organisms before using a worksheet to summarise and consolidate the learning.

Teaching objectives

- To reinforce the scientific view of the relationship between structures.
- To consolidate the idea that all organisms rely on a similar genetic structure.
- To prepare the ground for lessons 3 and 4.

Learning outcomes

By the end of this activity, most pupils will be able to:

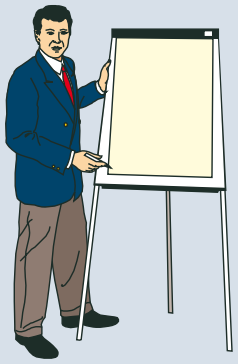
- identify the basic structures and understand how these relate to each other;
- recognise that the basic structure of all organisms, including plants, is similar.

What to prepare

- PowerPoint presentation or poster of amazing facts (see page 19).
- One copy of the worksheet ('Cells, chromosomes and genes') per pupil.

Mode of interaction

The teacher presentation and individual completion of the worksheet both focus on the correct scientific point of view: NON-INTERACTIVE/AUTHORITATIVE.



What happens during this activity

The teacher gives a lively presentation of facts about genes, DNA and chromosomes using concrete examples from a range of organisms (some examples are provided on page 19). The following ideas should be included, in preparation for lessons 3 and 4:

- chromosomes are organised into sets;
- the number of chromosomes in a set varies depending on the type of organism;
- the chromosomes within each set are different from each other; each chromosome contains a different selection of genes.

Pupils then complete the 'Cells, chromosomes and genes' worksheet individually. This is used to assess the learning outcomes for the session and may be collected in for marking or used as the basis for a quick plenary with whole class feedback and pupils marking each others' work. You will want to refer to it again in Lesson 3.

The correctly completed worksheet reads:

Cells, chromosomes and genes

- CELLS are the basic building blocks of all living things. The bulk of a human cell is made from cytoplasm and in the centre is the NUCLEUS.
- Inside the nucleus of a cell are CHROMOSOMES. The nucleus of a human cell contains 23 PAIRS of chromosomes.
- Each chromosome contains one long strand of DNA which provides genetic information.
- The DNA is divided into sections – GENES – which determine a person's inherited characteristics.

Activity 1.4: Homework

Ask pupils to find out about other examples of gene technology that have been in the news and to be prepared to talk about these during the next lesson.

Babies to Order

Read the article '*Babies to order*: *'Designer baby' saves sister's life'* then discuss the following questions in your group. Try to agree the answers as a group before writing down your individual ideas in your 'thinking file'.

1. How is it possible for parents who are unaffected to have an affected child?
2. Any ideas about how an unaffected embryo is identified?
3. Do you think parents should be allowed to do this? (Make sure you say why you think this)
4. Is there anything that you'd like to know more about before deciding?

Babies to order: 'Designer baby' saves sister's life

Friends and supporters were today celebrating the successful birth of baby Fozia. For her sister Nabila, Fozia is a life-saver - a 'designer baby' specially selected as an embryo so that she can provide Nabila with a bone marrow transplant.

Nabila has an inherited disorder, thalassaemia, and needs constant treatment, including regular blood transfusions, to survive. She badly needs a bone marrow transplant but the donor needs to be a perfect genetic match and none could be found – until now. Fozia was selected, as an embryo, because she was an exact match for Nabila.

Their delighted parents say *'We are thrilled. This has given us all new hope'*. Reactions from the public are mixed. Critics have likened the concept to producing a baby simply to harvest 'spare parts' but the HFEA* believes this is a legitimate use of new techniques saying *'This is an amazing breakthrough which has the potential to ease suffering ... and … save children's lives. There are strict conditions applying to all couples seeking this treatment and we will ensure all procedures … are highly regulated'*.

Fozia was produced using IVF techniques. Embryos were genetically screened, those which were healthy were tissue-typed to find the perfect match and the final selection (Fozia) was then implanted in her mother's womb.

**HFEA = Human Fertilisation and Embryo Authority*

AJ photo/Science Photo Library

‘Babies to order’

Background information for teachers

The ‘Babies to order’ article is based on the real case of Zain Hashmi. The background information which follows is taken from a BBC website:
www.news.bbc.co.uk/1/hi/health/2929781.stm

Why does Zain Hashmi need help?

Zain has thalassaemia major, a rare blood disorder which is thought to affect 100,000 people worldwide. Patients with this disorder are unable to make enough of a chemical vital to the construction of red blood cells. These are the cells which carry oxygen around the body to keep tissues alive – a child with severe thalassaemia will become anaemic, fail to thrive, and, if left without treatment, can die in childhood.

The normal treatment is blood transfusions, given once every three or four weeks – these supply the patient with enough red blood cells to keep going. However, over time, the level of iron in the body can build up to dangerous levels. From adulthood onwards, patients will need an extra drug to deal with this, and may have to wear a pump to infuse this slowly. Another possibility is a bone marrow transplant – the existing bone marrow cells are destroyed using chemotherapy, then new, healthy ones are transplanted in to take over their job. However, the technique requires finding a donor who is an exact match, which is very hard to do.

What causes thalassaemia?

Thalassaemia is caused by an abnormality of the gene in humans which helps produce haemoglobin, the vital chemical. People who are likely to carry the gene of thalassaemia are people with Mediterranean descent, for example Cyprus, Egypt, Greece, India, Italy, Lebanon, Malta, Middle East, Turkey and some parts of South East Asia. It is possible for people to people to carry the gene, yet only develop a relatively mild version of the illness, which may go unnoticed for years.

How can IVF doctors help?

In IVF, human embryos are created outside the body by mixing eggs and sperm together – making a so-called 'test tube baby'. A couple of days later, the best ones are selected and implanted into the woman, where a pregnancy will hopefully follow.

In this way, doctors could not only pick an embryo which did not carry the thalassaemia gene, but also pick one which was otherwise a complete genetic match for Zain. The embryo could develop into a child whose bone marrow would be the identical match needed for a bone marrow transplant. The cells needed for the transplant would be taken from the umbilical cord of the newborn baby. This technique is similar to other forms of pre-implantation genetic diagnosis (PGD), which picks out embryos likely to develop into babies with serious genetic diseases, such as muscular dystrophy.

Will it work?

Not necessarily. First, the experts must find embryos which are both free of the genetic defect, and which will produce a baby with matching umbilical cells. Doctors can carry out a Human Leukocyte Antigen (HLA) test (to find out which embryo) is genetically compatible with the sick child. This may mean that there are fewer good quality embryos than normal to re-implant into the woman, reducing her chances of successful pregnancy. Even if a child is born, there is no guarantee that the child will be cured by the infusion of cord cells or bone marrow.

What is the ethical dilemma facing doctors?

Doctors have no qualms about using umbilical cord blood from a baby in this way.

However, it is the motives of the parents in creating a child expressly for this purpose that are troubling.

Critics have likened the concept to producing a baby simply to harvest 'spare parts'.

There are concerns over whether the parents actually want another baby, and whether that baby would be valued in the same way as his or her brother.

In this case, the umbilicus is obviously surplus to requirements, and no harm comes to the baby by its use, but ethical experts would be nervous about setting any ethical precedent about the use of specially-created body parts in this way.

Why was there a court fight over this?

The pro-life group CORE (Comment on Reproductive Ethics) are opposed to the treatment. After the HFEA gave permission for the treatment to go ahead, they took the case to the High Court, arguing that the HFEA had no powers to grant permission for the procedure. The High Court judge originally agreed with CORE, and called a halt to the procedure. However, an application to the Court of Appeal was successful, and the ban was overturned.

What must couples wishing to do this do now?

The latest ruling still does not give couples and clinics *carte blanche* to carry out these procedures. Each case, including that of the Hashmis, must be considered individually. Applications to the HFEA are made via the clinic which wants to perform the procedure. The HFEA says it will take into account the likely welfare of any new child – alongside the situation of the existing child.

However, only those couples whose child suffers from a small number of genetic disorders are covered by the ruling. A couple whose child has developed leukaemia are not covered by the ruling.

Cards for 'genetic structures' card sort

TERMS

gene	nucleus
chromosome	DNA
organism	cell

DEFINITIONS

The basic unit of inheritance which allows information to pass from parent to offspring	Cell organelle which contains the genetic information
Thread-like structures in nuclei which are made up of genes	Double-stranded molecule that codes for genetic information
A living thing	The basic unit (or building block) of every living organism

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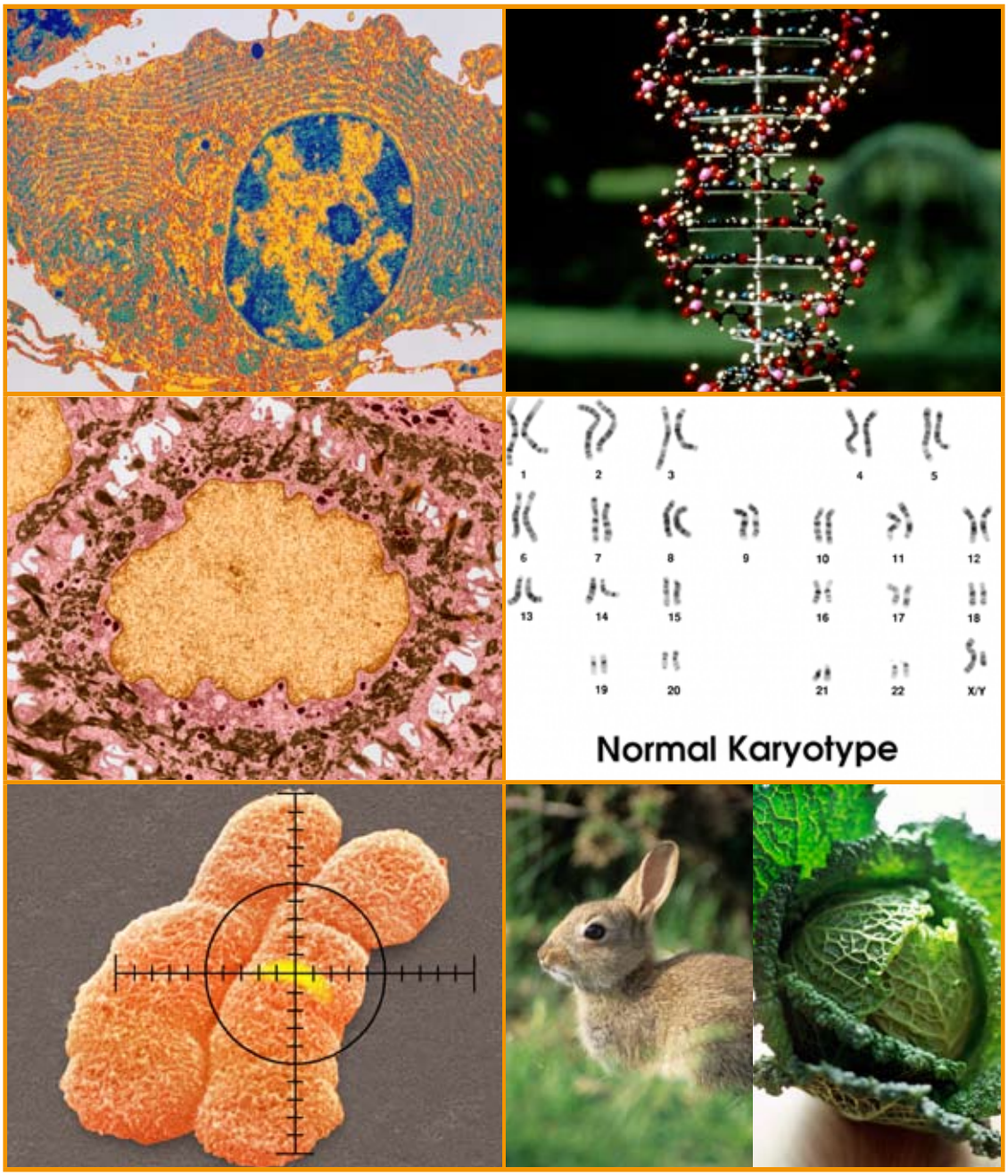
PICTURES



Clockwise from top right; Alfred Pasieka/Science Photo Library; Alain Pol, ISM/Science Photo Library; © Mediscan/Corbis; David Munns/Science Photo Library; David Aubrey/Science Photo Library; Andrew Syred/Science Photo Library; Steve Gschmeissner/Science Photo Library.

Teacher notes: Examples for 'Would you believe it?'

These are some examples to get you started but you might like to add more.

How much DNA do we have in our bodies?

- You have about 2 metres of DNA per cell and about 1,000,000,000,000 cells (one million million!) in your body!
- So… if you could unravel the chromosomes from every cell in your body the DNA would stretch to the moon and back 800 times!
- 99.9% of your DNA is exactly the same as that of the person next to you; only about 0.1% is different.

How many chromosomes in a cell?

See www.en.wikipedia.org/wiki/List_of_number_of_chromosomes_of_various_organisms for an extensive range.
The following are based on diploid (2n) numbers (you might need to explain that chromosomes occur in sets and that the cells in most organisms contain 2 sets, one from each parent; but avoid going into detail at this point).

Organism	Number of chromosomes
Mosquito	6
Potato	48
Hare	46
Human	46
Cabbage	18
Chicken	78
Kangaroo	12

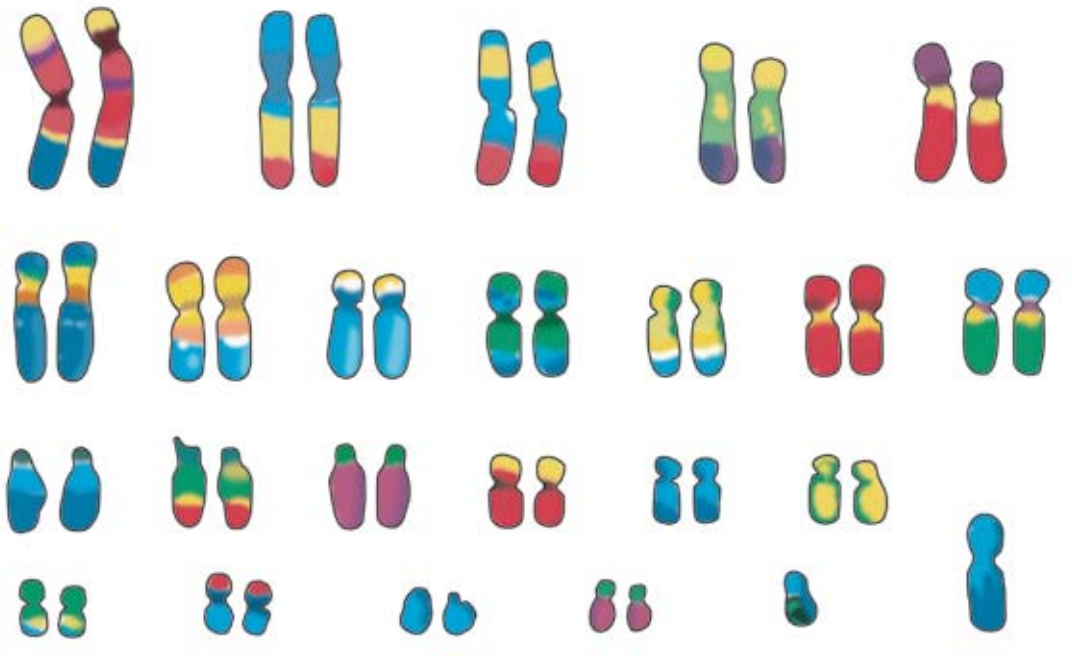
Amoebae have only 13 chromosomes but some other protozoans have 1600; some ferns have 1200+.

How many genes?

Each different chromosome contains a different set of genes.

Genes have a fixed position within any chromosome – see the photo: bands identify the position of different genes, for each pair of chromosomes the bands are in the same place.

Banding on chromosomes



Bacteria and viruses

You might want to include:

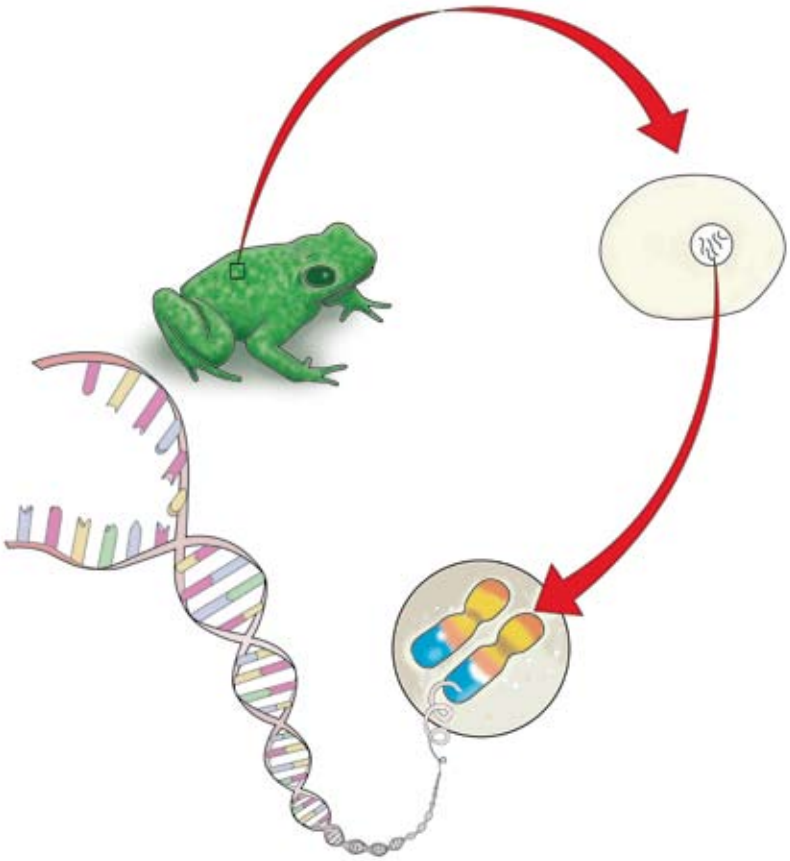
- some information on bacteria to show that they use the same basic structures – gene, DNA organised into a circular 'chromosome', cell (which is also the whole organism–and has no nucleus);
- some information on viruses, because they look spectacular, and to note they also contain genes.

Possible illustrations

(available from copyright free websites such as www.sciencephoto.com

- The moon
- Amoebae and other protozoa
- Mosquito
- Hare
- Human
- Cabbage
- Chicken
- Kangaroo
- Ferns

Cells, chromosomes and genes



Cells, chromosomes and genes

.....are the basic building blocks of all living things. The bulk of a human cell is made from cytoplasm and in the centre is the .....

Inside the nucleus of a cell are .....The nucleus of a human cell contains .....of chromosomes.

Each **chromosome** contains one long strand of .....which provides genetic information.

The DNA is divided into sections – .....– which determine a person's inherited characteristics.

Lesson 2: Turning genes on…

Teaching 'story'

This lesson explores the nature of genes, making explicit the idea of gene activation resulting in a gene product and so making more plausible the idea that, for any one individual, all body cells will carry the same genetic information. The lesson goes on to consider how these ideas can be used to explain genetic engineering. In the first activity a diagnostic question based on cell type is used to explore and challenge pupils' misconceptions.

Activity 2.1: Diagnostic question: 'Genetic information in cells'

Pupils work individually to complete the diagnostic question 'Genetic information in cells'. They are then presented with examples of gene activity which challenge a common misconception (that cells *only* contain those genes which they need to function) and are invited to reconsider their answers.

Teaching objectives

- To encourage pupils to explore and make explicit their intuitive ideas.
- To make explicit the contradictions within the class about this set of ideas.
- To provide additional information which might help pupils to resolve the problem.
- To provide pupils with an opportunity to reconsider their ideas.

Learning outcomes

By the end of this activity, most pupils will be able to:

- explain that different types of cell can carry the same genes/genetic information *because* in any one cell only some of the genes are active at any one time;
- recognise the implications of this: that when cells divide all the DNA (genes, genetic information) must be copied into each new cell.

What to prepare

- One copy of the diagnostic question 'Genetic information in cells' per pupil.
- Thinking files.

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What happens during this activity

This activity is in two distinct parts.

Part 1

Pupils complete the diagnostic question 'Genetic information in cells' individually and store their answers in their thinking file. This could be done as a 'settling' activity at the very start of the lesson. It is very important that when pupils are completing the diagnostic question they are encouraged to give the reasoning behind their answer.

Working with the whole class, the teacher uses a non-evaluative approach to review the range of responses, to make the pupils' lines of reasoning explicit and to help pupils recognise any inconsistencies in their lines of reasoning. At this stage most pupils are unaware that genes are activated according to need and that in any one cell most genes are inactive. A typical intuitive response is that cells only contain the information that they need to function. Alongside this, most pupils will have the idea that every human is unique but have little/no understanding of what this means genetically. For example:

T: 'Tom, what did you think about the two muscle cells from the same person?'

P: 'They're the same'.

T: 'So, they have the same genetic information – who agrees with Tom?'

[most of class]

T: 'OK … what was your reason Tom?'

P: 'They're the same sort of cell, do the same sort of job'.

T: 'Do you all agree?'

[more than half the class]

T: 'Anu, you're shaking your head. What reason did you give?'

P: 'Because they come from the same individual'.

T: 'OK … so we're agreed that the genetic information will be the same but we have different ideas about why that is. Let's look at the next question – a muscle cell and a nerve cell from the same person. Tahir, what did you say – do they have the same genetic information or not?'

P: 'Not, because they're different sorts of cells. They need different information to do different jobs.'

T: 'I can see that not all of you agree with that. Jane, what do you think?'

P: 'The genetic information will be the same because the cells are both from the same person.'

T: 'Hmmm… we seem to have two different ways of thinking about this. Does the next question help? Two muscle cells from two different people … Sue, what did you think?'

P: 'Different, because they're from two different people and everyone's different (unless you're a twin or something)'.

[lots of nodding heads]

T: 'I can see that most of you agree with that, but earlier most of you said that the two muscle cells would be the same because they did the same job. Can both kinds of explanation be right? This needs a bit more thinking about'.

Mode of interaction

The initial completion of the task by individual pupils is NON-INTERACTIVE and DIALOGIC.
The teacher led discussion is INTERACTIVE/DIALOGIC.

DIALOGIC HOTSPOT

Part 2

Still working with the whole class, the teacher introduces two interesting situations which might help pupils to develop their understanding of gene action. The first situation provides an explanation which makes the science plausible; the second situation provides evidence which supports the scientific view and challenges the alternative views. The questions could be used to explore pupils' ideas further, but the main purpose of this activity is to present the scientific explanation in a way which helps to make it plausible (a NON-INTERACTIVE and AUTHORITATIVE approach):

T - Have you noticed that during the summer, when a light skinned person is exposed to sunlight they develop a tan but in the winter the tan fades? Have you ever wondered why that happens? (UV light from the sun activates certain genes in the skin cells. These genes then produce a pigment, which protects the cell from UV light. As the amount of pigment in the skin cells increases the skin starts to look darker. In the winter there is less sunlight and it is less intense, the genes for skin pigment are no longer stimulated and no more pigment is produced and so as layers of skin are worn away the tan fades).

T - You've probably heard of Dolly the sheep. She was the first sheep to be cloned (from a skin cell from another sheep). If that skin cell only contained the genetic information needed to be a skin cell then the scientists would only have been able to grow more skin cells, but it didn't, so a whole new sheep grew! What does this tell us about the genetic information in cells? (This could only happen if the nucleus of that skin cell contained all the genes needed to produce a new individual. Genes which had been inactivated, because their products weren't needed in a skin cell, were re-activated in the laboratory and that single cell then had the potential to form all the different types of cell that are found in a sheep. This is why it was possible for a specialised cell to develop into a whole new sheep, but the cells of this new sheep contained exactly the same genetic information as the cells of the original sheep that the scientists took the skin cell from; this is why Dolly was a clone).

T - How is it possible that a specialised skin cell still contains all the genetic information needed to produce a whole new organism? (This is only possible if, each time a cell divides, all of the DNA is accurately copied into each of the new cells).

At this point pupils might like to make some changes to their initial response to the cells question. (*Collect thinking files in when they have done this*).

Mode of interaction

Teacher-led question, answer and presentation. INTERACTIVE/ AUTHORITATIVE.

Activity 2.2: Gene activation

Teaching 'story'

At this point pupils' acceptance and understanding of these science ideas may still be tenuous. They now have an opportunity to apply the ideas in a human context. In the process residual uncertainties and misunderstandings will be made explicit and can be addressed by the teacher. The time needed for this activity may vary depending on the extent of the misunderstandings.

This activity consolidates the ideas developed in the first activity:

- that different types of cell (from the same organism) will contain the same genes;
- that within any one cell some genes will be active and others will not;
- that gene activation results in a gene product.

It also reinforces the idea that a gene has a specific location on a specific chromosome.

Note: The focus here is on the gene, in particular the idea that a gene has a specific location on a chromosome and is associated with one specific product. The diagram shows a selection of 4 different chromosomes; the bands represent the location of different genes within each chromosome.

The idea that there are pairs of chromosomes is not introduced at this point because it is not needed for this activity. This avoids the need to talk about alleles when the intended learning relates to the gene.

Teaching objectives

- To identify and correct any residual misunderstandings.
- To consolidate the intended learning from Activity 2.1.

Learning outcomes

By the end of this activity, most pupils will be able to:

- understand that, within any one cell, only some genes will be active at any one time;
- recognise that gene activation results in a gene product.

What to prepare

- One copy of the worksheet 'Gene activation' per small group/pair.

Mode of interaction

Worksheet
Supported by the teacher, pupils work together in pairs to develop their understanding of the scientific point of view, supported by the teacher: INTERACTIVE/AUTHORITATIVE

What happens during this activity

Pupils work in pairs or small groups, using the ideas developed during Activity 2.1, to complete the worksheet 'Gene activation'. This activity compares the genes and the gene products found in a number of different specialised cells. Any type of cell could be used as an example but it is best to avoid sex cells (these could be confusing since they are not genetically identical to body cells; they will be considered during Lesson 4) and include pancreatic cells (to make the link with the next activity, which relates to insulin). The worksheet could be modified to include one copy of the diagram for each cell type, with pupils underlining the genes which would be present and ticking those which would be active. The teacher circulates, encouraging, supporting and questioning but not giving the correct answer. A teacher-led whole-class plenary, which draws on pupils' responses to confirm the correct scientific view, provides an AfL opportunity. In the process residual misunderstandings can be addressed.

The expected answer is that all cells will carry all of the labelled genes but any one gene will only be active in cells from the relevant organ. In the example here:

- gene 1 (for growth hormone) will be active in pituitary cells;
- gene 2 (for mucus) will be active in lung cells;
- gene 3 (for melanin) will be active in skin cells;
- gene 4 (for insulin) will be active in pancreatic cells.

Activity 2.3: Genetic engineering

Teaching 'story'

Pupils now have the basic ideas on which a simple explanation of genetic engineering can be built. Using pupils' examples of gene technology (homework, lesson 1) as the starting point the teacher focuses on the process of genetic engineering and presents a simple explanation of the process using insulin production as an example. Pupils' understanding of this is consolidated through the homework activity.

Teaching objective

- Starting with the pupils' own examples of gene technology, to lead into a very simple explanation of genetic engineering which builds on the science ideas developed during earlier activities.
- To encourage pupils to recognise that information in DNA is interpreted in the same way by all living things.

Learning outcomes

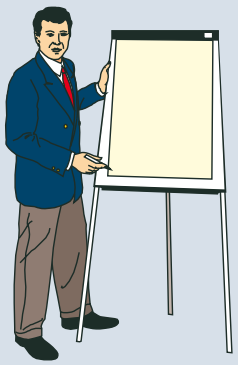
By the end of this activity, most pupils will be able to:

- apply the science ideas developed earlier to the process of genetic engineering;
- give an explanation of genetic engineering (at a basic level) which is *consistent* with the scientific explanation.

What to prepare

- One copy of the homework sheet ('Genetic engineering') per person.

The scientific explanation is presented by the teacher; pupils then work with this explanation to reinforce their understanding: NON-INTERACTIVE / AUTHORITATIVE.



What happens during this activity

Pupils draw on their homework task from Lesson 1 to identify current uses of gene technology. The teacher moves the focus of the talk to one particular use of gene technology, genetic engineering, noting that 'we can use the ideas from today's lesson to explain how this works'. The story of genetically engineered insulin, structured around today's homework sheet, is then presented.

Explanation of how insulin is produced by genetic engineering.

This explanation uses the ideas already developed during this lesson and also makes explicit the idea that all organisms use the same genetic language/code.

Key points include:

- one of the first successful applications of genetic engineering was the production of insulin for the treatment of diabetes;
- insulin is produced in response to glucose in the blood and is very important in controlling blood sugar levels; without insulin a person becomes very ill and can die;
- some people (diabetics) cannot make their own insulin in response to glucose; they need regular injections of insulin to survive;
- the insulin used to treat diabetics was originally extracted from animals such as pigs; this was not ideal, particularly as there are some differences between pig insulin and human insulin;
- because all body cells contain all our genetic information our cheek cells are a useful (and painless) way of accessing our genes;

(*optional information*: this is why the police use cheek swabs for DNA testing);

- starting with just a few cheek cells, taken from someone who was not diabetic, scientists were able to identify the gene which makes insulin;
- using a FIND – COPY – PASTE technique they transferred that gene from the cheek cells to bacterial cells:
  - they broke open the cheek cells to release the DNA;
  - **found** the gene for insulin;
  - **copied** this gene thousands of time and then mixed it with bacteria;
  - some of the bacteria picked up this extra DNA and '**pasted**' it into their own DNA;
- once in the bacterial cell, the insulin gene was activated to produce insulin whenever the bacterial gene next to it was activated, and each time the bacterial cell copied its DNA ready for cell division the insulin gene was copied too;
- when grown in liquid a bacterial cell can divide every 40 minutes; soon there were *millions* of bacteria cells producing insulin;
- all the scientists had to do then was extract the insulin from the liquid;
- the bacteria carried on dividing and carried on producing insulin, so we now have insulin 'on tap'.

If time allows, this could be modelled through a role-play:

- select 5–6 pupils to link arms in a chain to represent genes on a chromosome; give one of them a card saying 'insulin';
- select another 5–6 pupils to link arms and form a circle, to represent genes in bacterial DNA;
- select one pupil to represent enzyme activity (provide them with large cardboard scissors, alternatively ask the pupil to make extravagant scissor motions with their arms);
- the 'enzyme' pupil 'cuts' the links on each side of the insulin gene, moves the insulin gene across the room to the bacterial DNA; cuts open one link in the bacterial chain and 'pastes' in the insulin gene.

This story may raise questions about similarities and differences between DNA from different organisms. Some pupils may express the view that this is not really possible, for example that:

'It's obvious, sheep have sheep DNA and people have human DNA. If a sheep had human DNA it would be going round walking and talking like a human!'

Metaphors or analogies relating to language may be helpful in explaining this. For example:

'Information in the DNA is only written in one language (the 'genetic code') so all organisms must use the same language. This is why it is possible for a bacteria cell (or a sheep cell) to use information from a human gene to make insulin.'

Activity 2.3: Homework/plenary session

Pupils apply their developing understanding of key genetic concepts to explain the process of genetic engineering (an opportunity for AfL: self assessment).

Part 1 and 2

The task might be modified so that pupils:

- use arrows to link statements to unfinished sentences in boxes;

or

- copy statements to finish sentences in boxes; (This is the lowest level of interaction)

or

- finish the sentences in their own words and discussing with another group.

The answers to the questions are:

Box 1: A mouth swab is used to collect cheek cells.

Each one of these cells will contain the gene for insulin. This is because…

'… every cell in a person's body contains the same chromosomes, hence the same DNA, the same genes and the same genetic information.'

Box 2: The cheek cells are broken open to release the chromosomes.

This is important because …

'… genes are found in DNA, which the chromosomes are made of'.

Box 5: The bacterial cells rapidly divide to produce millions of cells, each containing the gene for insulin.

This is possible because …

'…. in cell division, all the genetic information (DNA) is accurately copied into each new cell'.

Box 6: These cells produce insulin, which is collected and used in the treatment of diabetes.

This shows that …

'…. genetic information in DNA is understood in exactly the same way by all living things'.

Part 3

An alternative to this activity is to use the diagram 'Genetic engineering' as a 'good enough' model.

Ask pupils to:

- Research the production of insulin using a variety of sources
- Evaluate the strengths and weaknesses of the model provided in the diagram in pairs
- Suggest an alternative model that is appropriate to explain insulin production.

This may lead to further discussion around the removal of the insulin gene as part of a piece of human DNA that is inserted into a circle of bacterial DNA (plasmid) and its role in the multiplication of the gene in insulin production.

Genetic information in cells

These two groups of skin cells are from the same person. Is the genetic information in these cells the same or different? (circle one response)

Same **Different** **Don't know**

Why do you think this?

These are some skin cells and a nerve cell from the same person. Is the genetic information in these cells the same or different? (circle one response)

Same **Different** **Don't know**

Why do you think this?

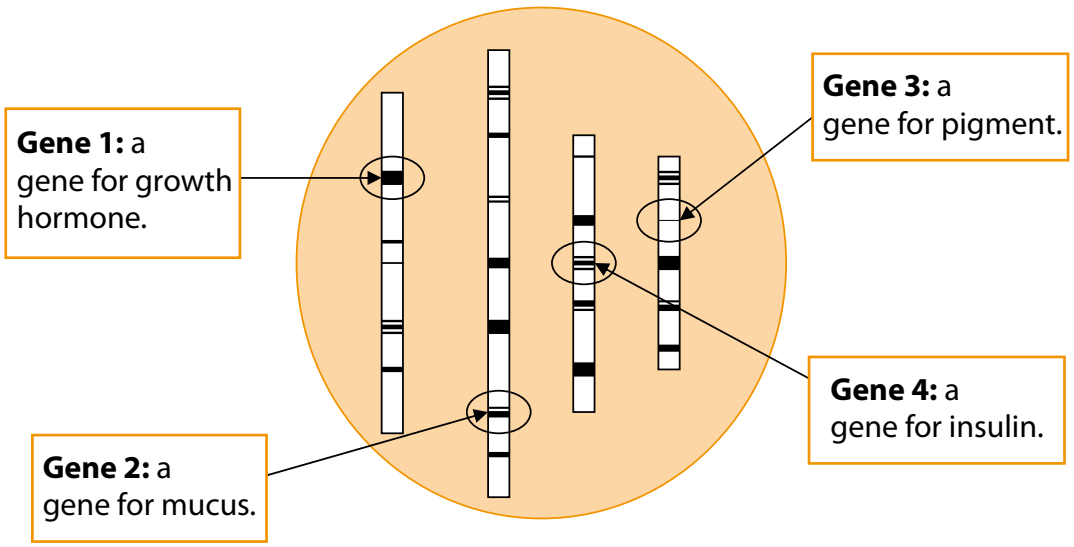
These two groups of skin cells are from two different people. Is the genetic information in these cells the same or different? (circle one response)

Same **Different** **Don't know**

Why do you think this?

Gene activation

The diagram below shows just some of the chromosomes found in the nucleus of a person's cells. Some important genes have been identified.



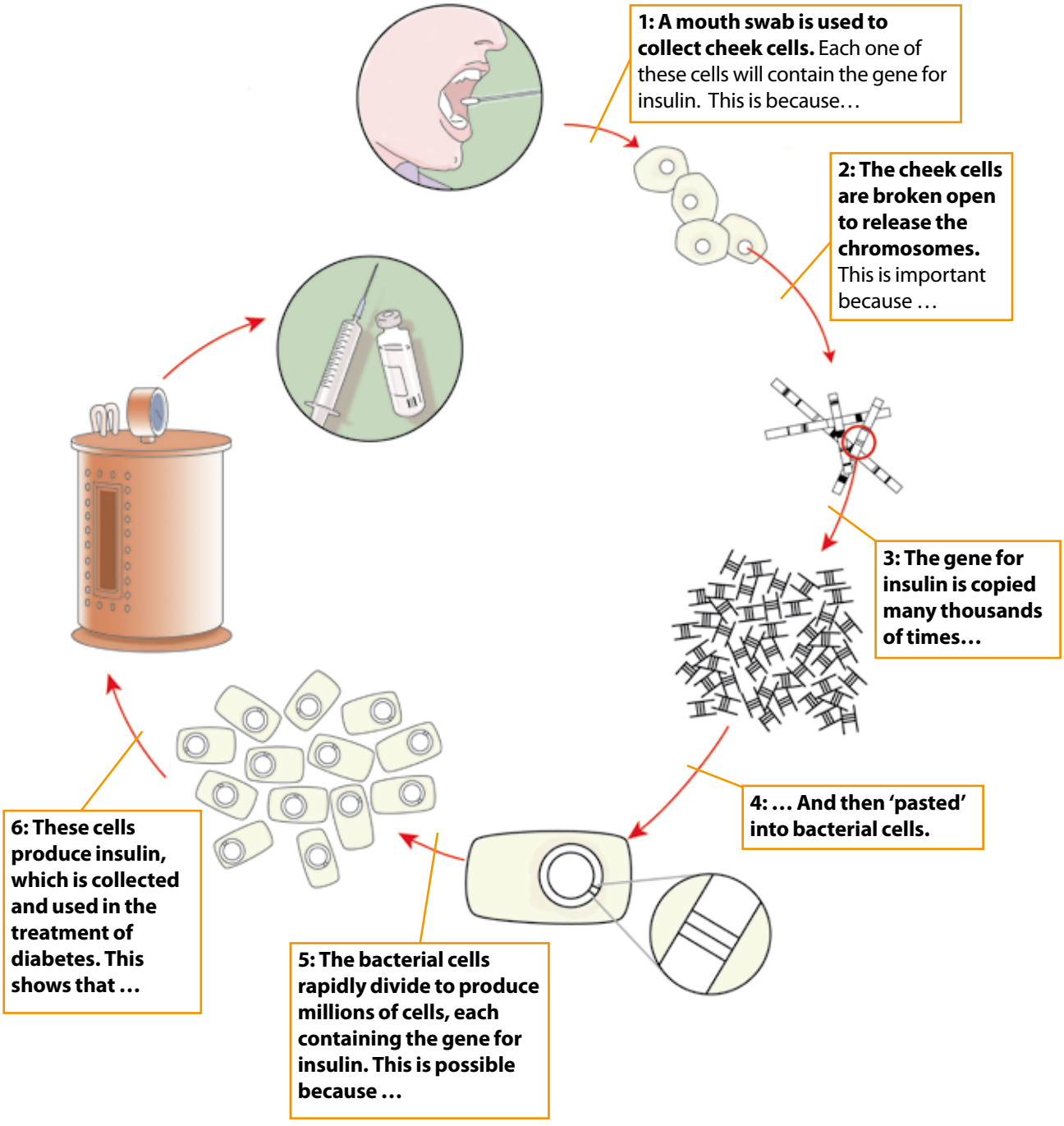
For each type of cell listed in the box below agree and record:

1. which of these genes are present in the cell;
2. which of these genes are active.

Say why you think this.

Cells from …	Genes present …	Genes active …	Reasons for your answer
Skin			
Lungs			
Pancreas			
Pituitary gland			

Genetic engineering



Part 1: Select from the following statements to complete the sentences:

'…genetic information in DNA is understood in exactly the same way by all living things'

'… genes are found in DNA, which the chromosomes are made of'

'… when a gene is activated there is a product'

'… every cell in a person's body contains the same chromosomes, hence the same DNA the same genes and the same genetic information.'

'…cell division, all the genetic information (DNA) is accurately copied into each new cell'

Part 2: There will be one statement left over. Use this to write one more sentence about the production of insulin.

Part 3: The diagram 'Genetic engineering' is a model used to explain simply how insulin is produced artificially.

Using the ideas in your thinking file and further research, suggest either:

- An alternate model to explain the production of insulin
- How the model (diagram) may be modified to explain how insulin is produced.

Lesson 3: All the same… (cell division for growth)

Teaching 'story'

This lesson presents cell division for growth (mitosis) from the perspective of the need to copy genetic information accurately. Ideas developed during lessons 1 and 2 are used to setup a very simple explanation of the processes in a broader genetic context, leading to a consideration of the genetic implications, both natural (asexual reproduction) and manufactured (cloning). It begins with an opportunity for pupils to model the process of mitotic cell division through three cycles and see the outcome for themselves.

Activity 3.1: Cell division for growth – the need to copy genetic information

This activity starts with a quick recap of key points from the last lesson, leading to an explanation of the process and how it results in accurate copying of the genetic information. Pupils then have an opportunity to model the process for themselves and to see the outcome.

Note: The focus of this explanation is the idea of copying the chromosome accurately so that each new cell gets a full copy of all the genetic information.

The idea of pairs of chromosomes is not needed in this explanation and so is not included. This helps to reduce some of the confusion between copies of a chromosome (the chromatids) and pairs of chromosomes.

The term 'chromatid' is not used in the explanation but could be introduced afterwards, once the key points of the process have been understood.

Teaching objective

- To model the process of cell division for growth.
- To support pupils in their use of this model.
- To encourage pupils to interpret the outcome of this modelling process and to recognise for themselves that the process can result in a rapid increase in cell numbers (growth) while maintaining the same genetic information in all cells.

Learning outcomes

By the end of this activity, most pupils will be able to:

- demonstrate how cells produced by mitosis all contain the same genetic information.

What to prepare

- Modelling materials ('Modelling mitosis' template);
- Scissors;
- Reusable sticky pads (sufficient for each pair of pupils to model 3 successive cell divisions).

Please also see www.sumanasonic.com/webcontent/animations/content/mitosis.html

Mode of interaction

The teacher presents a simple explanation; pupils work in pairs to model this: INTERACTIVE/ AUTHORITATIVE.

What happens in this activity

Begin by recapping some of the ideas from previous lessons (this could be developed as a starter/settling activity). The story that the pupils need to remember is that:

- most organisms start life as a single cell and grow by cell division;
- as the number of cells increase, many become specialised for different functions (muscle, nerve etc);
- even specialised cells still retain all the genetic information needed to produce a whole new organism (ref: Dolly the Sheep);
- this means that genetic information in the original cell must be copied accurately into each new cell at each cell division.

(They may also need reminding that DNA, and the genes within it, are stored in chromosomes [ref: 'Cells, chromosomes and genes' worksheet, lesson 1])

Introduce the explanation of cell division for growth (mitosis) by noting that what we now need is an explanation of how this is can happen.

Begin with a simple explanation (illustrated by a short video clip) which focuses on the fact that the chromosomes (and hence the DNA/genes within it) are copied and the copies then separate into the new cells.

Note: It is best to avoid the term 'chromatid' at this point and to talk instead about 'chromosomes' and 'copies of chromosomes'.

The combination of video and spoken explanation should help pupils to understand *and visualise* the basic process. The modelling exercise which follows on from this should help them to understand the consequence of *successive* cell divisions. Working in pairs, pupils are provided with sufficient cardboard cut-outs of cells and chromosomes to model three successive cell divisions. Note that for simplicity this model contains only two chromosomes. Real cells obviously contain more chromosomes but their behaviour (and the consequences) would be exactly the same. Model the first cell division with the pupils (see the templates).

Prepare the basic cell: take one 'cell' and place two chromosomes (one large, one small) inside it using reusable sticky pads;

Copy the chromosomes: take another large chromosome and stick it onto the first one; take another small chromosome and stick this onto the first small chromosome;

Separate the chromosome copies to produce two new cells: take another cardboard cell; transfer one copy of the large chromosome and one copy of the small chromosome into the new cell;

Result: two cells, each containing the same set of chromosomes.

For the second division both of these cells are copied, using the same technique, resulting in four cells, each containing the same set of chromosomes; for the third division the four cells from the second division are copied, using the same technique, resulting in eight cells, each containing the same set of chromosomes. Encourage pupils to think about the outcome by asking them to record the number of cells that are produced after three divisions and to compare and comment on the chromosome content of these.

Teaching 'story'

The next activity illustrates the biological possibilities that result from this accurate copying process. While it draws on, and makes use of, pupils' existing knowledge, it is mainly teacher-led and relatively quick. The aim is to make explicit the genetic basis of 'everyday' phenomena (plant propagation, twins etc.) then show how the same ideas can be applied in gene technology.

Activity 3.2: Asexual reproduction and cloning

This activity uses the products of the previous activity – the 8 cells, each with copies of the same 2 chromosomes (or previously prepared larger versions which can be stuck on the board or wall) – to model asexual reproduction and cloning.

Teaching objectives

- To help pupils to visualise how the ideas from Activity 3.1 can be used to explain familiar phenomena.
- For pupils to understand gene technology in terms of these ideas.

Learning outcomes

By the end of this activity, most pupils will be able to:

- explain, for example, how identical twins are formed and why they are genetically identical;
- give a simple explanation of embryo selection.

What to prepare

Optional:

- larger 'demonstration' set of model from Activity 3.1;
- spider plant showing asexual reproduction in plants.

Mode of interaction

The teacher presents the scientific explanation in a way which encourages the pupils to think: INTERACTIVE/ AUTHORITATIVE.

What happens during this activity

Building on Activity 3.1, the teacher uses the cell model to illustrate the genetic basis of asexual reproduction and cloning. The explanation is divided into two parts. The first uses naturally occurring examples to illustrate the general point. The second shows how the principle can be applied in gene technology. The approach is:

Display the 8 cells produced by activity 3.1 as a cohesive mass: note that as an organism grows by cell division the cells usually stick together.

Separate the single mass into two: ask 'If this happened, what would be the result?'. Give pupils time to think about this and if necessary stimulate their thinking by asking questions such as *'Have you ever noticed that if you break off a piece of a plant and put the broken bit in the soil it grows into a new plant?', 'Do you know any identical twins? What makes them identical?' and if need be 'Do you think this model could explain … why it's possible to grow new plants from cuttings; how identical twins are formed?'*. Provide an explanation (ideally, confirming the pupils' explanation) for plants and/or identical twins which emphasises (i) that because each cell contains all the genetic information of the original cell, both sets of cells can develop into a whole new organism and (ii) because both sets of cells originally came from the **same cell** the two new organisms are genetically identical – they are **clones**.

Make the following points:

1. identical twins are naturally occurring but can only form during the very early stages of development, before cells start to specialise; once cells specialise some genes are permanently de-activated;
2. in plants, genes do not seem to be de-activated in the same way and they retain the ability to form whole new plants from small pieces; this process of **asexual reproduction** occurs naturally; when a plant reproduces in this way it produces **clones** of itself;
3. scientists can make use of this genetic potential in gene technology.

Reassemble the cells into a single mass then separate out one cell: ask 'If this was a human embryo, what would happen to the remaining mass of cells?' [Answer: grow into a normal baby; opportunity for AfL self assessment – how have they understood the preceding work, can they apply it to this new context?]. Correct any misunderstandings and note that this is the basis of embryo selection – one cell is removed for genetic testing, if the result is positive the embryo is allowed to develop as normal. This may raise questions and ethical issues, in particular, what happens to embryos which are not selected. You will want to consider, in advance, how you will respond to such questions. The HFEA (www.hfea.gov.uk) will be able to provide the most up to date information on this. Remember, the aim at this point is to focus on the science rather than the related ethical issues (there will be an opportunity to discuss ethical issues in Lesson 5). In this context a 'safe' answer (one which is least likely to provoke further discussion) is that, usually, surplus embryos are stored for future use.

Reassemble the cells into a single mass: remind pupils that these were all formed from one original cell; note that the transfer of a useful gene from one organism to another is not very efficient – genetic engineering is an expensive process. Ask *'If these were cells from a genetically engineered organism, and we wanted to make clones of this organism, what could we do?'*

Scatter the cells, as if pushed through a fine sieve: note that if these were plant cells, or unspecialised animal cells, each cell has the potential to form a new individual.

Activity 3.3: Do clones look identical?

Teaching 'story'

The activities so far have emphasised the genetically identical nature of clones, moving from single genes to whole organisms. The next activity reminds pupils that even genetically identical organisms may show physical differences due to environmental factors.

A short activity taken from an interactive website is used to consider the impact of environmental factors on identical twins (clones). This could be undertaken as a whole class activity, inviting individual pupils to make each decision, or by pupils working in pairs. It doesn't really matter what decisions the pupils make; the end result demonstrates the purpose of this activity – that environmental factors also contribute to variation.

Teaching objective

- To help pupils to visualise the impact of environmental factors on variation.

Learning outcomes

By the end of this activity, most pupils will be able to:

- explain why clones do not always look identical.

What to prepare

This activity makes use of an interactive sequence where the possible impact of environmental factors on the development of twins is explored.

The main website is: The Centre of the Cell website www.centreofthecell.org

Follow the links:

Twins interactive: www.centreofthecell.org/interactives/twins/index.php

All about cells: www.centreofthecell.org/centre/?page_id=1&ks=3

One cell made you: www.centreofthecell.org/centre/?page_id=22&ks=3

Mode of interaction

This activity might be organised in a number of different ways depending on access to computers but the aim is to make it as INTERACTIVE as possible. The approach is AUTHORITATIVE.

What happens during this activity

Explore pupils' awareness of environmental variation by posing the question:

'Do clones look identical?'

Use the interactive website, in pupil pairs or as a whole class demonstration with pupil participation, to illustrate the impact of the environment on identical twins.

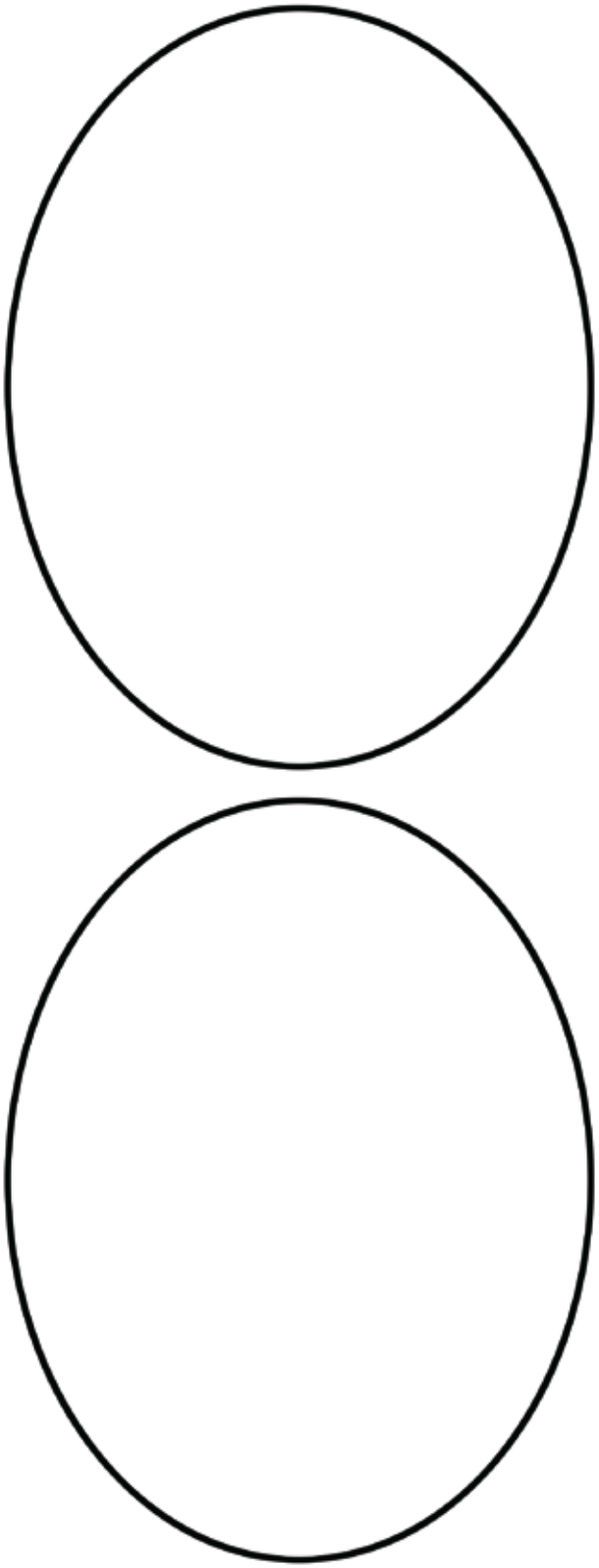
If there is time also present some plant examples, for example, the effect of soil pH on the colour of hydrangeas.

Homework

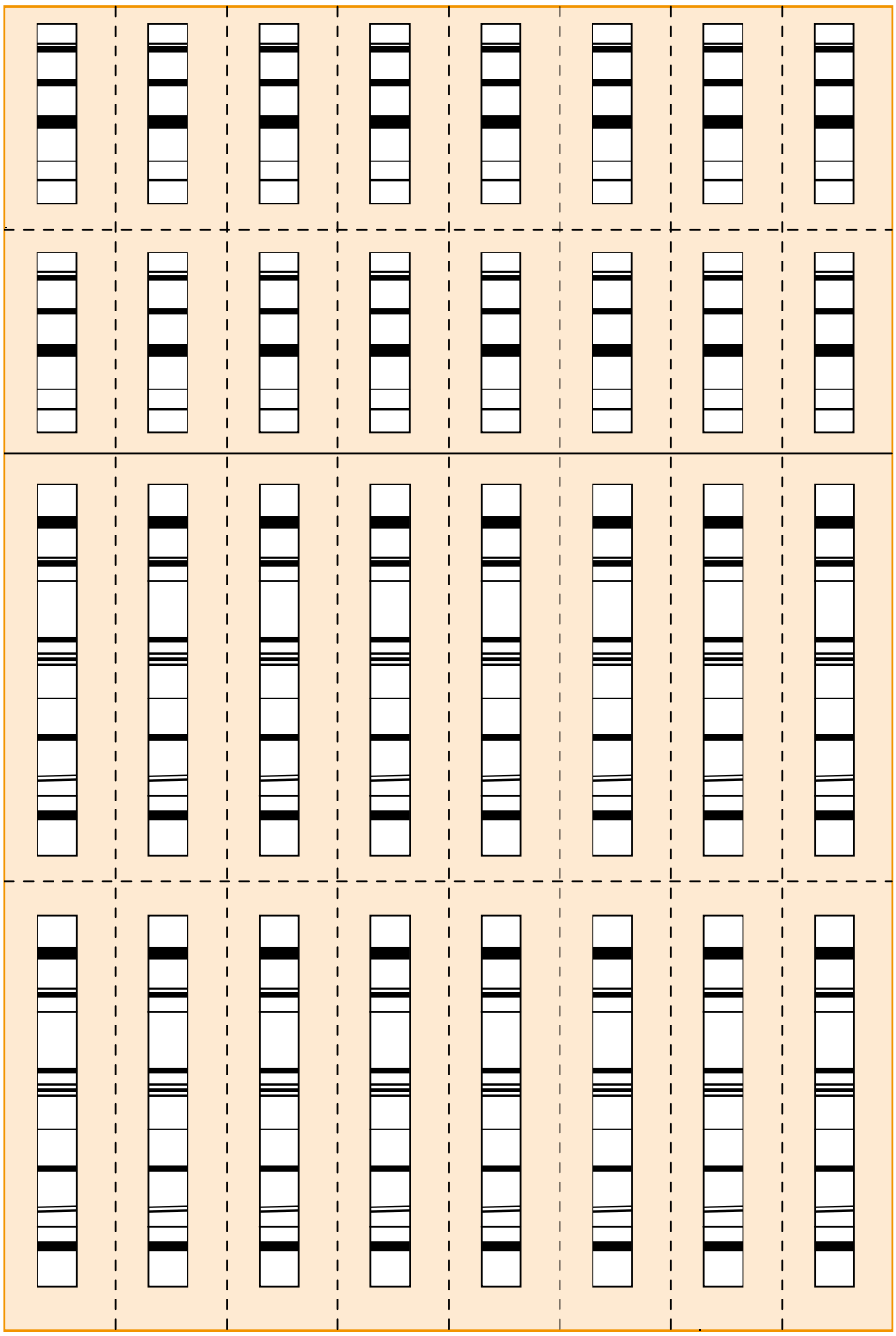
Ask pupils to use the ideas from this lesson to review and revise their response to Q2 of 'Babies to order'. They might also want to reconsider their ideas in response to Q3 – if so, encourage them to note their reasons.

Revised responses will need to be returned to pupils' thinking files before the final lesson.

3.1: Template for modelling mitosis: cells



3.1: Template for modelling mitosis: chromosomes



3.1: Teachers' notes

Each group of pupils will need a minimum of 8 blank 'cells', 8 large chromosomes and 8 small chromosomes. The template can be sliced along the dotted lines – no need to cut around the chromosomes. For demonstration purposes it might be helpful to have one larger set on card cut out.

Lesson 4: So why bother with sex?!

Teaching 'story'

This lesson draws on ideas developed in the previous lessons to consider the special case of cell division as preparation for sexual reproduction (meiosis). Having made the case for cell division in which genetic information is copied, the case for a second type of cell division, in which genetic information is halved, now needs to be presented. The emphasis is on genetic variation and the way in which meiotic cell division and subsequent fertilisation increases variation between individuals. In the process the importance of the distinction between genes and alleles is made very explicit and the idea of 'dominance' is presented. There are two brief, teacher-led, explanations of the basic science. The first explanation introduces the idea that chromosomes normally occur in pairs; the second considers the implications of this and introduces the concept of alleles. Both sets of ideas are reinforced through a series of role-plays. The lesson begins with a starter activity in which pupils identify the potential problem of sexual reproduction (exponential increase in the number of chromosomes), demonstrating the need for a different kind of cell division to overcome this.

Activity 4.1: Is more better?

This starter/settling activity allows pupils to explore the potential outcome of fertilisation if it were not preceded by a reduction division.

Teaching objectives

- To encourage pupils to consider why a second type of cell division might be needed if sexual reproduction is to succeed.

Learning outcomes

By the end of this activity, most pupils will be able to:

- explain why sexual reproduction is unsustainable if there is no reduction in the number of chromosomes.

What to prepare

- 1 worksheet 'Fertilisation' per pupil.

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Mode of interaction

Pupils work in pairs to calculate chromosome number: INTERACTIVE/ AUTHORITATIVE.

What happens during this activity

In this quick starter activity pupils work in pairs to calculate the number of chromosomes in a cell after six successive rounds of 'fertilisation'. This raises the question *'Does the number of chromosomes in a cell matter?'* and provides an explanation for why a second type of cell division, which reduces the number of chromosomes, is needed. In confirming that chromosome number, and the *amount* of genetic information does matter, it might be helpful to remind pupils that different types of organisms have different, but specified, numbers of chromosomes (Lesson 1, Activity 1.3) and/or refer to Downs or other syndromes linked to additional chromosomal material.

Note: Downs Syndrome results when one pair of chromosomes fails to separate during meiosis and the resulting individual has one additional chromosome. For more information see: www.bbc.co.uk/health/conditions/downssyndrome1.shtml

Activity 4.2: A simple explanation of meiosis

Teaching 'story'

Having justified the need for a second type of cell division, a simple explanation of meiosis, in which there is minimal use of terminology or detail, is presented. The intention is to present the key ideas in a way that is easy to understand, and to reinforce these by modelling the simplified version on the whiteboard. This explanation introduces the idea of pairs of chromosomes. The concept of alleles is not needed and they should not be mentioned here.

Teaching objective

- To help pupils to visualise and understand chromosome behaviour during meiosis and fertilisation.
- To encourage pupils to question the purpose of meiosis and fertilisation.

Learning outcomes

By the end of this activity, most pupils will be able to:

- explain how it is that meiosis results in cells that contain exactly half the number of chromosomes but the same set of genes.

What to prepare

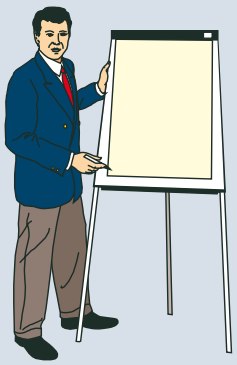
- Materials for modelling meiosis (see meiosis 'template');
- Photo of normal female karyotype, with chromosomes presented in matched pairs.

Note for non-specialist teachers

A karyotype is the observed characteristics (number, type, shape etc) of the chromosomes of an individual or species (for more information see: www.en.wikipedia.org/wiki/Karyotype). In the human female the two sex chromosomes (XX) are a matching pair; in the human male the two sex chromosomes (XY) are very different in appearance – unlike all the other pairs, this 'pair' *don't* match. This is an unnecessary complication at this stage in the explanation, which is why a female karyotype is chosen.

Mode of interaction

The teacher uses a NON-INTERACTIVE,/ AUTHORITATIVE approach to present a simple explanation of the science.



What happens during the activity

The teacher presents a very simple account of how the chromosome number is reduced in preparation for sexual reproduction. This *brief* explanation, which focuses on the genetic implications in terms of **sets** of chromosomes and genes, refers to the situation in humans. *Alleles are deliberately* **NOT** *mentioned at this point*. Research shows that Key Stage 4 (and older) pupils find it very difficult to distinguish between a gene and an allele, even after teaching. This very simple explanation of meiosis is focused on the way in which **sets** of chromosomes (and the genes within them) are separated to produce sex cells which can then combine (at fertilisation) to produce a new individual with *two sets* of chromosomes (and genes). Alleles are not essential to this explanation so, to avoid the risk of confusion with genes, they are not included. They are explained fully at the point where they are needed – in preparation for an explanation of inheritance (Activity 4.3).

Meiosis

The focus of this explanation is the role and origin of paired chromosomes.

The concept of alleles is not needed to explain meiosis and should not be included at this point – they will be introduced in the next activity, where the genetic implications of meiosis and fertilisation are considered.

A simple explanation: the key steps in the story

- for any one type of organism there is a specific number of chromosomes per cell (use the karyotype to illustrate that human cells have 46 chromosomes);
- in body cells there are two sets of chromosomes (use the karyotype to illustrate that there are two sets of 23 chromosomes);
- within a set, each chromosome is different and carries a different and distinctive set of genes (reminder: Lesson 1, Activity 1.3) (use the karyotype to illustrate that each chromosome within a set has a different size, shape and pattern of banding; remind pupils that particular genes are associated with specific bands);
- because body cells contain two sets of chromosomes, each different chromosome, and each gene within it, occurs twice (use the karyoptype to show that pairs of chromosomes have a similar pattern of bands – these relate to the position of specific genes);
- in the production of sex cells (sperm and egg) pairs of chromosomes separate so that each sex cell has just one set of chromosomes (23 in humans) – each chromosome and each gene occur only once;
- at fertilisation male and female cells fuse to form a new individual with two sets of chromosomes (46 in humans) – each chromosome and each gene occur twice.

Model a simplified version of this process with reference to an imaginary animal with just three chromosomes per set (see the guidance below). For this you will need 1 sperm cell and 2 round cells + 3 sets of 3 chromosomes (see Template 4.2). You may want to practise this demonstration before using it in the classroom.

Modelling a simple explanation of meiosis

Step 1: Assemble one body cell (2 sets of chromosomes): take one round 'cell' + two sets of three chromosomes; stick the six chromosomes into the cell, randomly.

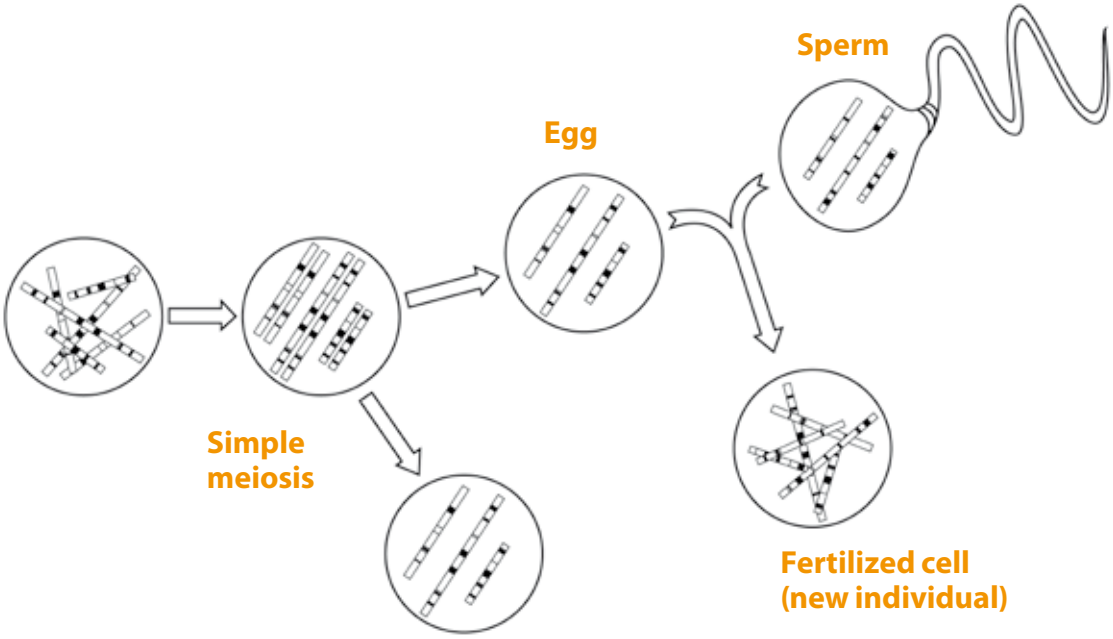
Step 2: Show how pairs of chromosomes can line up: re-arrange the chromosomes so that pairs are lined up next to each other;

Step 3: Model separation of pairs into separate cells: separate each pair, moving one into a new cell; the result is two cells (eggs), each with one set of three chromosomes;

Step 4: Note that sperm are produced in the same way: put up a sperm cell (one set of three chromosomes);

Step 5: Fertilise: take one egg cell and 'fertilize' with the sperm cell by moving the chromosomes from sperm to egg. The result is a fertilized cell (new individual) with two sets of three chromosomes – back where we started.

Note: the main idea you want your pupils to understand at this point is the ability of matching chromosomes to pair up, resulting in accurate separation of the two sets of chromosomes. Be explicit about this – *'The exact process is more complicated but we are focussing on the key feature'*. It will be necessary to explain the steps in meiosis is eventually to prevent confusion with mitosis.



Note that the net result appears to be no change and wonder aloud – '*what's the point?*' ('*why bother with sex?!*'). The one word answer is 'variation'. The next two activities show how that variation comes about.

Activity 4.3: A simple explanation of alleles

Teaching 'story'

Understanding variation at the gene level means understanding the difference between a gene and an allele and understanding what happens to alleles during meiosis and fertilisation. This next activity presents a simple explanation of the difference between genes and alleles and of the dominant/recessive relationship, which arises when a pair of genes carries different alleles.

Teaching objective

- To make explicit, and help pupils to understand, the difference between a gene and an allele;
- To help pupils to understand why we need to consider the concept of dominance in relation to a pair of alleles;
- To help pupils to understand that 'dominance' defines the relationship between a specified pair of alleles.

Learning outcomes

By the end of this activity, most pupils will be able to:

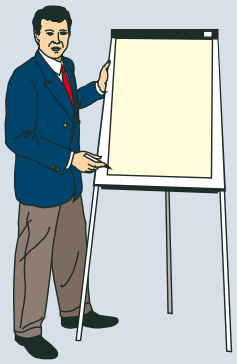
- distinguish between a gene and an allele;
- explain the concept of dominance.

What to prepare

- Nothing.

Mode of interaction

The teacher presents the key concepts as simply as possible, being careful to explain the difference between genes and alleles in ways that are meaningful to the pupils: NON-INTERACTIVE/ AUTHORITATIVE.



What happens during the activity

The example of a gene for fur colour is used to illustrate the difference between a gene and an allele. This simple explanation should be very brief and straightforward. The concept will be illustrated in more detail during the next activity, where it is used to explain inheritance.

The difference between a gene and an allele

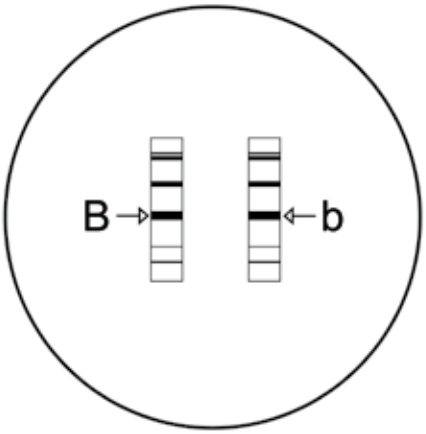
The focus of this explanation is the distinction between a gene and an allele and the genetic implications of this when chromosomes are paired.

To make the explanation more credible, an animal example is chosen rather than Mendel's peas – this is because many pupils find it difficult to accept that sexual reproduction (the source of the paired chromosomes) can occur in plants.

A simple explanation: key steps in the story

- a recap of the key points from activity 4.2: that chromosomes occur in pairs in normal body cells and this means that each cell carries two copies of each gene (e.g. for fur colour);
- the two copies of a gene have the same function (i.e. they determine fur colour) but the genetic information within them (the exact sequence of DNA) may vary (e.g. may indicate black fur or may indicate white fur);
- these different forms of a gene are called alleles;
- if a pair of genes carry two different alleles (e.g. one 'black' and one 'white') then the resulting characteristic (fur colour) is determined by the relationship between the two different alleles; in the case of fur colour, the black allele produces a pigment, the white allele does not, so the end result is an animal with black fur; in this circumstance the black allele is said to be dominant to the white allele – the dominant allele is the one which determines the characteristic;
- the convention is to use a letter to denote the gene and upper or lower case to denote dominant and recessive (in this case 'B' for the black fur allele and 'b' for the white fur allele);
- when the two alleles are the same (BB, bb) they are called homozygous; when they are different (Bb) they are called heterozygous.

Note: This explanation could be illustrated using the representation of a body cell from activity 4.2, selecting a band on one pair of chromosomes and labelling them B and b.



Note for teachers

Remember that dominance is determined by the relationship between two alleles. Where there are several possible alleles for a single gene the status of any allele may vary. For example, there are three alleles for the determination of ABO blood groups; if A combines with O it is dominant and the result is blood group A; if A combines with B the two alleles are co-dominant and both are expressed, resulting in blood group AB.

Activity 4.4: Implications for variation

Teaching 'story'

Role-play, supported by a writing frame, is now used to demonstrate how the concept of alleles can be used to explain inheritance and genetic variation. The full story – from the alleles, which determine parental characteristics, to the genetic information in the sex cells, to the characteristics of the offspring – is made explicit. The writing frame helps pupils to follow the flow of the process and provides a tool which they can use to support the development of their own explanations.

Teaching objectives

- To help pupils to visualise and make sense of the mechanism by which sexual reproduction leads to variation.
- To support pupils in making the genetic links between the different processes involved in inheritance (meiosis, fertilisation, and the impact of chance and probability).
- To help pupils to develop an awareness of the different levels at which the process of inheritance acts.

Learning outcomes

By the end of this activity, most pupils will be able to:

- use the writing frame to make predictions about the inheritance of a particular characteristic;
- explain the process of inheritance and how it results in variation.

What to prepare

- Materials for a sequence of role-plays (see 'role-play' template);
- Copies of the writing frame;
- Materials for the plenary session (optional).

Mode of interaction

All pupils participate in the role-play and interpret the end result, which the teacher summarises within the writing frame: INTERACTIVE / AUTHORITATIVE.

What happens during this activity

A series of role-plays, supported by the writing frame, demonstrate how parental alleles (parental genotypes) influence the possible characteristics of their offspring (the phenotypes of the offspring). Possible combinations of parental genotypes, using fur colour as the gene, include:

a. homozygous black (BB) x homozygous white (bb);

b. heterozygous black (Bb) x homozygous white (bb);

c. heterozygous black (Bb) x heterozygous black (Bb).

Try to include a plant example too, for example, a gene for sweetness in tomatoes with a sweet allele (S) and a flavourless allele (s). Punnett Squares are a convenient way of recording the outcomes of sexual reproduction, but many pupils find it difficult to accept that sexual reproduction occurs in plants – *because plants can't move*. To explore this, and before starting this particular role play, ask the question '*Do plants have sex?*'. Your pupils may need reminding that sexual reproduction refers to the fusing of two cells from different parents to form one new cell/individual, not the process by which that fusion is brought about – plants may be stationary but they can still exchange cells, courtesy of pollinating insects, for example.

The role of the teacher

- Using the writing frame to support your explanation, introduce the parents (for example homozygous black and homozygous white). Record their alleles in the writing frame.
- Ask '*what happens during the production of eggs/sperm?*'. As each possible outcome is recorded in the writing frame distribute the appropriate 'sex cell' card to one quarter of the pupils (see role-play template).
- Introduce the concept of the Punnett Square, using arrows to show how the products of meiosis (the sex cells) feed into it. You are now ready to consider the possible outcomes of fertilisation.
- Ask pupils to stand and, on the command of '**fertilise!**', those pupils holding a sperm card pair up with someone holding an egg card (to make this easier use different coloured card for egg and sperm cells).

- Ask pairs to look at their combined alleles and decide what colour their fur will be. Direct those with white fur to one corner of the room and those with black fur to another.
- Ask those with the same colour of fur to check the other pairs in their group and decide if they all have the same or different combinations of alleles. Show how the Punnett Square can be used to record these combinations (the genotypes).
- Finally, ask pupils to count the number of pairs with each genotype and record these numbers underneath the Punnett Square. Reduce the numbers to a ratio.

Repeat the process using different parental genotypes until time or enthusiasm are exhausted. Make sure combination (c) is included as this is the basis of the answer to Q1 of the embryo selection scenario, and pupils will be asked to revisit this for homework. The point to note when completing the writing frame for this particular cross is that some of the offspring have white fur but both the parents had black fur.

Note: For a summary of this activity see the example of a completed writing frame on page 57.

The outcomes for the three crosses suggested above are:

- 100% heterozygous black (genotype Bb);
- 50% heterozygous black (genotype Bb); 50% homozygous white (genotype bb); a ratio of 1 : 1 (black : white);
- 25% homozygous black (genotype BB); 50% heterozygous black (genotype Bb); 25% homozygous white (genotype bb); a ratio of 3 : 1 (black : white).

Note that the role-play has modelled just one gene and one pair of alleles on one chromosome. In reality there are many chromosomes, and thousands of genes. During production of the sex cells each pair of chromosomes behaves independently of the others. This increases the variation in the offspring.

Plenary session

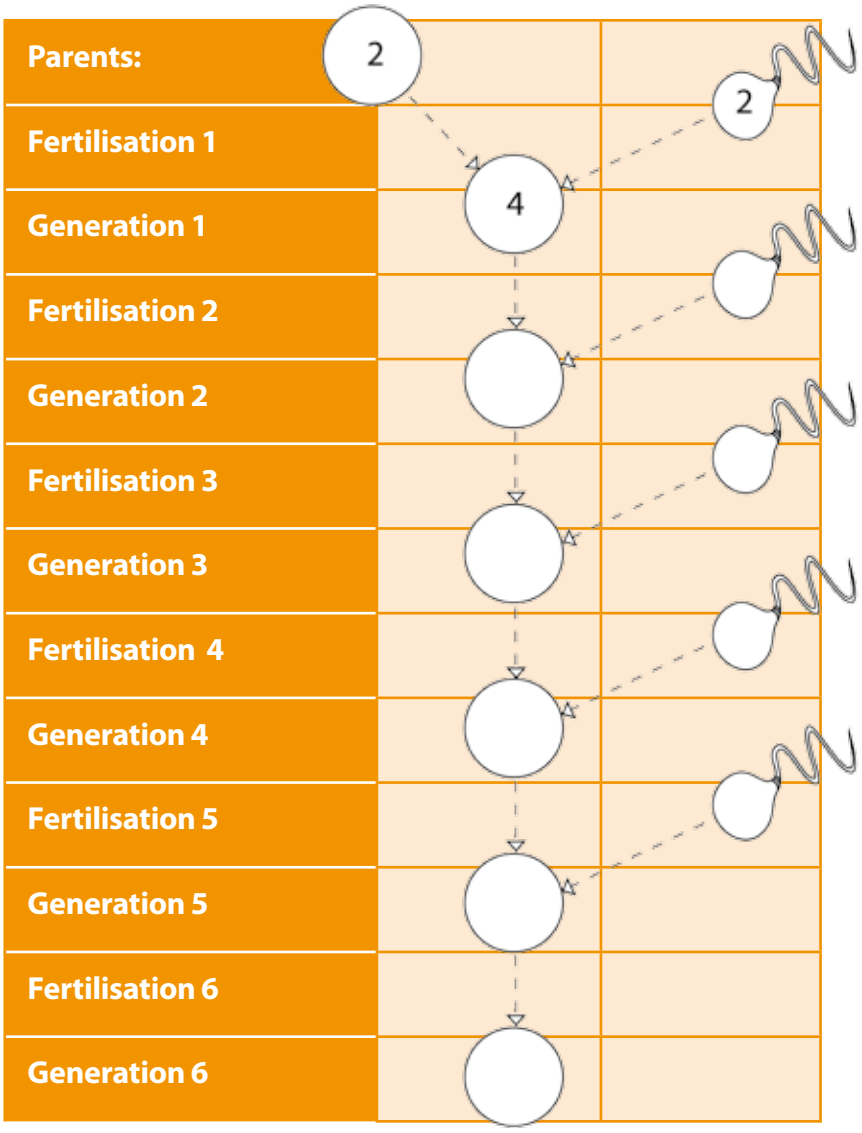
To demonstrate this, return to the imaginary animal with three pairs of chromosomes. For each pair of chromosomes, pick a band to represent a gene, and label one as the dominant allele and the other as the recessive. Challenge pupils to identify how many different combinations could occur in the sex cells using just these 3 pairs of alleles (they may need to draw or model these). The answer is 8 (ABC, ABc, AbC, aBC, Abc, abC, aBc, and abc). Just think how much variation there must be when there are 23 pairs of chromosomes, each carrying hundreds of pairs of alleles.

Activity 4.5: Homework

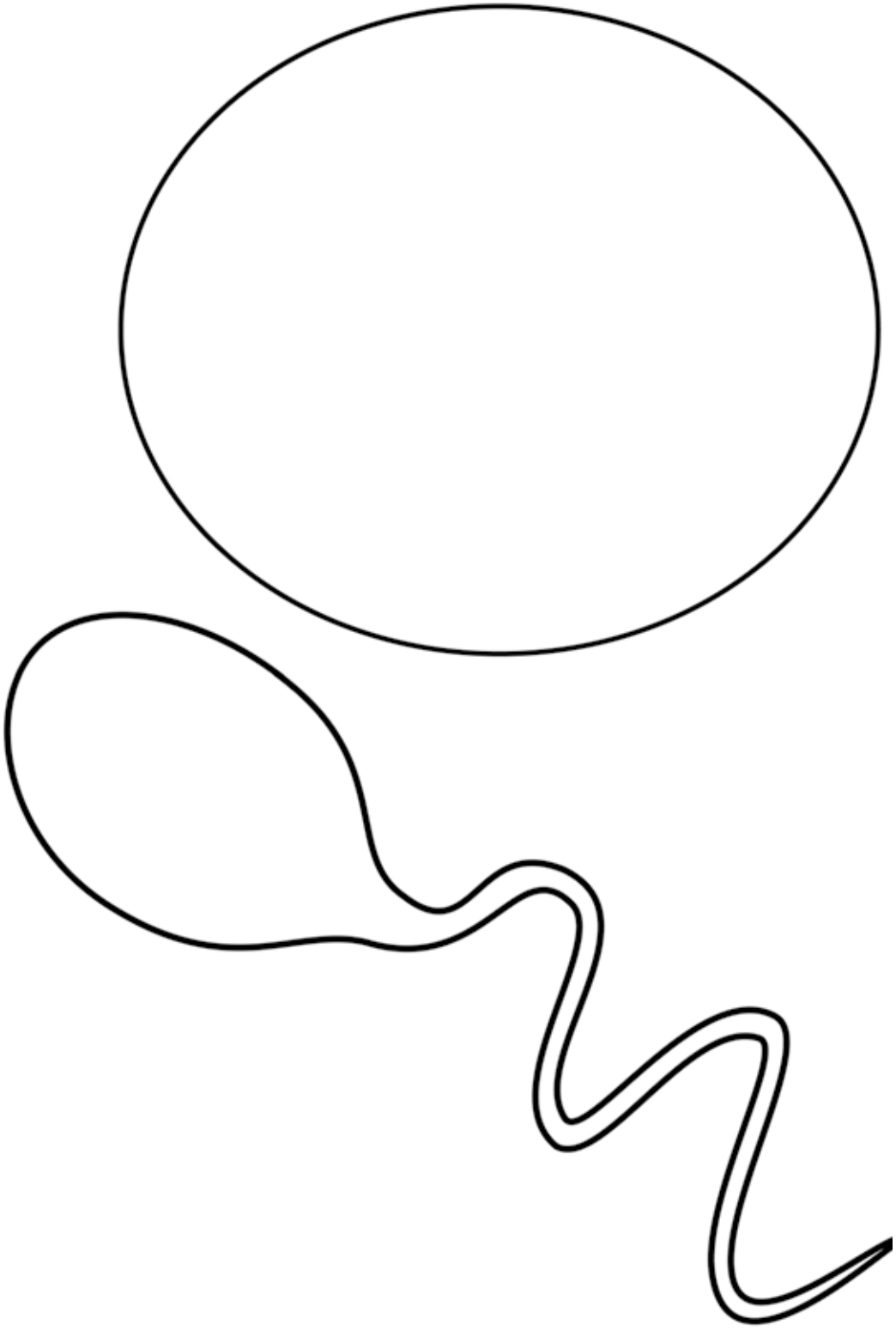
This lesson provides pupils with the scientific answer to Q1 in 'Babies to order'. Ask them to use the writing frame to explain the answer to Q1. (You will need to provide symbols to denote dominant and recessive alleles for the condition).

4.1: Fertilisation

Cells fuse at fertilisation to produce one new cell. If you start with two chromosomes per cell, how many chromosomes could you have after 6 generations? Humans have 46 chromosomes per cell. How many could we have after 6 generations?



4.2: Template for modelling meiosis – cells



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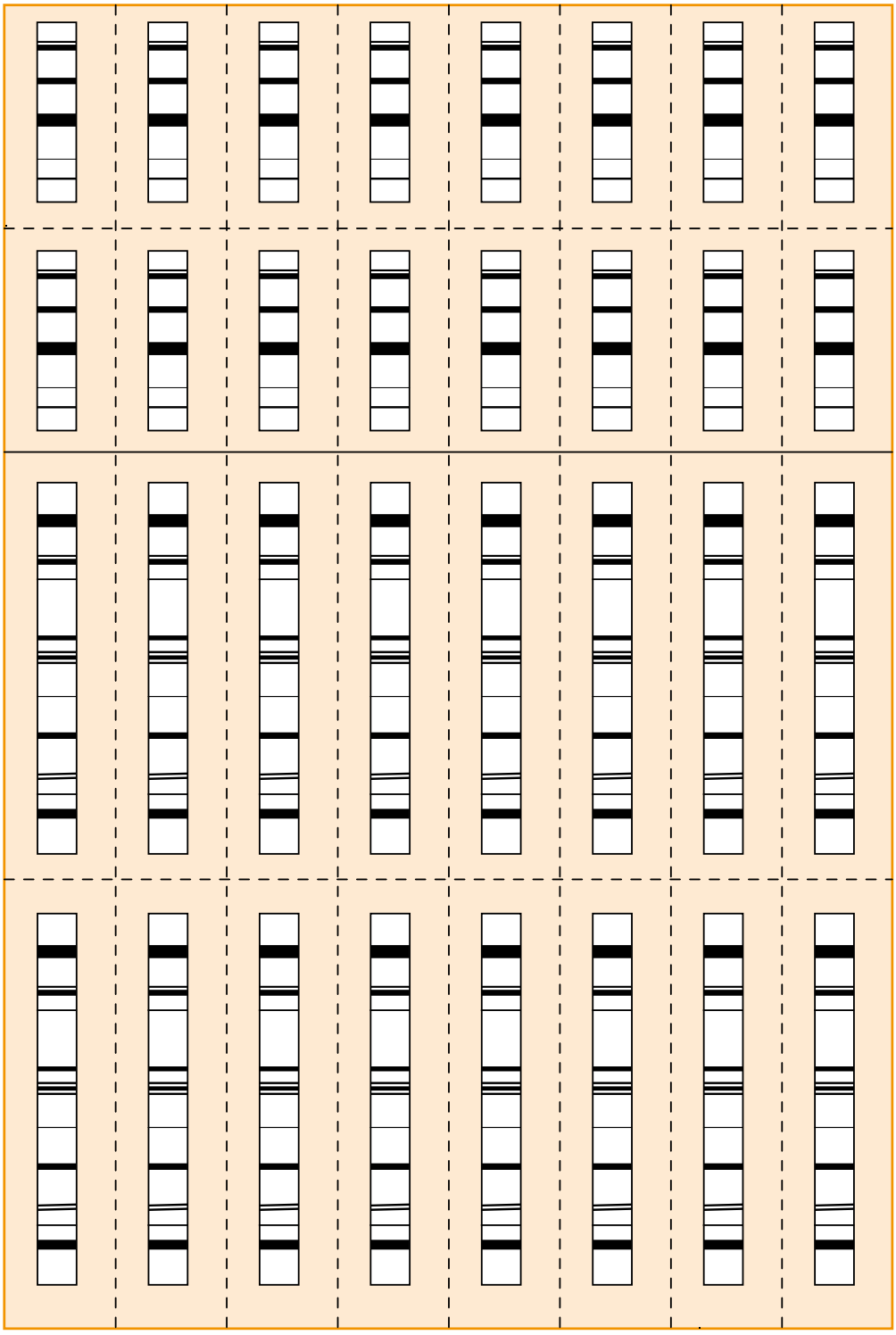
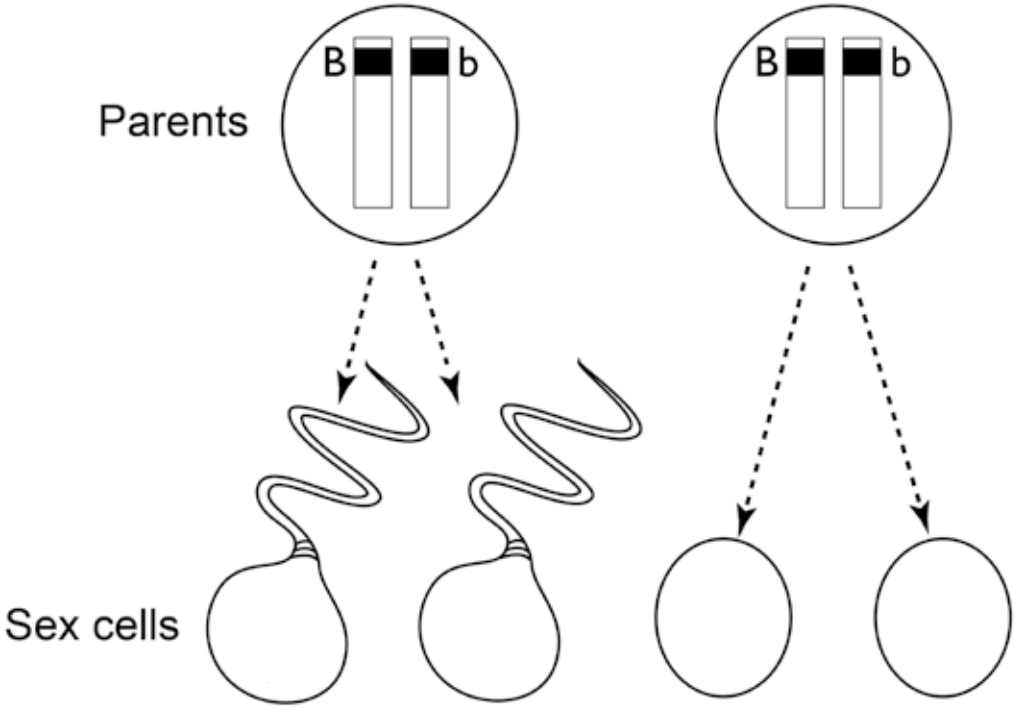
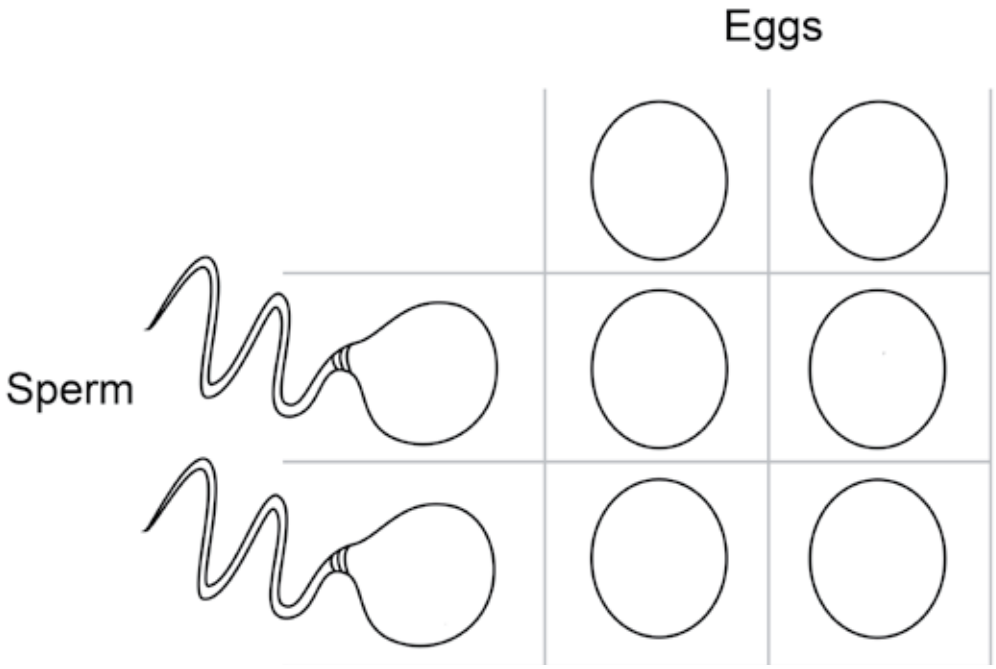
4.2: Template for modelling mitosis: chromosomes

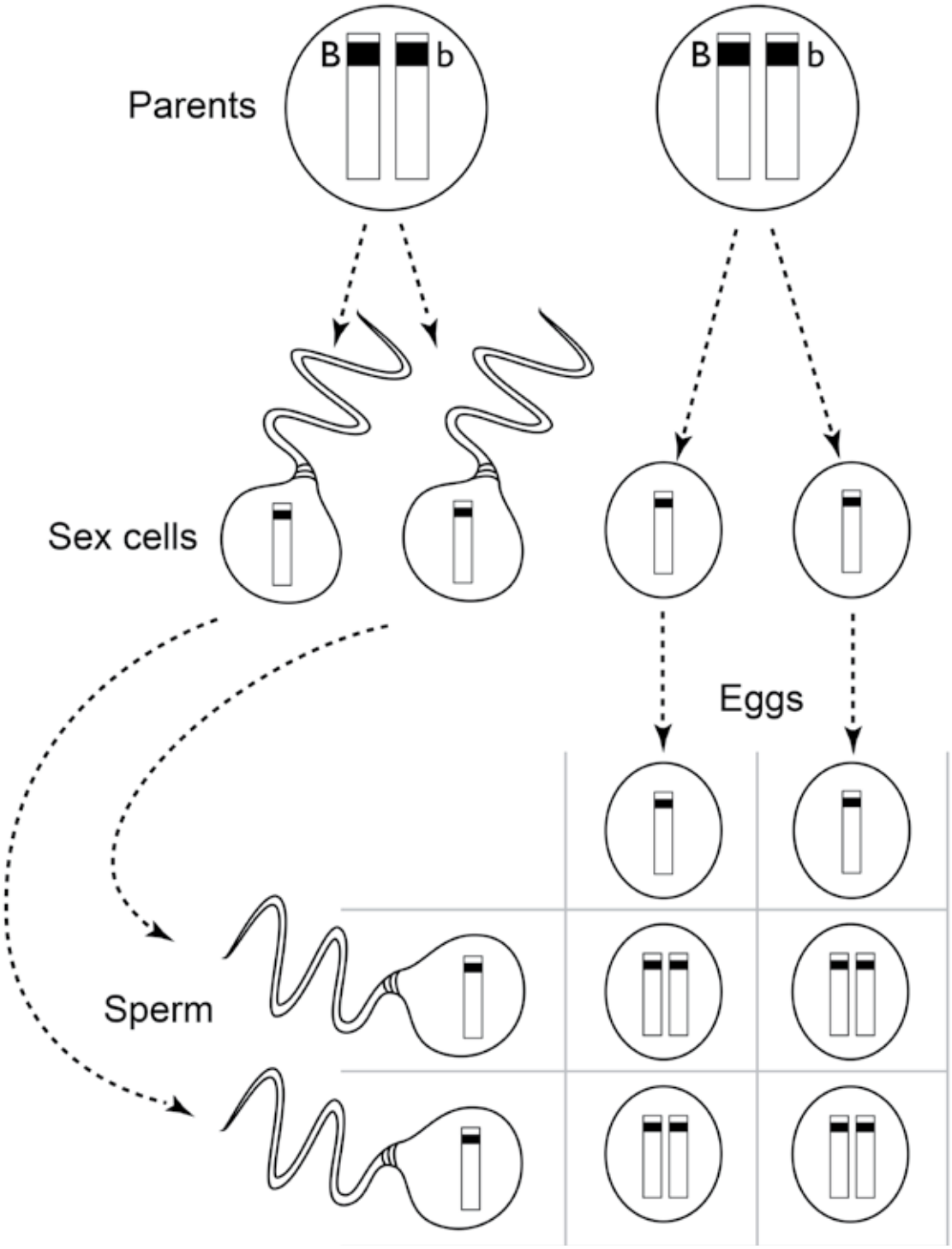


4.4: Inheritance writing frame (blank)



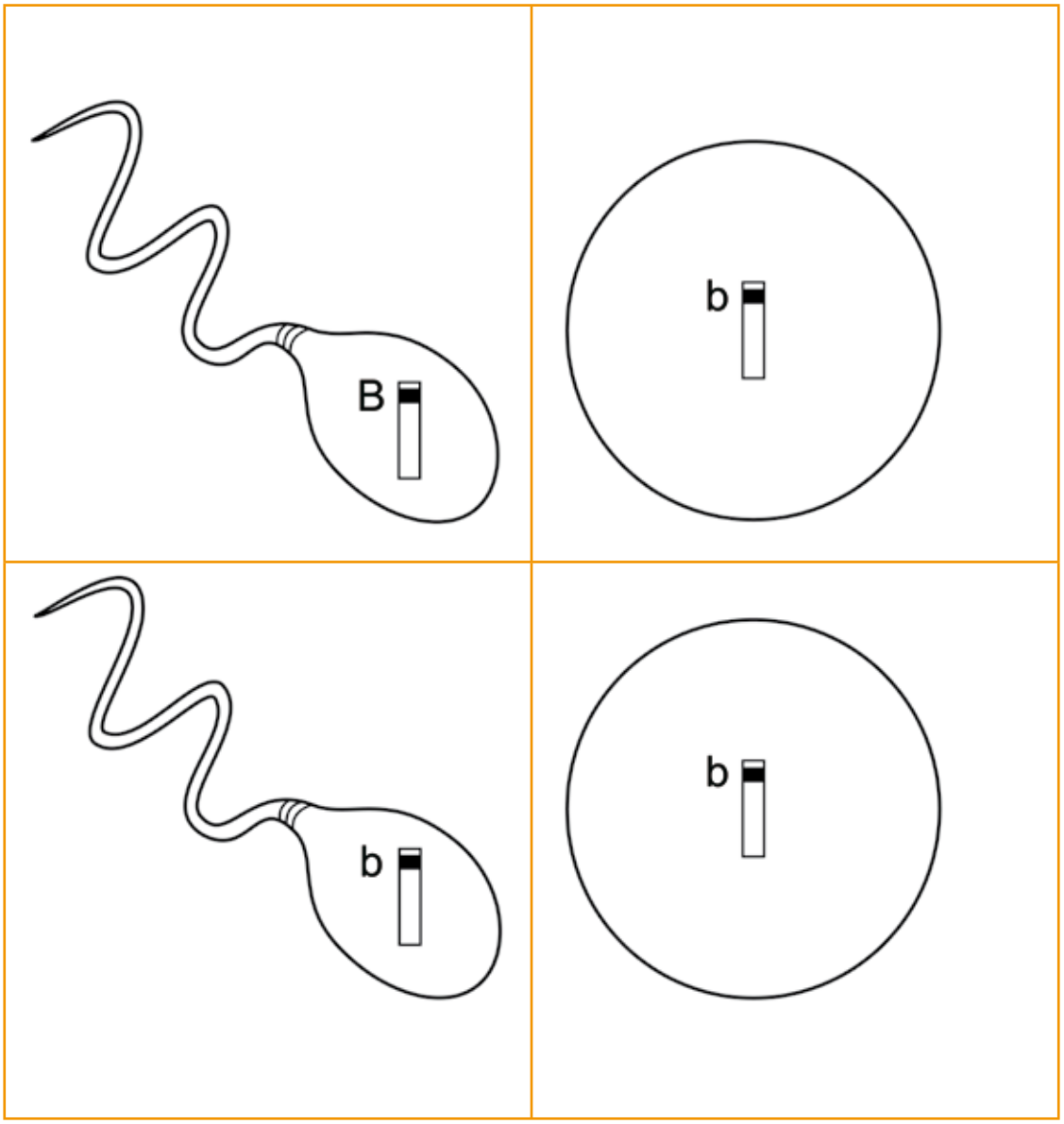


4.4: Inheritance writing frame (completed example)

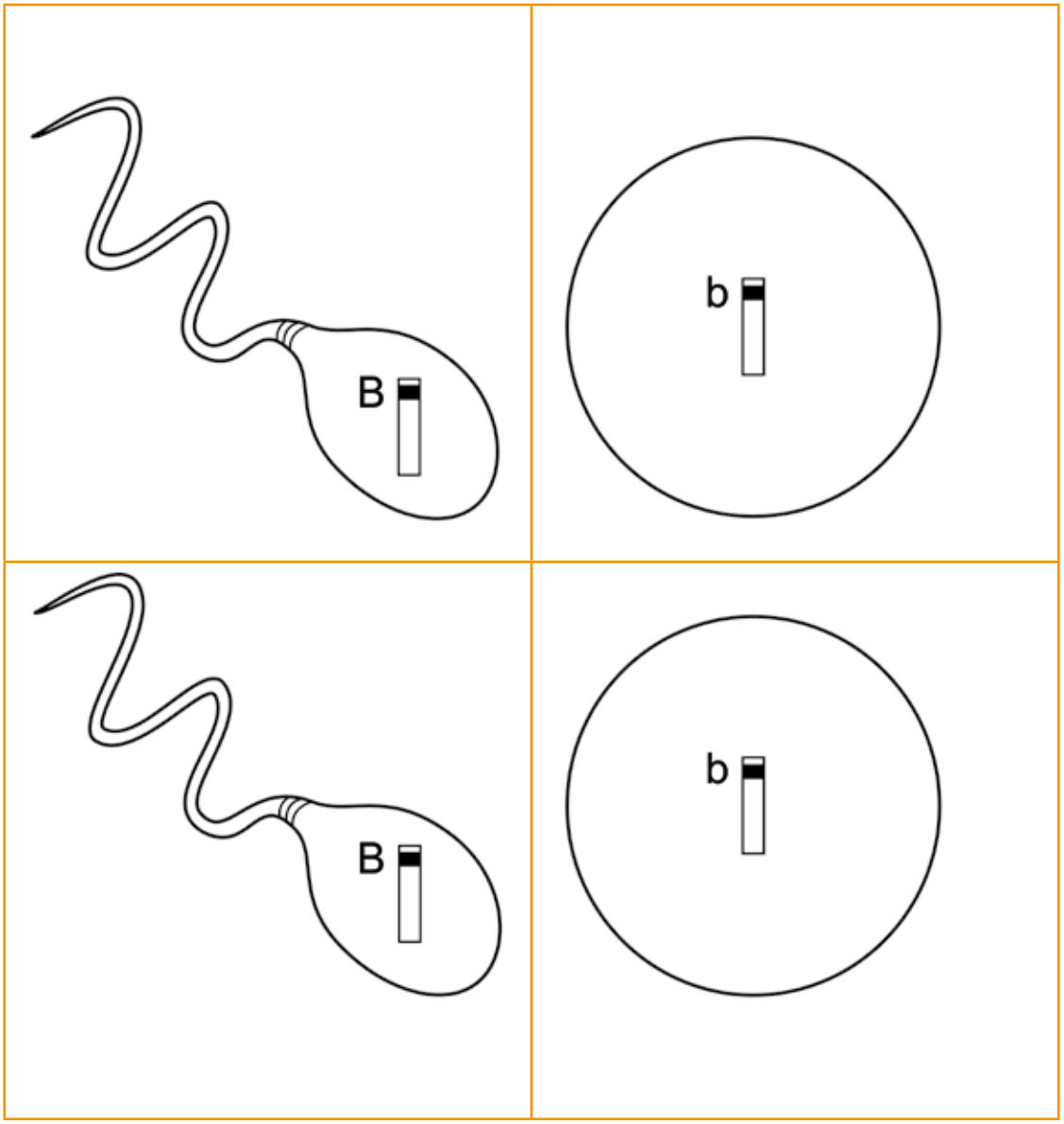


4.4: Templates for 'fertilise!' role-play

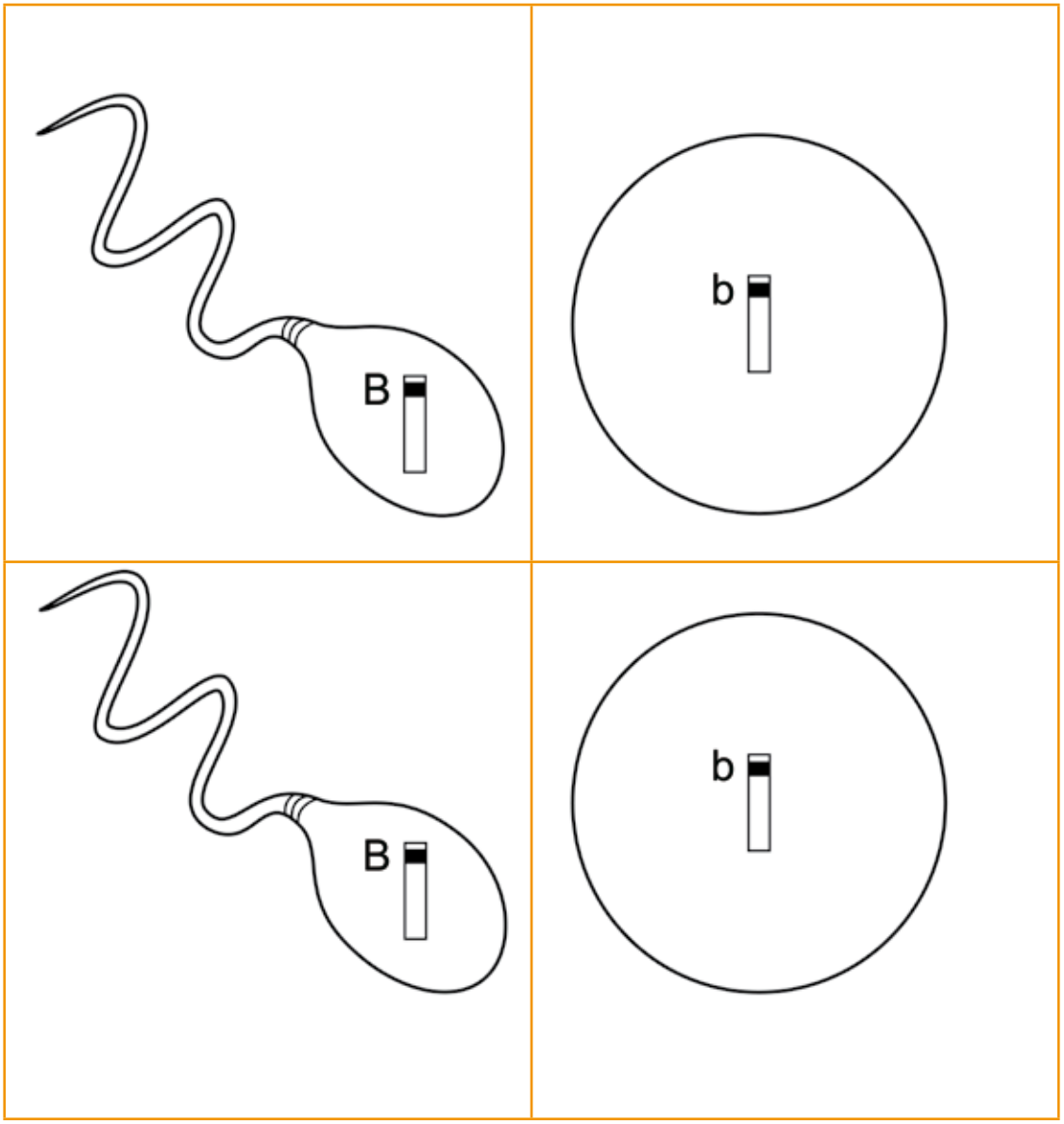
homozygous black (BB) x homozygous white (bb)



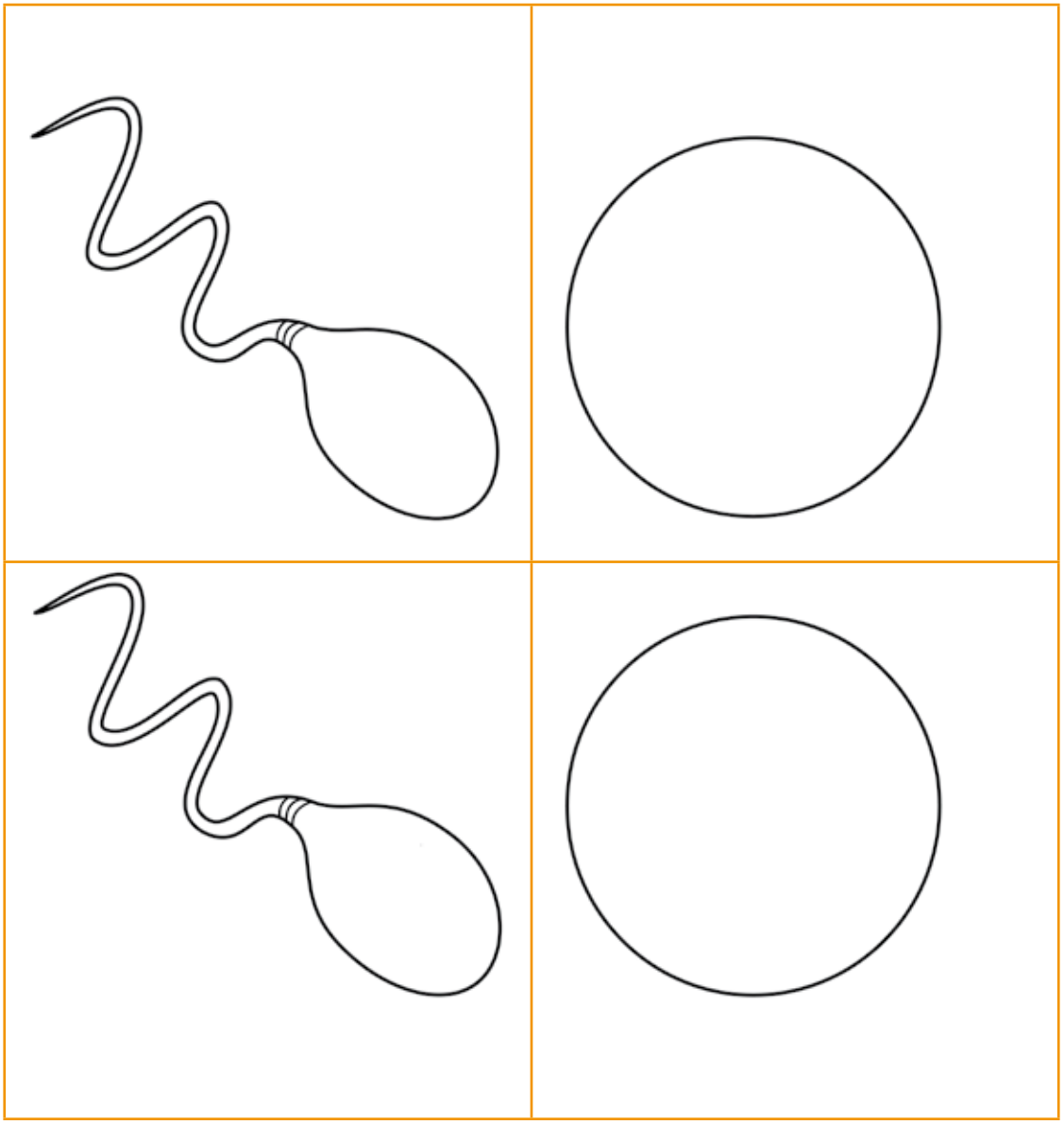
heterozygous black (Bb) x homozygous white (bb)



heterozygous black (Bb) x heterozygous black (Bb)



template to make up your own crosses



Lesson 5: Bringing it all together

Teaching 'story'

In this final lesson, the ideas developed through the sequence are brought together in a comparison of cloning, genetic engineering and selective breeding. This provides the backdrop for a reconsideration of embryo screening. The resulting discussions draw out the distinction between genetic engineering and selective breeding, make explicit the distinction between scientific 'fact' and opinion, and encourage pupils to engage in reasoned argument and present justifications for their views.

Activity 5.1: Cloning, genetic engineering and selective breeding

This is a card sort activity which pupils work on in small groups.

Teaching objectives

- To explore the ways in which pupils understand the ideas developed during the previous lessons through a consideration of cloning, genetic engineering and selective breeding.
- To ensure that pupils are aware of the key distinction between selective breeding (no manipulation of DNA) and genetic engineering (transfer of DNA between organisms), in preparation for the discussion activity 5.2.

Learning outcomes

By the end of this activity, most pupils will be able to:

- use knowledge gained from preceding lessons to explain similarities and differences between cloning, genetic engineering and selective breeding.

What to prepare

- 1 set of cards per group (see Worksheet 'Cloning, genetic engineering and selective breeding').

Mode of interaction

Pupils work in small groups to agree the card sort; they explore their thinking but the focus is on developing the scientific view INTERACTIVE / AUTHORITATIVE.

What happens during this activity

The teacher begins by drawing on pupils' ideas to present a quick recap and comparison of the two different types of cell division. Pupils then work in small groups to agree which statements belong under which heading – cloning, genetic engineering or selective breeding (see card sort template). The emphasis is on encouraging pupils to use their knowledge to explain their thinking and the role of the teacher is to circulate, questioning pupils in ways which support this aim. During feedback on this activity, the teacher draws on the pupils' ideas (their responses to the card sort and their reasons for this) to confirm the scientific view:

- that **cloning** involves asexual reproduction and results in exact copying of the 'parent' cell, for example, Dolly the sheep;
- that **selective breeding** involves sexual reproduction and as a result new combinations of alleles are produced and offspring may vary from their parents; for example, the development of different breeds of dog;
- that in **genetic engineering**, genes can be swapped across species, new cells then contain new combinations of DNA, for example, the use of bacteria to make human insulin.

It is important that the crucial distinction between selective breeding (no manipulation of DNA) and genetic engineering (transfer of DNA between organisms) is made explicit during this activity, since pupils' views and lines of argument in the discussion activity which follows may be influenced by their understanding of this.

Click here to watch teacher clarification of this

Teaching 'story'

By the end of the first activity pupils should be clear about the differences between cloning, selective breeding and genetic engineering. The second activity revisits 'Babies to order' and asks the pupils to reconsider their views in light of what they now know about the science. They are encouraged to give reasons for their views and to distinguish between scientific fact and opinion. By the end of this activity pupils should be aware that there are some questions that science can answer and some that it cannot.

Activity 5.2: Embryo selection – should it be allowed?

In this activity pupils have the opportunity to draw on the ideas they have developed during this sequence of lessons to discuss the 'Babies to order' article (Activity 1.1) in more depth.

Teaching objectives

- To model *reasoned* argument and make clear the need to *justify* a view.
- To make explicit the distinction between justifications which are supported by facts (the science) and justifications that are based on opinion.
- To help pupils to recognise one consequence of this distinction – that there are some questions which science cannot answer.
- To encourage pupils to reflect on their own learning.

Learning outcomes

By the end of this activity, most pupils will be able to:

- distinguish between fact and opinion;
- justify a view;
- recognise how their understanding of the science has changed during this teaching sequence.

What to prepare

- Materials for posters.
- Thinking files including homework from Lessons 3 and 4.
- 'Reflections' writing frame.

Mode of interaction

Discussion
Pupils present and justify their views (INTERACTIVE/DIALOGIC); the teacher provides an overview of the different perspectives and summarises the learning outcomes (INTERACTIVE / AUTHORITATIVE).

What happens during this activity

Pupils are reminded, by reference to their homework, *why* it is that these parents want to select the embryo for their second child. Working in small groups they discuss the reasons why they think this should/should not be allowed, summarise these as a poster and try to come to a decision on whether or not they think it should be allowed. During

these discussions, the teacher's role is to encourage pupils to explore their thinking – to ask for justification, to highlight inconsistencies in reasoning, and to draw attention to additional factors which should be considered.
During feedback the teacher draws out the different lines of argument within the class and makes explicit the distinction between scientific 'fact' and opinion, demonstrating that there are some questions which science cannot answer. For example:

'Ling's group thinks that embryo selection should be allowed because it is just a particular form of selective breeding and there is no manipulation of DNA involved. John's group think that it shouldn't be allowed because it is treating someone as a 'spare parts' factory. Who else thinks it should be allowed? Are your reasons the same as Ling's? What about the rest of you, are your reasons the same as John's? Perhaps some of you are unsure – why is that?'

'Is Ling's view based on fact?… What about John's?… How do we know?… (Ling's justification is based on the science; John's justification is based on opinion)

'In this situation, are facts more important that opinions – could more facts give us the answer to the question? (more facts might influence the view we come to personally but they cannot give us a definitive answer – moral and ethical issues also need to be considered and science cannot address these).

Click here to watch an approach to this discussion

Plenary/final homework session

To complete this sequence the pupils return to their thinking files and summarise the ways in which their thinking has changed over the sequence of lessons. It is important for them to appreciate that they have been distinguishing between opinions and scientific facts when developing their own points of view on ethical dilemmas.

You could use some combination of the following questions to help pupils to focus and structure their writing, depending on the particular pupil group.

- How has your understanding of the science changed (what do you now know that you did not know at the start)?
  - note 3 (or 5, or more) things you now know' *or*
  - note 1 (or however many) things you now know about genes, chromosomes, alleles etc.' *or*
  - note 1 (or 2, or more) things you believed at the start of this topic but which you now know are not true. For each one note the correct science idea.
- How has your understanding of the gene technology used in 'Babies to order' changed?
- How have your opinions about 'Babies to order' changed?
- What new knowledge or ideas have led to this change?

5.1: Template for cloning, genetic engineering and selective breeding card sort

Genetic engineering	Makes exact copy of parent cell
Selective breeding	New cells contain different DNA
Cloning	New combinations of alleles are produced
Genes can be swapped across species	Involves asexual reproduction
For example, making human insulin using bacteria	Involves sexual reproduction
For example, the development of different breeds of dogs	For example, Dolly the sheep
	Offspring may vary from their parents

Acknowledgements

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Audience: Science subject leaders, teachers of science and higher level teaching assistants.

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