3 MENDELIAN GENETICS

This unit will explain for the first time the laws that dictate the inheritance of characteristics. This is why it is very important that before starting, students have a good knowledge of certain concepts, such as the structure of chromosomes, the meaning of haploid and diploid, and the processes of cell division, with a particular focus on meiosis.

The first section defines basic genetic concepts, such as phenotype, genotype, allele, homozygous, heterozygous and so on. Understanding these terms is an essential prerequisite to understanding the rest of the unit. The second section begins with a short introduction explaining the contribution of Mendel to the field of genetics, before outlining and explaining Mendel's laws using a range of diagrams.

Once students have a good grounding in the mechanics of inheritance, we study some exceptions that do not seem to follow Mendel's laws. These examples are included here because they are common and simple to understand. They introduce students to the concepts of intermediate inheritance, co-dominance, lethal genes, gene interaction, multiple alleles and quantitative inheritance.

The following section reviews the chromosome theory of inheritance. This section will connect previous knowledge about meiosis and recombination with the distribution mechanism followed by genes during inheritance. We then explain the different systems of sex determination in organisms, as well as the way characteristics linked to sex are transmitted to offspring. The final section gives students an overview of how to apply their knowledge of genetics when solving genetic problems.

Objectives

LEARNING OBJECTIVES
▮ Define the basic concepts of genetics.
▮ Identify Mendel's laws of inheritance.
▮ Apply Mendel's laws of inheritance in order to solve simple problems.
▮ Differentiate between the inheritance of sex, inheritance linked to sex and inheritance influenced by sex.
▮ Solve simple problems related to the inheritance linked to sex.
▮ Carry out a research task.

Mixed-ability needs

In order to meet the needs of different students, a variety of resources are offered as complements or alternatives to the work in the unit: an Oxford investigation, a science experiment, an animation, an extension worksheet, a slideshow presentation and a concept map with core content. Since science combines many skills, it is important that students of mixed-ability are paired up in order for them to support each other.

Suggested Timing

This unit could be covered in a period of four weeks (approximately 12 sessions). The number of sessions should be determined by the interest that the students show for the content and by the general unit planning.

Sections	N.° of sessions
Warmer	½
1. Key concepts of genetics	½
2. Early genetic studies	2
3. Special cases	1 ½
4. Location of genes	1 ½
5. The inheritance of sex	2 ½
6. Applications of Mendel's laws	1
Consolidation	1
Work and experimentation techniques	1
Final task and Self-assessment	1 ½

UNIT LESSON PLAN		
Contents	**Assessment criteria**	**Learning outcomes**
Key concepts of genetics	1. Understands the meaning of basic genetic concepts.	1.1. Defines and differentiates the fundamental concepts of genetics (LC, MCST, LL).
Early genetic studies ▮ Mendel's laws	2. Formulates the basic principles of Mendelian genetics.	2.1. Recognises the basic principles of Mendelian genetics (LC, MCST, LL).
Special cases ▮ Intermediate inheritance and co-dominance ▮ Multiple alleles ▮ Gene interaction ▮ Lethal genes ▮ Quantitative inheritance	3. Understands the different types of inheritance that do not follow Mendelian proportions.	3.1. Identifies the causes of exceptions to Mendelian proportions in the inheritance of some characteristics (LC, MCST, LL, SIE).
Location of genes ▮ The chromosome theory of inheritance ▮ Linked genes ▮ Chromosome maps	4. Relates the chromosome theory of inheritance with the appearance of variations in offspring.	4.1. Identifies the cause of the formation of different types of gametes depending on the location of genes on chromosomes (LC, MCST, LL).
The inheritance of sex ▮ Sex determination ▮ Inheritance linked to sex ▮ Inheritance influenced by sex	5. Differentiates between sex determination systems and inheritance linked to sex.	5.1. Differentiates between different types of sex determination systems (LC, MCST, LL). 5.2. Solves practical problems about inheritance of sex and sex-linked inheritance (LC, MCST, LL).
Applications of Mendel's laws ▮ Genetic problems ▮ Genealogical trees	6. Solves practical problems applying Mendelian genetics.	6.1. Solves practical problems crossing one or two characteristics (MCST, DC, SIE).

LC: Linguistic communication; **MCST**: Mathematical competence and basic competences in science and technology; **DC**: Digital competence; **LL**: Learning to learn; **SIE**: Sense of initiative and entrepreneurship; **SCC**: Social and civic competence.

UNIT CONCEPT MAP

STUDENT RESOURCES

Oxford investigation > > > > > >

Interactive activities > > > > > >

Talking book > > > > > >

Video 1: How does genetic inheritance work?
Weblink 1: Quizlet

Weblink 2: Gregor Mendel (1822-1884)
Weblink 3: Some genes are dominant
Video 2: How Mendel's pea plants helped us understand genetics
Weblink 4: Working out Punnett square examples
Animation: Mendel's laws

Video 3: The ABO group – multiple alleles and co-dominance

Weblink 5: Chromosomes

Unit 3: Mendelian genetics

1. Key concepts of genetics

2. Early genetic studies
2.1. Mendel's laws

3. Special cases
3.1. Intermediate inheritance and co-dominance
3.2. Multiple alleles
3.3. Gene interaction
3.4. Lethal genes
3.5. Quantitative inheritance

4. Location of genes
4.1. The chromosome theory of inheritance
4.2. Linked genes
4.3. Chromosome maps

TEACHER RESOURCES

Concept map
Presentation

Weblink 3 worksheet

> > > > > >

Oxford investigation

> > > > > >

Interactive activities

> > > > > >

Talking book

Video 4: Sex determination: more complicated than you thought
Weblink 6: Sex determination
Video 5: Genetics-Xlinked

Science experiment: Identify the percentage of recessive phenotypes
Weblink 7: Drag and drop pedigree

5. The inheritance of sex
5.1. Sex determination
5.2. Inheritance linked to sex
5.3. Inheritance influenced by sex

6. Application of Mendel's laws
6.1. Genetic problems
6.2. Genealogical trees

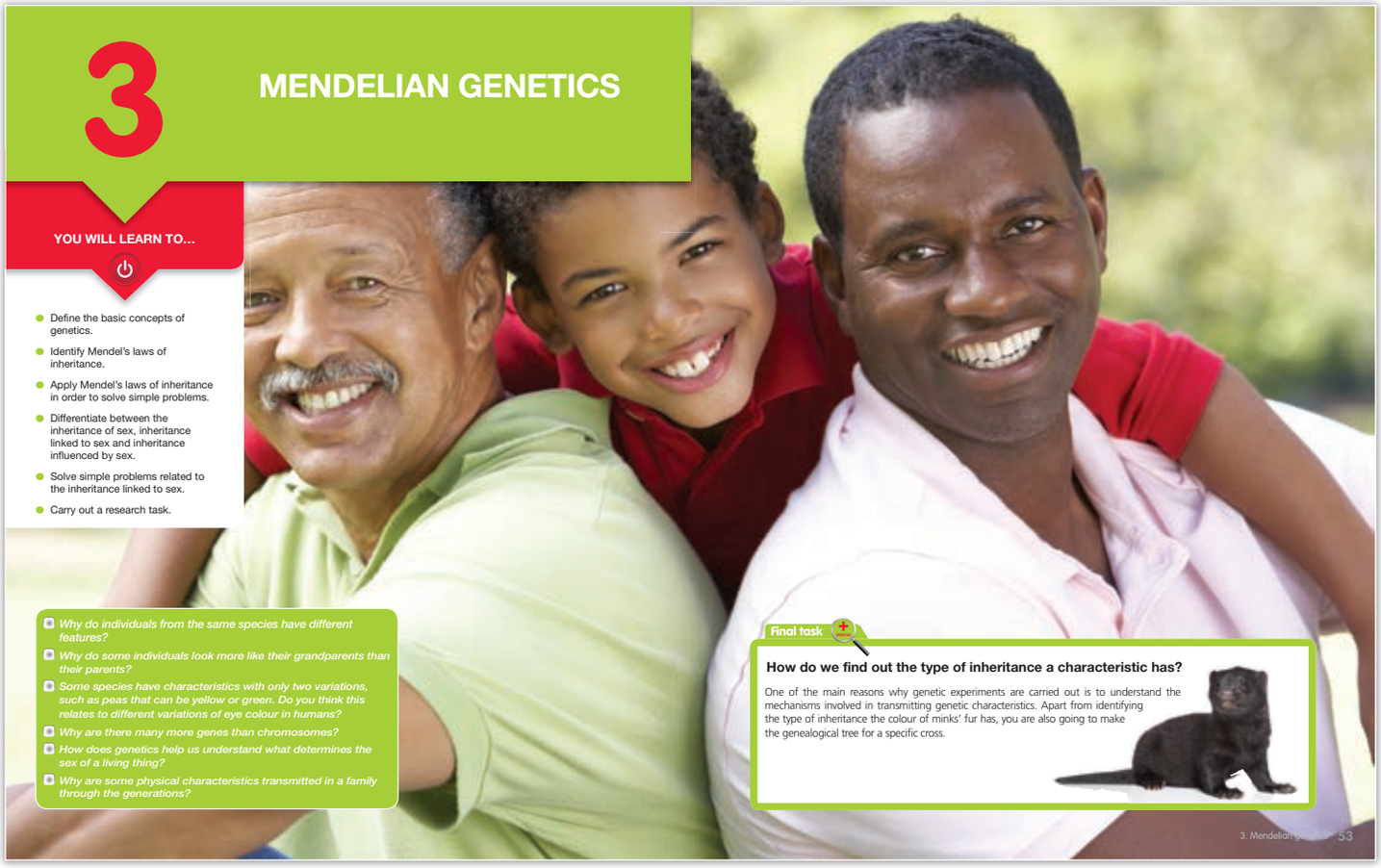
Consolidation

Work and experimentation techniques
Study of the distribution of a quantitative characteristic

Final task
How do we find out the type of inheritance a characteristic has?

Concept map
Competence test
Extension worksheet
Presentation
Unit tests

TEACHING SUGGESTIONS



3 MENDELIAN GENETICS

YOU WILL LEARN TO...

- Define the basic concepts of genetics.
- Identify Mendel's laws of inheritance.
- Apply Mendel's laws of inheritance in order to solve simple problems.
- Differentiate between the inheritance of sex, inheritance linked to sex and inheritance influenced by sex.
- Solve simple problems related to the inheritance linked to sex.
- Carry out a research task.

- *Why do individuals from the same species have different features?*
- *Why do some individuals look more like their grandparents than their parents?*
- *Some species have characteristics with only two variations, such as peas that can be yellow or green. Do you think this relates to different variations of eye colour in humans?*
- *Why are there many more genes than chromosomes?*
- *How does genetics help us understand what determines the sex of a living thing?*
- *Why are some physical characteristics transmitted in a family through the generations?*

Final task

How do we find out the type of inheritance a characteristic has?

One of the main reasons why genetic experiments are carried out is to understand the mechanisms involved in transmitting genetic characteristics. Apart from identifying the type of inheritance the colour of minks' fur has, you are also going to make the genealogical tree for a specific cross.

Before starting, review some of the concepts learned in **Unit 1 (Cells)**. In mixed-ability pairs, students create their own definition of meiosis. They can use words, or, if they prefer, diagrams. Give students a few minutes to do so and then share their answers in open class.

Students read the **You will learn to** section in pairs or groups, discuss the meaning of the terms as well as the objectives' meanings and explore any prior knowledge they have. This will help students understand the objectives. Ask students to create their own set of questions that they would like to find answers for so they can refer back to them at the end of the unit and see if they can answer them.

Direct students' attention to the questions on page 52 of the Student's book. Give them a maximum of 10 minutes to read and confer in pairs. By doing this, you will be able to see how much they already know. Once they have finished, ask students to share their answers with the class, however, do not correct them if they are wrong, as this is a warm-up exercise and they will be able to correct themselves throughout the unit.

- *Why do individuals from the same species have different features?*

  Even though they all have the same types of genes, they can contain different genetic information, such as hair or eye colour.

- *Why do some individuals look more like their grandparents than their parents?*

  Individuals can carry genes in their DNA from their parents that are not expressed. This does not mean that they are not there; it only means that they have not been manifested in the individual's phenotype. These genes can be expressed in future offspring. As a result they might look more like their grandparents than their parents.

- *Some species have characteristics with only two variations, such as peas that can be yellow or green. Do you think this relates to different variations of eye colour in humans?*

  This type of inheritance is not related to eye colour in humans. The colour in peas only has 2 variations and human eye colour has many slightly different variations which follow a different type of inheritance called quantitative inheritance (where several pairs of alleles that have an additive effect intervene).

- *Why are there many more genes than chromosomes?*

  This is because chromosomes are made up of genes and other substances.

- *How does genetics help us understand what determines the sex of a living thing?*

  The field of genetics helps us understand that the sex of a living thing is determined by sex chromosomes in many organisms; however, it can also be determined by the environment, genes and other factors.

- *Why are some physical characteristics transmitted in a family through the generations?*

  This is because some characteristics are dominant over others, so they tend to be expressed through the generations.

Show students the following video to introduce them to the concepts they will learn in this unit. Before playing it, write down the following questions on the board to make it easier for students to understand the video, and allow them some time to discuss the questions in small groups. This way, you will be making sure they understand the questions and they can exchange any prior knowledge.

- *Who discover the rules of inheritance?*

  The Austrian monk Gregor Mendel discovered the rules of inheritance.

- *How did he discover the rules of inheritance?*

  He did so by tracing patterns of inheritance through many generations of pea plants. He then carefully quantified the results to formulate some simple rules.

- *During the demonstration, why were the blue balls in the boxes larger than the yellow ones?*

  The blue balls were larger because they represent dominant genes; the yellow ones were smaller because they represent recessive genes.

- *If the blue balls in the box are dominant, would all future generations be blue?*

  No, successive generations may be yellow, as we saw in the demonstration of the second generation. That is the reason why some of us look more like our grandparents than our parents.

Play the video several times if necessary. Allow students some time to discuss their answers in their groups each time you play the video. Then discuss their answers in open class.

Video 1: HOW DOES GENETIC INHERITANCE WORK?

Great introductory video to genetic inheritance in which Dr. Allison Woollard performs a series of simple demonstrations to explain the work of Gregor Mendel.

Point out the **Final task (How do we find out the type of inheritance a characteristic has?)**. Ask them to read the text briefly, in pairs, to find out the main objectives of the task. Students should then explain the task to the class, using full sentences. Write some sentence openers on the board to help them if necessary:

- *In this task we will… We will also have to create….*

Explain that the steps to carry out the final task are in the **Final Task** section at the end of the unit.

PRESENTATION

Use the slideshow presentation to show the different sections in the unit and to evaluate students' prior knowledge. The slides can stimulate student participation, as they can be asked about certain topics before they study them. This tool can also be used as revision at the end of the unit.

CONCEPT MAP

To introduce the contents of the unit, you could show an incomplete concept map and ask the students to complete the gaps, either in their notebooks or orally with the whole group. It is okay if students make mistakes at this stage. However, they should correct their mistakes at the end of the unit, as it will help them visualise the links between the different contents of the unit and see how much they have learnt.

At the end of the lesson, introduce the key vocabulary in the **Study Skills** section on page 73 of the Student's book. By carrying out vocabulary building tasks, you will help students become familiar with the vocabulary of the unit and be more willing to learn/review the concepts.

Weblink 1: QUIZLET

This is an excellent resource that can be used in many different subjects. Students and teachers can make flashcard sets and share them with each other. The program then makes tests and study games. It also keeps a record of each user's progress, which can add an element of competition that can help motivate some students and it helps you keep track of their understanding.

If you have access to the Internet, ask students to create digital flashcards of the vocabulary used in this lesson using the online program Quizlet. If students have not used Quizlet before, give them a demonstration of how the flashcards can be used and show students how to create a free account and make their own flashcards. Students create their digital flashcards with the vocabulary word on one side and definition on the other. Remind students that they should only create flashcards for words they do not know. This can be done in class or at home as homework.

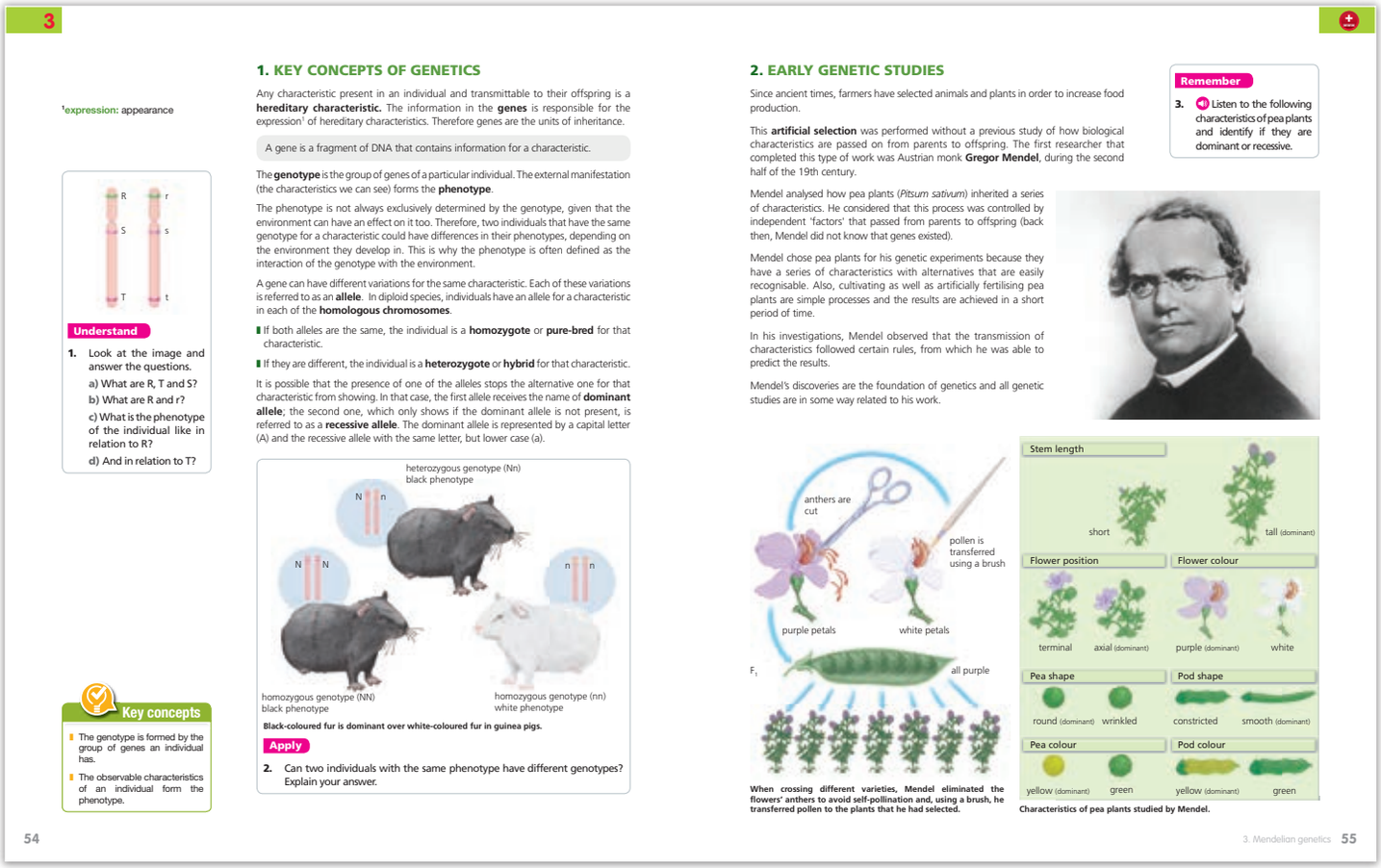
Explain to students that throughout the unit, they will be creating more digital flashcards for new terminology. At the end of the unit, they can all share their flashcards sets with each other and pick the ones they like the most.

If you do not have access to the Internet, students could work in groups to create graphic organisers in their notebooks. Graphic organisers allow students to interact with the vocabulary in a variety of ways, from a variety of angles, to reach a fuller understanding of its meaning. To do this, students write the new vocabulary in the middle of a triangle and label each corner *definition, example sentence* and *image*. They should then find or create a definition, an image and an example sentence for the vocabulary.

To help students remember new vocabulary during the lessons, you could ask volunteer students to create, at the end of each lesson or at home, small A4 posters for the new terminology and put them up on the wall. The posters should show the word, its definition and an image that represents it. This way, students can quickly refer back to them in class if they need to. Make sure that it is not always the same students creating these posters. You could encourage students' participation by giving them extra marks for participating.

OXFORD INVESTIGATION

This includes an **introduction** to the unit with preliminary questions and a description of the **Final task**. The Final task is usually a practical problem, involving a variety of learning skills and research. Explain that in particular activities students will learn the concepts and/or the procedures necessary to solve the problem.



3

[1]expression: appearance

R r
S s
T t

Understand

1. Look at the image and answer the questions.
   a) What are R, T and S?
   b) What are R and r?
   c) What is the phenotype of the individual like in relation to R?
   d) And in relation to T?

Key concepts

- The genotype is formed by the group of genes an individual has.
- The observable characteristics of an individual form the phenotype.

1. KEY CONCEPTS OF GENETICS

Any characteristic present in an individual and transmittable to their offspring is a **hereditary characteristic.** The information in the **genes** is responsible for the expression[1] of hereditary characteristics. Therefore genes are the units of inheritance.

A gene is a fragment of DNA that contains information for a characteristic.

The **genotype** is the group of genes of a particular individual. The external manifestation (the characteristics we can see) forms the **phenotype**.

The phenotype is not always exclusively determined by the genotype, given that the environment can have an effect on it too. Therefore, two individuals that have the same genotype for a characteristic could have differences in their phenotypes, depending on the environment they develop in. This is why the phenotype is often defined as the interaction of the genotype with the environment.

A gene can have different variations for the same characteristic. Each of these variations is referred to as an **allele**. In diploid species, individuals have an allele for a characteristic in each of the **homologous chromosomes**.

- If both alleles are the same, the individual is a **homozygote** or **pure-bred** for that characteristic.
- If they are different, the individual is a **heterozygote** or **hybrid** for that characteristic.

It is possible that the presence of one of the alleles stops the alternative one for that characteristic from showing. In that case, the first allele receives the name of **dominant allele**; the second one, which only shows if the dominant allele is not present, is referred to as a **recessive allele**. The dominant allele is represented by a capital letter (A) and the recessive allele with the same letter, but lower case (a).

heterozygous genotype (Nn) black phenotype
N n
N N
n n
homozygous genotype (NN) black phenotype
homozygous genotype (nn) white phenotype

Black-coloured fur is dominant over white-coloured fur in guinea pigs.

Apply

2. Can two individuals with the same phenotype have different genotypes? Explain your answer.

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2. EARLY GENETIC STUDIES

Since ancient times, farmers have selected animals and plants in order to increase food production.

This **artificial selection** was performed without a previous study of how biological characteristics are passed on from parents to offspring. The first researcher that completed this type of work was Austrian monk **Gregor Mendel**, during the second half of the 19th century.

Mendel analysed how pea plants (*Pitsum sativum*) inherited a series of characteristics. He considered that this process was controlled by independent 'factors' that passed from parents to offspring (back then, Mendel did not know that genes existed).

Mendel chose pea plants for his genetic experiments because they have a series of characteristics with alternatives that are easily recognisable. Also, cultivating as well as artificially fertilising pea plants are simple processes and the results are achieved in a short period of time.

In his investigations, Mendel observed that the transmission of characteristics followed certain rules, from which he was able to predict the results.

Mendel's discoveries are the foundation of genetics and all genetic studies are in some way related to his work.

Remember

3. Listen to the following characteristics of pea plants and identify if they are dominant or recessive.

anthers are cut
pollen is transferred using a brush
purple petals
white petals
F_1
all purple

When crossing different varieties, Mendel eliminated the flowers' anthers to avoid self-pollination and, using a brush, he transferred pollen to the plants that he had selected.

Stem length: short, tall (dominant)
Flower position: terminal, axial (dominant)
Flower colour: purple (dominant), white
Pea shape: round (dominant), wrinkled
Pod shape: constricted, smooth (dominant)
Pea colour: yellow (dominant), green
Pod colour: yellow (dominant), green

Characteristics of pea plants studied by Mendel.

3. Mendelian genetics 55

1. Key concepts of genetics

Before starting to study Mendelian genetics in more detail, it is important that students have a good understanding of certain concepts learned during the previous unit. The main concept is that when cells or organisms reproduce, they transmit their biological information to their offspring. This includes basic information to carry out their biological functions, as well as the specific characteristics of that cell or organism.

Ask students to listen to and read the first paragraph in pairs. Make sure they also read the definition of expression in their Student's book. Ask:

- *What is a hereditary characteristic?*

  A hereditary characteristic is any characteristic present in an individual that is transmittable to their offspring.

- *Why are genes the units of inheritance?*

  Because the information in the genes is responsible for the expression of hereditary characteristics.

Write the definition of hereditary characteristic on the board using students' contributions. Read the definition of genes highlighted in grey and add it to the board. Put students into mixed-ability groups of four or five. Say:

- *In this section we are going to learn terms that we will be using for the rest of the unit. You are going to create definitions for the following terms using the information in your Student's book.*

On the board write *genotype*, *phenotype*, *allele*, *homologous chromosomes*, *homozygote*, *heterozygote*, *dominant allele* and *recessive allele*. Students work in their groups to create definitions for the terms. Encourage groups to be as creative as possible and add diagrams or drawings to their definitions.

Still in their mixed-ability groups, students complete Activities 1 and 2. When they are working on Activity 1, make sure students understand that the two structures form a pair of homologous chromosomes. Then discuss their answers in open class.

2. Early genetic studies

Students listen to and read the first three paragraphs. As they are doing so, write the following questions on the board.

- *How did ancient farmers increase food production?*

  They selected their animals and plants; the best producing specimens were kept.

- *Who was the first person to study how biological characteristics are passed onto offspring?*

  Gregor Mendel, who was an Austrian monk that lived during the second half of the 19th century.

- *What did Mendel call genes back then?*

  He did not know that genes existed, so he referred to them as 'factors'.

In pairs, students find the answers to the questions. Then discuss their answers in open class. Say:

- *Now listen to and read the next paragraph to find out why Mendel chose pea plants.*

Make sure that students understand that he chose these plants because they have certain characteristics that are easily recognisable, with few alternatives. Also, they were easy plants to cultivate and fertilise.

Students listen to and read the final two paragraphs. When they have finished, ask:

- *Why are Mendel's discoveries the foundation of genetics?*

  He was the first person to study genes and realise that the transmission of characteristic followed certain rules.

In open class, analyse the two diagrams at the bottom of the page. Students can see how Mendel pollinated his pea plants during his experiments and also the main characteristics of pea plants that he studied.

Students complete Activity 3 individually and compare their answers in pairs, then discuss in open class.

To extend their knowledge, students could write a short fictional story about Mendel and his peas. They can do this in small mixed-ability groups or pairs. Alternatively students could work individually and write short diary entries imagining they are Mendel. When students have finished, display their work on the wall.

Students can find more information about Mendel in the following link.

Weblink 2: **GREGOR MENDEL (1822-1884)**
This web page has a short biography about the father of genetics, Gregor Mendel.

Finally, to help students remember key vocabulary and summarise the key concepts of the lesson, ask students to add any new vocabulary to their Quizlet set of cards, or alternatively to their graphic organisers, and ask volunteer students to prepare the A4 posters of new vocabulary to hang up on the wall.

EXTRA RESOURCES
AUDIO
TALKING BOOK
PDF
INTERACTIVE ACTIVITIES

Answer Key

Understand

1. Look at the image and answer the questions.

a) What are R, T and S?

They are genes.

b) What are R and r?

They are alleles.

c) What is the phenotype of the individual like in relation to R?

Heterozygote

d) And in relation to T?

Heterozygote

Apply

2. Can two individuals with the same phenotype have different genotypes? Explain your answer.

Yes, as long as one allele is dominant over the other, heterozygotes and homozygotes have the same phenotype, given that the recessive allele of the heterozygotes is not expressed.

Remember

3. Listen to the following characteristics of pea plants and identify if they are dominant or recessive.

a) Yellow coloured peas

Dominant

b) Smooth pods

Dominant

c) White flowers

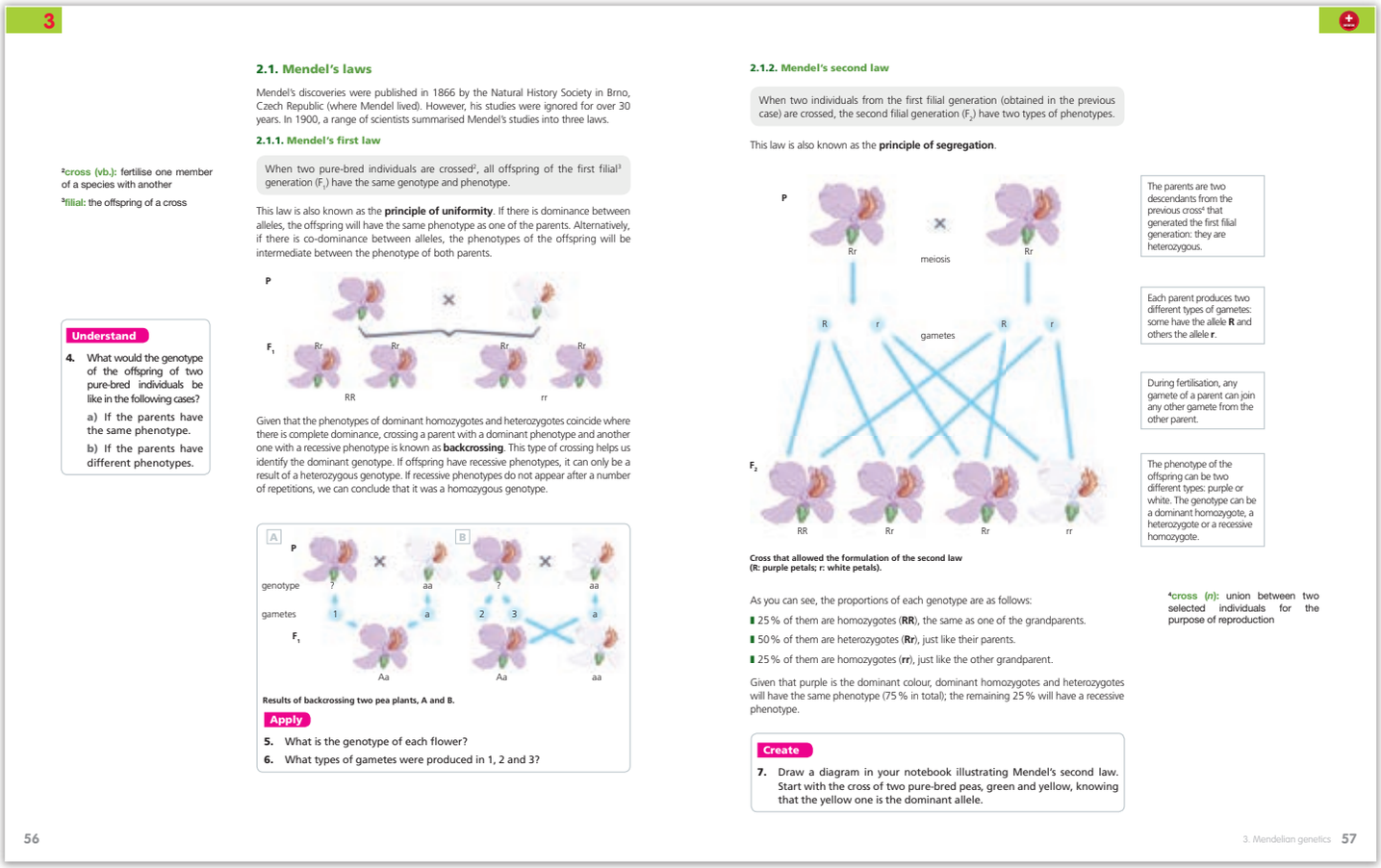
Recessive

d) Tall plants

Dominant

e) Wrinkled peas

Recessive



3

2.1. Mendel's laws

Mendel's discoveries were published in 1866 by the Natural History Society in Brno, Czech Republic (where Mendel lived). However, his studies were ignored for over 30 years. In 1900, a range of scientists summarised Mendel's studies into three laws.

2.1.1. Mendel's first law

When two pure-bred individuals are crossed[2], all offspring of the first filial[3] generation (F_1) have the same genotype and phenotype.

This law is also known as the **principle of uniformity**. If there is dominance between alleles, the offspring will have the same phenotype as one of the parents. Alternatively, if there is co-dominance between alleles, the phenotypes of the offspring will be intermediate between the phenotype of both parents.

[2]cross (vb.): fertilise one member of a species with another

[3]filial: the offspring of a cross

Understand

4. What would the genotype of the offspring of two pure-bred individuals be like in the following cases?
   a) If the parents have the same phenotype.
   b) If the parents have different phenotypes.

Given that the phenotypes of dominant homozygotes and heterozygotes coincide where there is complete dominance, crossing a parent with a dominant phenotype and another one with a recessive phenotype is known as **backcrossing**. This type of crossing helps us identify the dominant genotype. If offspring have recessive phenotypes, it can only be a result of a heterozygous genotype. If recessive phenotypes do not appear after a number of repetitions, we can conclude that it was a homozygous genotype.

Results of backcrossing two pea plants, A and B.

Apply

5. What is the genotype of each flower?
6. What types of gametes were produced in 1, 2 and 3?

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2.1.2. Mendel's second law

When two individuals from the first filial generation (obtained in the previous case) are crossed, the second filial generation (F_2) have two types of phenotypes.

This law is also known as the **principle of segregation**.

Cross that allowed the formulation of the second law (R: purple petals; r: white petals).

The parents are two descendants from the previous cross[4] that generated the first filial generation: they are heterozygous.

Each parent produces two different types of gametes: some have the allele **R** and others the allele **r**.

During fertilisation, any gamete of a parent can join any other gamete from the other parent.

The phenotype of the offspring can be two different types: purple or white. The genotype can be a dominant homozygote, a heterozygote or a recessive homozygote.

As you can see, the proportions of each genotype are as follows:

- 25 % of them are homozygotes (**RR**), the same as one of the grandparents.
- 50 % of them are heterozygotes (**Rr**), just like their parents.
- 25 % of them are homozygotes (**rr**), just like the other grandparent.

Given that purple is the dominant colour, dominant homozygotes and heterozygotes will have the same phenotype (75 % in total); the remaining 25 % will have a recessive phenotype.

[4]cross (n): union between two selected individuals for the purpose of reproduction

Create

7. Draw a diagram in your notebook illustrating Mendel's second law. Start with the cross of two pure-bred peas, green and yellow, knowing that the yellow one is the dominant allele.

3. Mendelian genetics 57

2.1. Mendel's laws

Students listen to and read the paragraph. Ask:

- *When were Mendel's discoveries published?*

  They were published in 1866 by the Natural History Society in Brno.

- *How did the scientific community receive Mendel's work?*

  It was ignored for over 30 years. It was not until the 1900s that Mendel's work was properly looked at and summarised into three laws.

2.1.1. Mendel's first law

Students listen to and read Mendel's first law, which is highlighted in grey. Ask:

- *What was the genotype? What was the phenotype?*

  The genotype is the group of genes of a particular individual. The phenotype is the external manifestation of those genes.

- *What occurs when two pure-bred individuals are crossed?*

  All offspring of the first filial generation have the same genotype and phenotype.

Listen to and read the following paragraph as a whole class. Look at the diagram and ask:

- *What happens to the phenotype of F1 if one allele is dominant over the other one?*

  Offspring will have the same phenotype as one of the parents.

- *What if the two alleles are equally dominant?*

  Then, the phenotypes of offspring will be intermediate between the phenotypes of both parents.

Complete Activity 4 in open class. Draw a diagram on the board with two parent flowers and four offspring. Explain that the two parent flowers have the same phenotype and that they are both pure-bred. Label both parents as AA. Do not label the four flowers resulting from F_1. Ask:

- *What would the genotype of F1 be like?*

  All the individuals resulting from F_1 would be AA.

Allow students to write their answers for the first part of Activity 4. Then, they can complete the second part of the question in mixed-ability pairs. Encourage them to create their own diagrams.

Students listen to and read the last paragraph on the page. As they are reading, write the following questions on the board.

- *What is backcrossing?*

  Backcrossing is crossing one parent with a dominant phenotype and another one with a recessive phenotype.

- *Why and how is backcrossing important?*

  It helps us identify the dominant genotype. Heterozygous genotypes will lead to offspring with recessive phenotypes; if those recessive phenotypes do not appear after a few generations, we can conclude it is a homozygous genotype.

In their pairs, students complete Activities 5 and 6. As they are doing so, copy the diagram onto the board. When they have finished, ask volunteers to explain their answers using the diagram on the board. Discuss their answers in open class.

2.1.2. Mendel's second law

Listen to and read Mendel's second law as a class and look at the diagram **Cross that allowed the formulation of the second law (R: purple petals, r: white petals).** Then listen to and read the four text boxes explaining the process that occurred during the cross. Ask:

- *What are the two possible phenotypes of resulting offspring in F_2?*

  Purple and white

- *What are the genotypes in F_2?*

  Dominant homozygote, heterozygote or recessive homozygote

- *Which pairs of letters represent the three phenotypes in the picture?*

  Dominant homozygote: RR, heterozygote: Rr and recessive homozygote: rr

Students listen to and read the rest of the section. Students complete Activity 7 individually and compare their answers in pairs, then discuss in open class. Use their answers to assess their understanding.

Use the following web page to revise the concepts studied in this section:

Weblink 3: **SOME GENES ARE DOMINANT**
This web page explains the principle of dominance using Mendel's pea plants. The animations help students become more familiar with the terms used in genetics. Students complete Weblink 3 worksheet.

Finally, to help students remember key vocabulary and summarise the key concepts of the lesson, ask students to add any new vocabulary to their Quizlet set of cards, or alternatively to their graphic organisers, and ask volunteer students to prepare the A4 posters of new vocabulary to hang up on the wall.

EXTRA RESOURCES
AUDIO
TALKING BOOK
PDF
INTERACTIVE ACTIVITIES

Answer Key

Understand

4. What would the genotype of the offspring of two pure-bred individuals be like in the following cases?

a) If the parents have the same phenotype.

They would all be either AA or aa.

b) If the parents have different phenotypes.

They would be Aa.

Apply

5. What is the genotype of each flower?

A. AA

B. Aa

6. What types of gametes were produced in 1, 2 and 3?

1. A
2. A
3. a

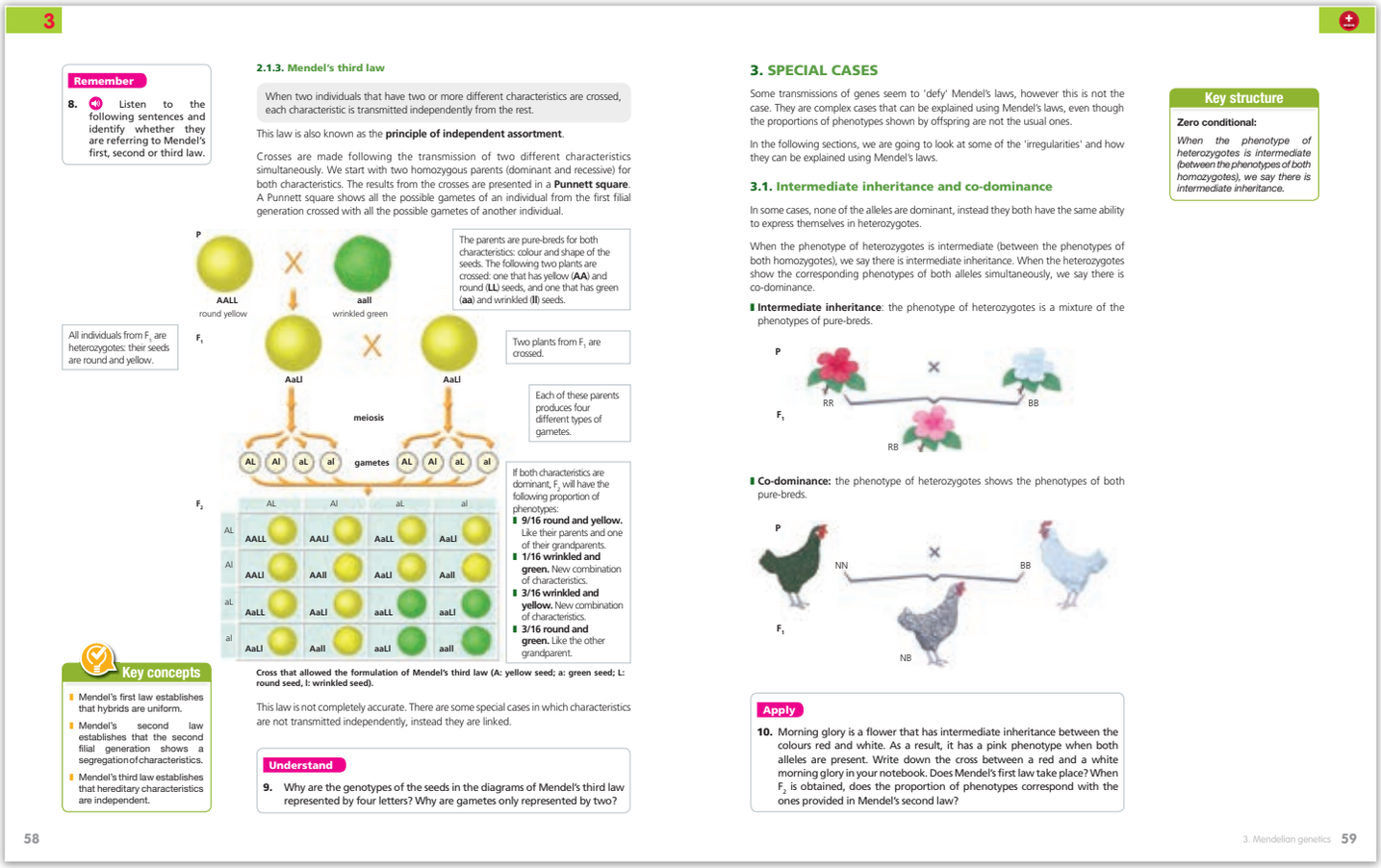
Create

7. Draw a diagram in your notebook illustrating Mendel's second law. Start with the cross of two pure-bred peas, green and yellow, knowing that the yellow one is the dominant allele.

The F_1 are all Ll (yellow).

The F_2 are:

- 25 % LL (yellow)
- 50 % Ll (yellow)
- 25 % ll (green)



3

Remember

8. Listen to the following sentences and identify whether they are referring to Mendel's first, second or third law.

2.1.3. Mendel's third law

When two individuals that have two or more different characteristics are crossed, each characteristic is transmitted independently from the rest.

This law is also known as the **principle of independent assortment**.

Crosses are made following the transmission of two different characteristics simultaneously. We start with two homozygous parents (dominant and recessive) for both characteristics. The results from the crosses are presented in a **Punnett square**. A Punnett square shows all the possible gametes of an individual from the first filial generation crossed with all the possible gametes of another individual.

The parents are pure-breds for both characteristics: colour and shape of the seeds. The following two plants are crossed: one that has yellow (**AA**) and round (**LL**) seeds, and one that has green (**aa**) and wrinkled (**ll**) seeds.

All individuals from F_1 are heterozygotes: their seeds are round and yellow.

Two plants from F_1 are crossed.

Each of these parents produces four different types of gametes.

If both characteristics are dominant, F_2 will have the following proportion of phenotypes:
- **9/16 round and yellow.** Like their parents and one of their grandparents.
- **1/16 wrinkled and green.** New combination of characteristics.
- **3/16 wrinkled and yellow.** New combination of characteristics.
- **3/16 round and green.** Like the other grandparent.

Cross that allowed the formulation of Mendel's third law (A: yellow seed; a: green seed; L: round seed, l: wrinkled seed).

This law is not completely accurate. There are some special cases in which characteristics are not transmitted independently, instead they are linked.

Understand

9. Why are the genotypes of the seeds in the diagrams of Mendel's third law represented by four letters? Why are gametes only represented by two?

Key concepts
- Mendel's first law establishes that hybrids are uniform.
- Mendel's second law establishes that the second filial generation shows a segregation of characteristics.
- Mendel's third law establishes that hereditary characteristics are independent.

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3. SPECIAL CASES

Some transmissions of genes seem to 'defy' Mendel's laws, however this is not the case. They are complex cases that can be explained using Mendel's laws, even though the proportions of phenotypes shown by offspring are not the usual ones.

In the following sections, we are going to look at some of the 'irregularities' and how they can be explained using Mendel's laws.

3.1. Intermediate inheritance and co-dominance

In some cases, none of the alleles are dominant, instead they both have the same ability to express themselves in heterozygotes.

When the phenotype of heterozygotes is intermediate (between the phenotypes of both homozygotes), we say there is intermediate inheritance. When the heterozygotes show the corresponding phenotypes of both alleles simultaneously, we say there is co-dominance.

- **Intermediate inheritance**: the phenotype of heterozygotes is a mixture of the phenotypes of pure-breds.
- **Co-dominance:** the phenotype of heterozygotes shows the phenotypes of both pure-breds.

Key structure

Zero conditional:

When the phenotype of heterozygotes is intermediate (between the phenotypes of both homozygotes), we say there is intermediate inheritance.

Apply

10. Morning glory is a flower that has intermediate inheritance between the colours red and white. As a result, it has a pink phenotype when both alleles are present. Write down the cross between a red and a white morning glory in your notebook. Does Mendel's first law take place? When F_2 is obtained, does the proportion of phenotypes correspond with the ones provided in Mendel's second law?

3. Mendelian genetics 59

2.1.3. Mendel's third law

In this section, students will continue working with the mathematical concepts of proportion and probability. Students will also become familiar with the use of a Punnett square to solve problems involving Mendelian genetics.

Listen to and read the definition of Mendel's third law. Ask students to look at the top of the diagram **Cross that allowed the formulation of Mendel's third law (A: yellow seed; a: green seed; L: round seed, l: wrinkled seed)**. Ask:

- *What are the two characteristics studied in this case?*

  Pea colour and pea shape

- *Which characteristics are dominant and which characteristics are recessive?*

  Round shape and yellow colour are both dominant characteristics; wrinkled and green are recessive characteristics.

Students listen to and read the next two paragraphs in pairs. Ask:

- *Are the two starting parents homozygous or heterozygous?*

  They are homozygous (pure-breed).

- *Is F_1 heterozygous or homozygous?*

  They are heterozygotes (hybrids).

- *Why are Punnett squares useful to determine the transmission of characteristic when two or more characteristics are involved?*

  Because there are many combinations (just 2 independent characteristics in heterozygotes is equal to 16 possible genotypes).

The following video reviews Mendel's laws and shows how Punnett squares are used.

Video 2: HOW MENDEL'S PEA PLANTS HELPED US UNDERSTAND GENETICS

This video, part of TED-Ed, explains Mendel's laws and how to make Punnett squares. There are activities that will help students understand and internalise the information. To answer the questions, students will need to create an account.

Draw a diagram on the board like the one in the Student's book but do not add the Punnett square. Students work in pairs, with their Student's book closed, to create a Punnett square using the diagram on the board. If you need to prompt them, draw the outline and add the four possible gametes to the *x* and *y* axis. Then students work out all of the possible combinations, for example AL + AL = AALL.

Now ask students to work out the proportions of phenotypes, using the Punnett squares that they have just made and with their Student's book closed. Ask:

- *How many seeds are round and yellow? Can you express it as a fraction?*

  Nine peas are round and yellow. 9/16.

  Repeat with remaining characteristics: wrinkled and green (1/16), wrinkled and yellow (3/16), and round and green (3/16).

Repeat the process a few times using other characteristics of pea plants (see Student's book page 55). By creating more Punnett squares, students will become more familiar with Mendel's laws. Alternatively, use the following link which has a range of practice activities.

Weblink 4: **WORKING OUT PUNNETT SQUARE EXAMPLES**

This web page has a variety of increasingly complex Punnett squares for students to complete and work out the probabilities of having a particular descendant.

Students complete Activity 8 in mixed-ability pairs. They compare their answers with another pair, then discuss in open class. Students complete Activity 9 in the same pairs. Discuss their answers in open class.

To revise Mendel's three laws, show the following animation.

Animation: **MENDEL'S LAWS**

This animation explains how Mendel's laws were developed.

3. Special cases

It is important that students understand that although there are some cases that do not seem to follow Mendel's laws as the offspring present different proportions of phenotypes, they can still be explained using his laws.

Students listen to and read the two paragraphs in the section. Ask:

- *Why are the words 'defy' and 'irregularities' written using inverted commas?*

  This is because they are talking about special cases that do not seem to follow the laws, but actually do follow Mendel's laws.

3.1. Intermediate inheritance and co-dominance

The difference between intermediate inheritance and co-dominance is very subtle and has to be explained using specific examples: generally characteristics that reflect an intermediate colouring between other two (flowers, feathers and so on) are useful to explain intermediate inheritance; on the other hand, if patterns such as spots appear, we can clearly see that both characteristics have been expressed simultaneously.

Ask students to listen to and read the first paragraph. Ask:

- *Why do intermediate inheritance and co-dominance occur?*

  They occur because none of the alleles are dominant and they both have the same ability to express themselves.

In open class, look at the descriptions of intermediate inheritance and co-dominance. Explain the difference using the diagrams. Students need to know that in intermediate inheritance the phenotypes are mixed and in co-dominance they are both expressed simultaneously. Students complete Activity 10 in mixed-ability pairs. They compare their answers with another pair, then discuss in open class.

Finally, to help students remember key vocabulary and summarise the key concepts of the lesson, ask students to add any new vocabulary to their Quizlet set of cards, or alternatively to their graphic organisers, and ask volunteer students to prepare the A4 posters of new vocabulary to hang up on the wall.

EXTRA RESOURCES

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Answer Key

Remember

8. Listen to the following sentences and identify whether they are referring to Mendel's first, second or third law.

a) The second filial generation has different characteristics.

Mendel's second law

b) Hereditary characteristics are independent.

Mendel's third law

c) All offspring are the same.

Mendel's first law

Understand

9. Why are the genotypes of the seeds in the diagrams of Mendel's third law represented by four letters? Why are gametes only represented by two?

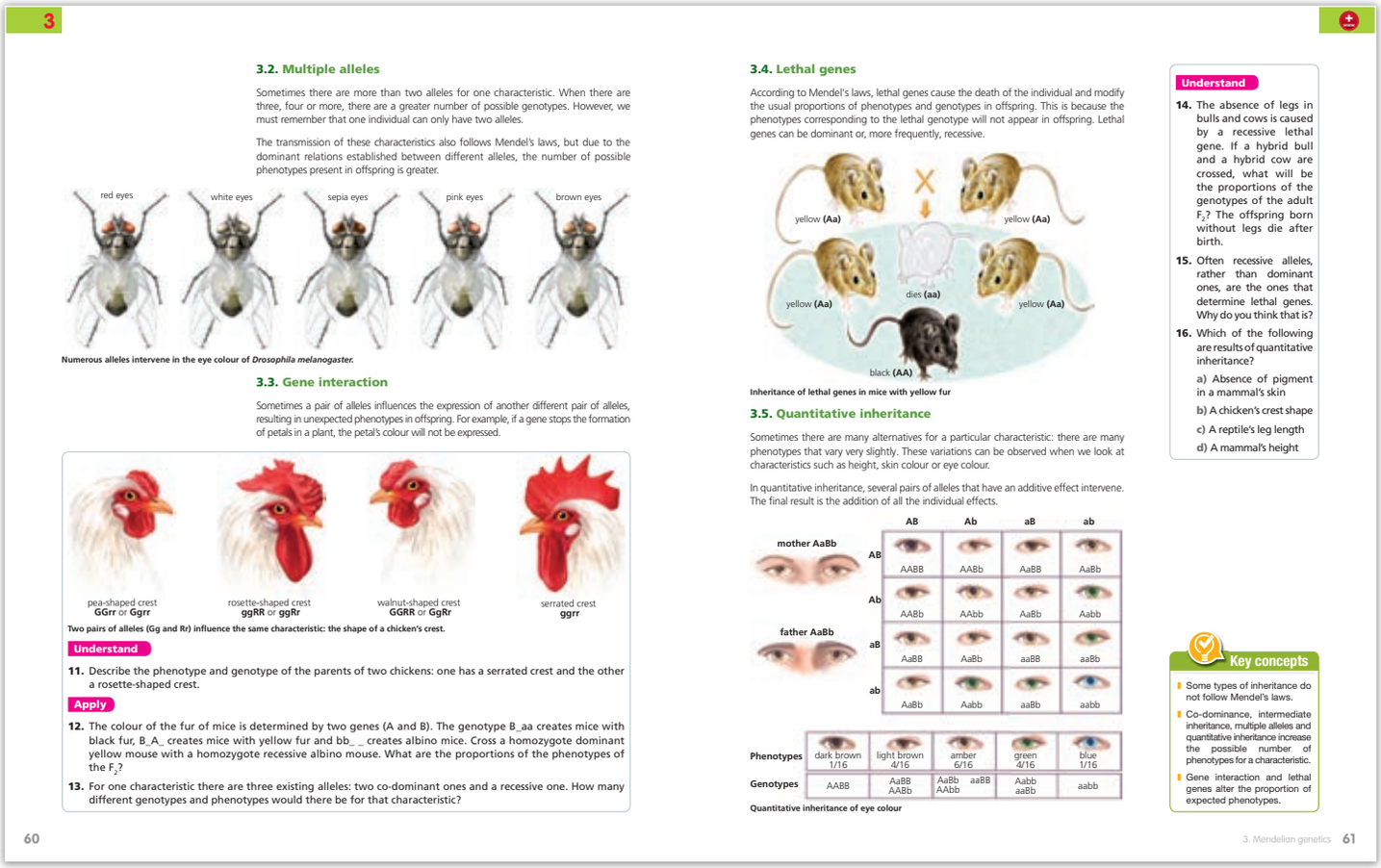
- The diagram is showing the possible genotypes for two characteristics: pea colour and pea shape. The first two letters correspond to the homologous genes for seed colour and the second two to the homologous genes for seed shape.
- The gametes only have two letters because they contain half of the genetic information (the first letter is for seed colour and the second for seed shape), so that when two gametes join, a cell with a complete set of genetic information is made

Apply

10. Morning glory is a flower that has intermediate inheritance between the colours red and white. As a result, it has a pink phenotype when both alleles are present. Write down the cross between a red and a white morning glory in your notebook. Does Mendel's first law take place? When F_2 is obtained, does the proportion of phenotypes correspond with the ones provided in Mendel's second law?

Both the first law and the second law take place: F_1 is uniform and F_2 presents the right proportions of genotypes.

P	RR (red)	x	WW (white)
F_1	100 % RW (pink)	x	100 % RW (pink)
F_2	25 % RR (red)	50 % RW (pink)	25 % WW (white)



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3.2. Multiple alleles

Sometimes there are more than two alleles for one characteristic. When there are three, four or more, there are a greater number of possible genotypes. However, we must remember that one individual can only have two alleles.

The transmission of these characteristics also follows Mendel's laws, but due to the dominant relations established between different alleles, the number of possible phenotypes present in offspring is greater.

Numerous alleles intervene in the eye colour of *Drosophila melanogaster*.

3.3. Gene interaction

Sometimes a pair of alleles influences the expression of another different pair of alleles, resulting in unexpected phenotypes in offspring. For example, if a gene stops the formation of petals in a plant, the petal's colour will not be expressed.

Two pairs of alleles (Gg and Rr) influence the same characteristic: the shape of a chicken's crest.

Understand

11. Describe the phenotype and genotype of the parents of two chickens: one has a serrated crest and the other a rosette-shaped crest.

Apply

12. The colour of the fur of mice is determined by two genes (A and B). The genotype B_aa creates mice with black fur, B_A_ creates mice with yellow fur and bb_ _ creates albino mice. Cross a homozygote dominant yellow mouse with a homozygote recessive albino mouse. What are the proportions of the phenotypes of the F_2?

13. For one characteristic there are three existing alleles: two co-dominant ones and a recessive one. How many different genotypes and phenotypes would there be for that characteristic?

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3.4. Lethal genes

According to Mendel's laws, lethal genes cause the death of the individual and modify the usual proportions of phenotypes and genotypes in offspring. This is because the phenotypes corresponding to the lethal genotype will not appear in offspring. Lethal genes can be dominant or, more frequently, recessive.

Inheritance of lethal genes in mice with yellow fur

3.5. Quantitative inheritance

Sometimes there are many alternatives for a particular characteristic: there are many phenotypes that vary very slightly. These variations can be observed when we look at characteristics such as height, skin colour or eye colour.

In quantitative inheritance, several pairs of alleles that have an additive effect intervene. The final result is the addition of all the individual effects.

	AB	Ab	aB	ab
AB	AABB	AABb	AaBB	AaBb
Ab	AABb	AAbb	AaBb	Aabb
aB	AaBB	AaBb	aaBB	aaBb
ab	AaBb	Aabb	aaBb	aabb

Phenotypes	dark brown 1/16	light brown 4/16	amber 6/16	green 4/16	blue 1/16
Genotypes	AABB	AaBB AABb	AaBb aaBB AAbb	Aabb aaBb	aabb

Quantitative inheritance of eye colour

Understand

14. The absence of legs in bulls and cows is caused by a recessive lethal gene. If a hybrid bull and a hybrid cow are crossed, what will be the proportions of the genotypes of the adult F_2? The offspring born without legs die after birth.

15. Often recessive alleles, rather than dominant ones, are the ones that determine lethal genes. Why do you think that is?

16. Which of the following are results of quantitative inheritance?

a) Absence of pigment in a mammal's skin

b) A chicken's crest shape

c) A reptile's leg length

d) A mammal's height

Key concepts

- Some types of inheritance do not follow Mendel's laws.
- Co-dominance, intermediate inheritance, multiple alleles and quantitative inheritance increase the possible number of phenotypes for a characteristic.
- Gene interaction and lethal genes alter the proportion of expected phenotypes.

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3.2. Multiple alleles

Students listen to and read the two paragraphs describing multiple alleles. Ask:

- *What does the term multiple alleles refer to?*

  It refers to specific cases in which there are more than two alleles for one characteristic.

- *Can an individual have more than two alleles for one characteristic?*

  No, an individual can only have two alleles per characteristic.

- *Would the number of resulting phenotypes be the same when there are multiple alleles?*

  No, it would be greater.

Students look at the diagram **Numerous alleles intervene in the eye colour of *Drosophila melanogaster*** to see the resulting five phenotypes.

Show the following video which explores another well-known case of multiple alleles.

> Video 3: **THE ABO GROUP – MULTIPLE ALLELES AND CO-DOMINANCE**
>
> This great video, part of TED-Ed, explains how the ABO blood group in humans is a result of multiple allelism. There are activities which will help students understand and internalise the information.

Students complete Activity 11 in mixed-ability groups. When finished, groups share their answers to self assess their work. To help the groups complete Activity 12, you can draw a blank Punnett square on the board and write the pairs of alleles belonging to the parents (BBAA and bbaa). Students complete their own Punnett square in their groups to find the resulting genotypes for F_2.

3.3. Gene interaction

Students listen to and read the paragraph and discuss its meaning in pairs. Ask:

- *What occurs when a pair of alleles influences the expression of another pair of alleles?*

  Unexpected phenotypes might occur.

Students complete Activity 13 in mixed-ability pairs. To get them started write on the board: a1 = a2 > a3. Ask students to find all of the possible genotypes and phenotypes. When they have finished, share some of their answers in open class and clarify any misconceptions.

3.4. Lethal genes

Students listen to and read the paragraph and then complete Activity 14 in mixed-ability pairs. To help students get the proportions right, ask them to use the diagram **Inheritance of lethal genes in mice with yellow fur.**

Then, still in their pairs, they complete Activity 15. Discuss their answers in open class.

If time allows, you could explain to students that we can differentiate between different types of lethal genes:

- Some of them affect gametes and others appear before reaching sexual maturity.
- They can be completely lethal (95 % of the gene carriers die); semi-lethal (between 50 % and 90 % of gene carriers die) or sub-lethal (less than 10 % of gene carriers die).

3.5. Quantitative inheritance

Students listen to and read the two paragraphs in this section. Then, ask students to stand up and get into a line that shows all of the different eye colours in the class in order. Encourage them to cooperate with each other to assess the different shades (for example, there may be five students that have green eyes, but they will probably be quite different shades of green).

When they have finished, repeat the process but this time order themselves according to their hair colour, or their height. Ask:

- *Was classifying the colour of your eyes easy?*

  It probably wasn't easy, because there were lots of different variations.

Then, students complete Activity 16 in pairs. Discuss their answers in open class.

Finally, to help students remember key vocabulary and summarise the key concepts of the lesson, ask students to add any new vocabulary to their Quizlet set of cards, or alternatively to their graphic organisers, and ask volunteer students to prepare the A4 posters of new vocabulary to hang up on the wall.

EXTRA RESOURCES

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Answer Key

Understand

11. Describe the phenotype and genotype of the parents of two chickens: one has a serrated crest and the other a rosette-shaped crest.

- Genotypes of the parents of a chicken with a serrated crest: _g_r × _g_r. Both parents must have the alleles g and r.
- The phenotypes of the parents of a chicken with a serrated crest (ggrr) can be any of the following: pea-shaped (Ggrr), rosette-shaped (ggRr), walnut-shaped (GgRr) and serrated (ggrr).
- Genotypes of the parents of a chicken with a rosette-shaped crest: _gR_ × _gR_. Both parents must have alleles g and R.
- The phenotypes of the parents of a chicken with a rosette-shaped crest can be any of the following:

  _rosette (ggRR o ggRr) × rosette (ggRR o ggRr)

  walnut (GgR) × walnut (GgR_)

  walnut (GgR) × rosette (ggRR o ggRr)

Apply

12. The colour of the fur of mice is determined by two genes (A and B). The genotype B_aa creates mice with black fur, B_A_ creates mice with yellow fur and bb_ _ creates albino mice. Cross a homozygote dominant yellow mouse with a homozygote recessive albino mouse. What are the proportions of the phenotypes of the F_2?

P: BBAA × bbaa

F_1: BbAa × BbAa

	BA	Ba	bA	ba
BA	BBAA	BBAa	BbAA	BbAa
Ba	BBAa	BBaa	BbAa	Bbaa
bA	BbAA	BbAa	bbAA	bbAa
ba	BbAa	Bbaa	bbAa	bbaa

3/16: black

9/16: yellow

4/16: albino

13. For one characteristic there are three existing alleles: two co-dominant ones and a recessive one. How many different genotypes and phenotypes would there be for that characteristic?

a1 = a2 > a3

There would be six different genotypes: a1a1, a1a2, a1a3, a2a2, a2a3 and a3a3.

There would be four different phenotypes, the ones corresponding to:

- a1a1, a1a3
- a2a2, a2a3
- a1a2
- a3a3

Phenotypes a1a1 and a1a3 lead to the same phenotype, given that a3 is recessive. The same process happens with a2a2 and a2a3.

Understand

14. The absence of legs in bulls and cows is caused by a recessive lethal gene. If a hybrid bull and a hybrid cow are crossed, what will be the proportions of the genotypes of the adult F_2? The offspring born without legs die after birth.

P: Pp × Pp

F_2 Genotypes: 1/3 PP, 2/3 Pp

Phenotypes: 100 % with legs

15. Often recessive alleles, rather than dominant ones, are the ones that determine lethal genes. Why do you think that is?

Recessive alleles are not expressed in heterozygous individuals, so the individual that carries them can survive and transmit the genes to offspring. When the lethal allele is dominant it is expressed in both homozygous and heterozygous individuals. This means that there would not be any healthy carriers of the lethal allele, because the individuals that carry it do not survive.

16. Which of the following are results of quantitative inheritance?

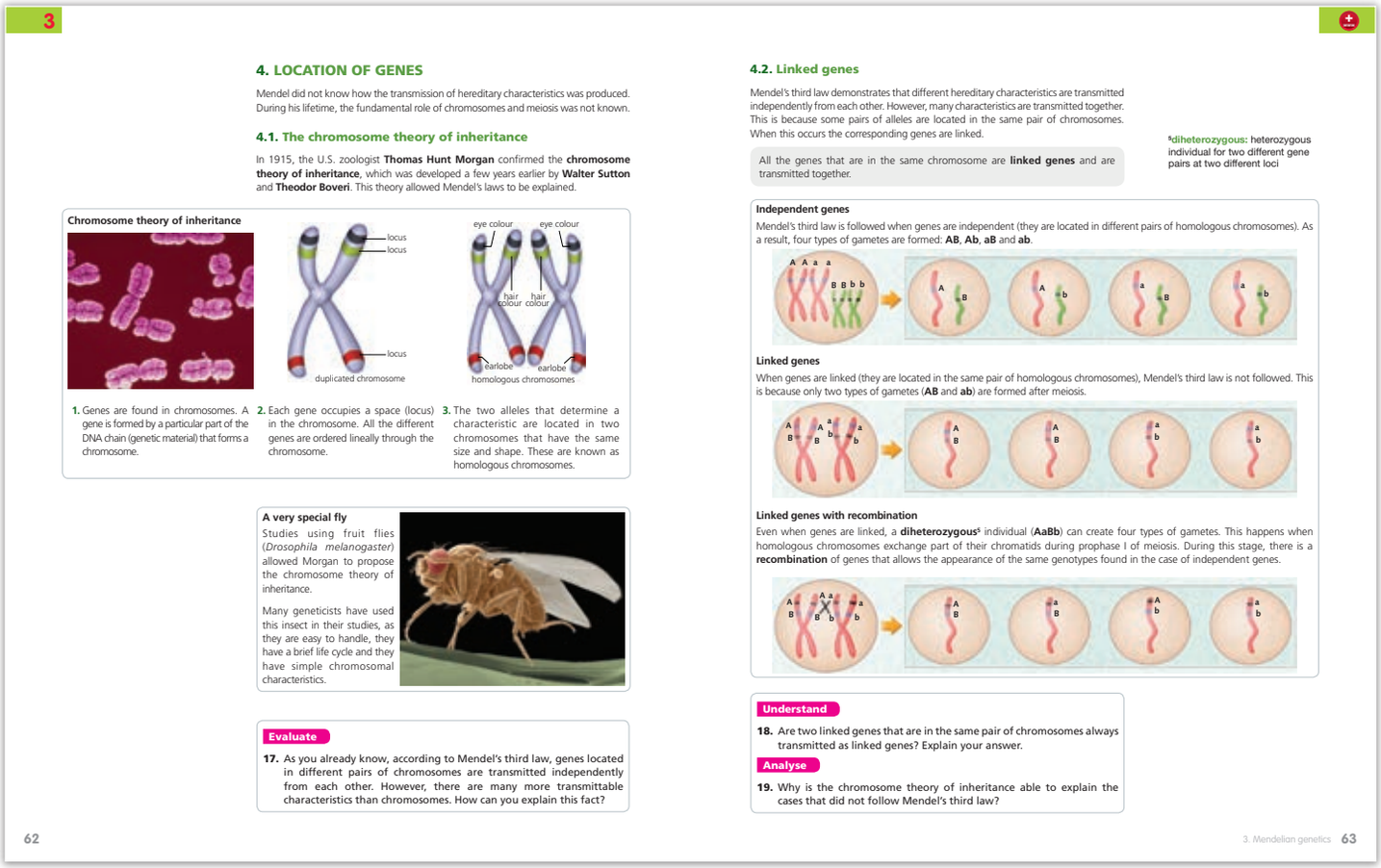
a) Absence of a pigment in a mammal's skin

b) A chicken's crest shape

c) A reptile's leg length

d) A mammal's height

Characteristics c) and d) are results of quantitative inheritance.



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4. LOCATION OF GENES

Mendel did not know how the transmission of hereditary characteristics was produced. During his lifetime, the fundamental role of chromosomes and meiosis was not known.

4.1. The chromosome theory of inheritance

In 1915, the U.S. zoologist **Thomas Hunt Morgan** confirmed the **chromosome theory of inheritance**, which was developed a few years earlier by **Walter Sutton** and **Theodor Boveri**. This theory allowed Mendel's laws to be explained.

Chromosome theory of inheritance

1. Genes are found in chromosomes. A gene is formed by a particular part of the DNA chain (genetic material) that forms a chromosome.
2. Each gene occupies a space (locus) in the chromosome. All the different genes are ordered lineally through the chromosome.
3. The two alleles that determine a characteristic are located in two chromosomes that have the same size and shape. These are known as homologous chromosomes.

A very special fly

Studies using fruit flies (*Drosophila melanogaster*) allowed Morgan to propose the chromosome theory of inheritance.

Many geneticists have used this insect in their studies, as they are easy to handle, they have a brief life cycle and they have simple chromosomal characteristics.

Evaluate

17. As you already know, according to Mendel's third law, genes located in different pairs of chromosomes are transmitted independently from each other. However, there are many more transmittable characteristics than chromosomes. How can you explain this fact?

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4.2. Linked genes

Mendel's third law demonstrates that different hereditary characteristics are transmitted independently from each other. However, many characteristics are transmitted together. This is because some pairs of alleles are located in the same pair of chromosomes. When this occurs the corresponding genes are linked.

All the genes that are in the same chromosome are **linked genes** and are transmitted together.

[5]**diheterozygous:** heterozygous individual for two different gene pairs at two different loci

Independent genes

Mendel's third law is followed when genes are independent (they are located in different pairs of homologous chromosomes). As a result, four types of gametes are formed: **AB**, **Ab**, **aB** and **ab**.

Linked genes

When genes are linked (they are located in the same pair of homologous chromosomes), Mendel's third law is not followed. This is because only two types of gametes (**AB** and **ab**) are formed after meiosis.

Linked genes with recombination

Even when genes are linked, a **diheterozygous**[5] individual (**AaBb**) can create four types of gametes. This happens when homologous chromosomes exchange part of their chromatids during prophase I of meiosis. During this stage, there is a **recombination** of genes that allows the appearance of the same genotypes found in the case of independent genes.

Understand

18. Are two linked genes that are in the same pair of chromosomes always transmitted as linked genes? Explain your answer.

Analyse

19. Why is the chromosome theory of inheritance able to explain the cases that did not follow Mendel's third law?

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4. Location of genes

To further understand the importance of Mendel's work, it is important to mention that when he was carrying out his experiments, there was no knowledge of genes, and therefore no knowledge of their location in chromosomes. Additionally, the role of meiosis and gametes in hereditary transmission was not known at the time. Mendel's conclusions were a truly remarkable achievement.

Students listen to and read the short paragraph. Then, using the knowledge learned during previous units, discuss in open class all of the facts we currently know that Mendel did not know. Write students' contributions on the board.

4.1. The chromosome theory of inheritance

Ask students to listen to and read the first paragraph to find out who confirmed the chromosome theory of inheritance in 1915 (Thomas Hunt Morgan). Ask:

- *Who developed the theory before Thomas Hunt Morgan confirmed it?*

  Walter Sutton and Theodor Boveri

In mixed-ability pairs, students listen to and read the box **Chromosome theory of inheritance** as well as the box **A very special fly**. As they are doing so, write the following questions on the board:

- *Where are genes located?*

  Genes are located in chromosomes.

- *What is the term used to refer to the place each gene occupies?*

  Locus

- *What are homologous chromosomes?*

  They are two chromosomes that have the same size and shape and carry the pairs of alleles that determine the same characteristics.

- *Why are fruit flies often used in genetics?*

  Because they are easy to handle, they have a brief life cycle and they have simple chromosomal characteristics.

Students answer the questions in their pairs. Complete Activity 17 in open class and discuss possible answers. You could mention that they will find out more about linked genes in the next section.

4.2. Linked genes

Students listen to and read the paragraph and the definition highlighted in grey. Ask:

Is Mendel's third law always correct?

No, because some pairs of alleles are located in the same pairs of chromosomes. This means that they are linked genes and are not independent.

Students read the table showing three different scenarios (independent genes, linked genes and linked genes with recombination). Make sure they also read the definition of *diheterozygous*. As they are doing so, draw the three different scenarios on the board (only the images on the left showing the two pairs of homologous chromosomes).

When they have finished reading, ask students to write down all of the possible gametes. Use the Student's book to check that they are correct. You could repeat the process but changing the letter representing the alleles. Ask:

- *Can linked genes produce four types of gametes?*

  Yes they can, it occurs when homologous chromosomes exchange chromatids during prophase I of meiosis. Genetic recombination takes place resulting in the same genotypes dictated by Mendel's third law.

Finally, to help students remember key vocabulary and summarise the key concepts of the lesson, ask students to add any new vocabulary to their Quizlet set of cards, or alternatively to their graphic organisers, and ask volunteer students to prepare the A4 posters of new vocabulary to hang up on the wall.

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Evaluate

17. As you already know, according to Mendel's third law, genes located in different pairs of chromosomes are transmitted independently from each other. However, there are many more transmittable characteristics than chromosomes. How can you explain this fact?

Given that there are many more transmittable characteristics than chromosomes, many genes are located in the same chromosomes and are linked as a result.

Understand

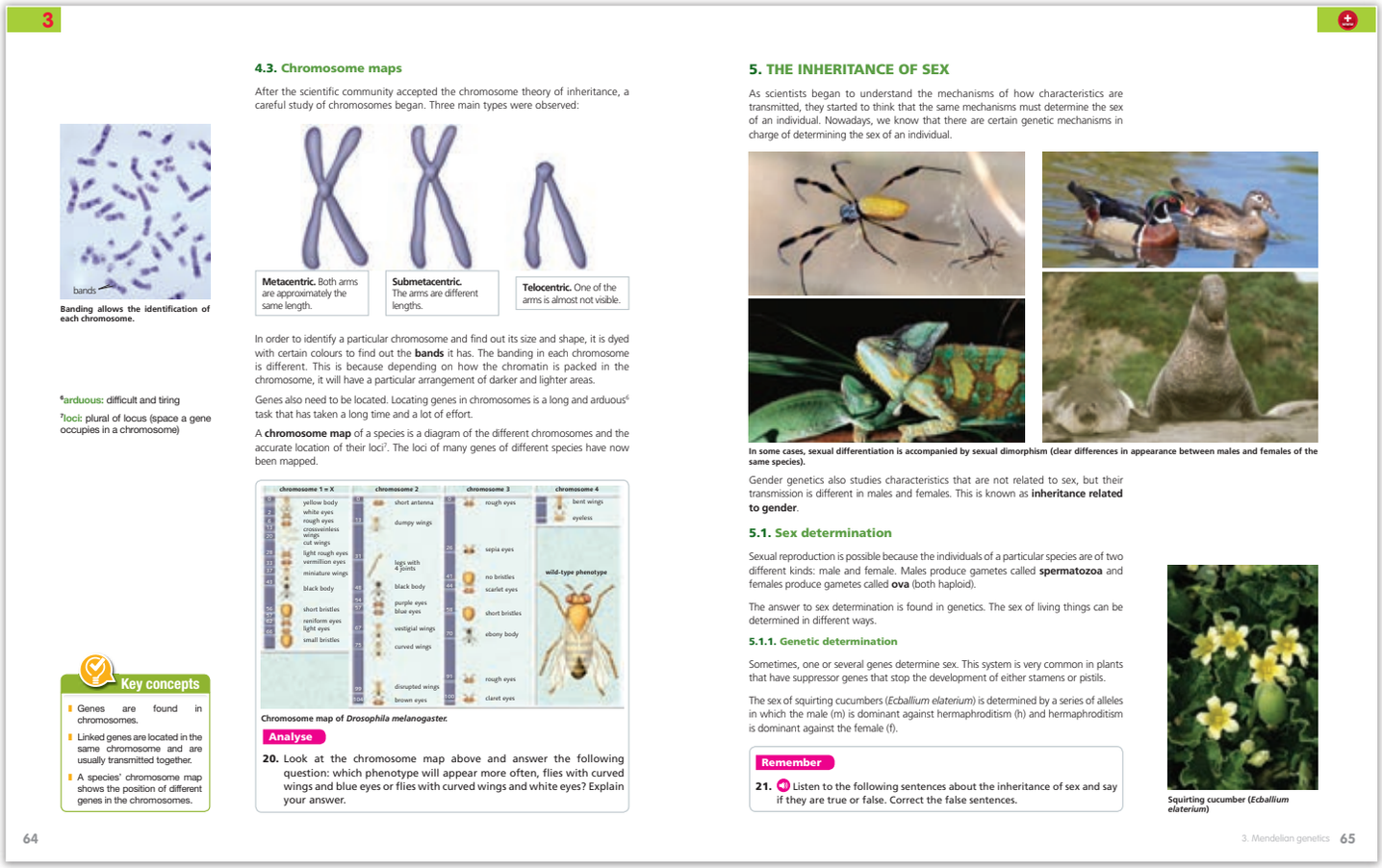
18. Are two linked genes that are in the same pair of chromosomes always transmitted as linked genes? Explain your answer.

Linked genes tend to be transmitted together, but can be transmitted separately if genetic recombination takes place during prophase I of meiosis.

Analyse

19. Why is the chromosome theory of inheritance able to explain the cases that did not follow Mendel's third law?

The chromosome theory of inheritance locates genes in chromosomes, where they occupy a specific space. It also explains that characteristics are determined by alleles that are located in homologous chromosomes. The genes can be independent (in which case they follow Mendel's third law) or linked (they do not follow the law if recombination does not take place).



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4.3. Chromosome maps

After the scientific community accepted the chromosome theory of inheritance, a careful study of chromosomes began. Three main types were observed:

bands

Banding allows the identification of each chromosome.

Metacentric. Both arms are approximately the same length.

Submetacentric. The arms are different lengths.

Telocentric. One of the arms is almost not visible.

In order to identify a particular chromosome and find out its size and shape, it is dyed with certain colours to find out the **bands** it has. The banding in each chromosome is different. This is because depending on how the chromatin is packed in the chromosome, it will have a particular arrangement of darker and lighter areas.

Genes also need to be located. Locating genes in chromosomes is a long and arduous[6] task that has taken a long time and a lot of effort.

A **chromosome map** of a species is a diagram of the different chromosomes and the accurate location of their loci[7]. The loci of many genes of different species have now been mapped.

[6] arduous: difficult and tiring

[7] loci: plural of locus (space a gene occupies in a chromosome)

chromosome 1 = X: yellow body, white eyes, rough eyes, crossveinless wings, cut wings, light rough eyes, vermillion eyes, miniature wings, black body, short bristles, reniform eyes, light eyes, small bristles

chromosome 2: short antenna, dumpy wings, legs with 4 joints, black body, purple eyes, blue eyes, vestigial wings, curved wings, disrupted wings, brown eyes

chromosome 3: rough eyes, sepia eyes, no bristles, scarlet eyes, short bristles, ebony body, rough eyes, claret eyes

chromosome 4: bent wings, eyeless

wild-type phenotype

Chromosome map of *Drosophila melanogaster.*

Key concepts

- Genes are found in chromosomes.
- Linked genes are located in the same chromosome and are usually transmitted together.
- A species' chromosome map shows the position of different genes in the chromosomes.

Analyse

20. Look at the chromosome map above and answer the following question: which phenotype will appear more often, flies with curved wings and blue eyes or flies with curved wings and white eyes? Explain your answer.

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5. THE INHERITANCE OF SEX

As scientists began to understand the mechanisms of how characteristics are transmitted, they started to think that the same mechanisms must determine the sex of an individual. Nowadays, we know that there are certain genetic mechanisms in charge of determining the sex of an individual.

In some cases, sexual differentiation is accompanied by sexual dimorphism (clear differences in appearance between males and females of the same species).

Gender genetics also studies characteristics that are not related to sex, but their transmission is different in males and females. This is known as **inheritance related to gender**.

5.1. Sex determination

Sexual reproduction is possible because the individuals of a particular species are of two different kinds: male and female. Males produce gametes called **spermatozoa** and females produce gametes called **ova** (both haploid).

The answer to sex determination is found in genetics. The sex of living things can be determined in different ways.

5.1.1. Genetic determination

Sometimes, one or several genes determine sex. This system is very common in plants that have suppressor genes that stop the development of either stamens or pistils.

The sex of squirting cucumbers (*Ecballium elaterium*) is determined by a series of alleles in which the male (m) is dominant against hermaphroditism (h) and hermaphroditism is dominant against the female (f).

Remember

21. Listen to the following sentences about the inheritance of sex and say if they are true or false. Correct the false sentences.

Squirting cucumber (*Ecballium elaterium*)

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4.3. Chromosome maps

Chromosome maps are a summary of the genetic information a species has. Ask students to listen to and read the section. Make sure they read the definitions of arduous and loci. As they are doing so, write the following questions on the board:

- *What are the three main types of chromosomes?*

  Metacentric, submetacentric and telocentric

- *Why is the banding in each chromosome different?*

  This is because depending on how the chromatin is packed in the chromosome, it will have a particular arrangement of darker and lighter areas.

- *What is a chromosome map?*

  A chromosome map is a diagram that displays the different chromosomes and the location of their loci. It has a summarised version of the genetic information of a particular species.

Look at the chromosome map at the bottom of the page as a class. You might want to explain to students that the numbers displayed next to the traits in the **Chromosome map of *Drosophila melanogaster*** are the distance between genes along a chromosome, measured in centimorgans. A centimorgan is equivalent to the distance between two genes whose recombination frequency is 1 %.

Also make sure that students realise that many traits can be located in the same gene (these are known as linked genes). Then students complete Activity 20 in mixed-ability pairs, compare their answers with another pair, then discuss in open class.

Now that we start to delve deep into the world of chromosomes, students could create a poster that shows some of the information about chromosomes given on this page. They could do this activity in pairs or small groups. The posters could include information about the different types of chromosomes (metacentric, telocentric and submetacentric), how they are identified, how genes are located, chromosome maps, and maybe even some information about how the chromosome theory on inheritance was confirmed in 1915.

The following link provides students with additional information about chromosomes, which they can use to make their posters more interesting and varied:

Weblink 5: CHROMOSOMES

This web page has a large amount of information about chromosomes. Use the first few pages (up to Things to remember...) to provide students with additional information and diagrams.

5. The inheritance of sex

Before reading the information in this section, ask students to look at the four pictures showing a range of animals. Tell students to cover the caption underneath the pictures and ask:

- *What do you notice about the pairs of animals?*

  Students might say that there are differences between males and females.

Students read the caption to find out about the concept of sexual dimorphism. Ask:

- *What determines the inheritance of sex?*

  Discuss students' prior knowledge of the question.

Then they listen to and read this section. Make sure they understand that we currently know that a range of genetic mechanisms can determine the sex of an individual (genetic determination, sex chromosomes, environmental determination).

5.1. Sex determination

Students listen to and read the information in this section. Ask:

- *What are the names of the male and female gametes?*

  They are spermatozoa and ova respectively.

The following video gives students an overall view of how sex is determined in animals.

Video 4: **SEX DETERMINATION: MORE COMPLICATED THAN YOU THOUGHT**
This great animation is a brief introduction to the different systems used by animals to determine the sex of their offspring. There are activities which will help students understand and internalise the information.

5.1.1. Genetic determination

Students listen to and read the information in the section. Ask:

- *Which living things normally have their sex determined by a gene or genes?*

  Plants normally have their sex determined by a gene or genes: the system of genetic determination is very common in plants.

In order to complete Activity 21, ask students to first read the information on the page one more time. Then they stand up. Play the audio and pause after each sentence. Students remain standing if the sentence is true, or they sit down if the sentence is false. If they think the sentence is false, ask them to explain why and correct it. You may want to play the whole audio track first without pausing to allow them more time to think.

Finally, to help students remember key vocabulary and summarise the key concepts of the lesson, ask students to add any new vocabulary to their Quizlet set of cards, or alternatively to their graphic organisers, and ask volunteer students to prepare the A4 posters of new vocabulary to hang up on the wall.

EXTRA RESOURCES
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Answer Key

Analyse

20. Look at the chromosome map above and answer the following question: which phenotype will appear more often, flies with curved wings and blue eyes or flies with curved wings and white eyes? Explain your answer.

Flies with curved wings and blue eyes will appear more often. This is because both genes are found in the same chromosome, so they are linked genes.

Remember

21. Listen to the following sentences about the inheritance of sex and say if they are true or false. Correct the false sentences.

a) Gender genetics only studies how sex is determined.

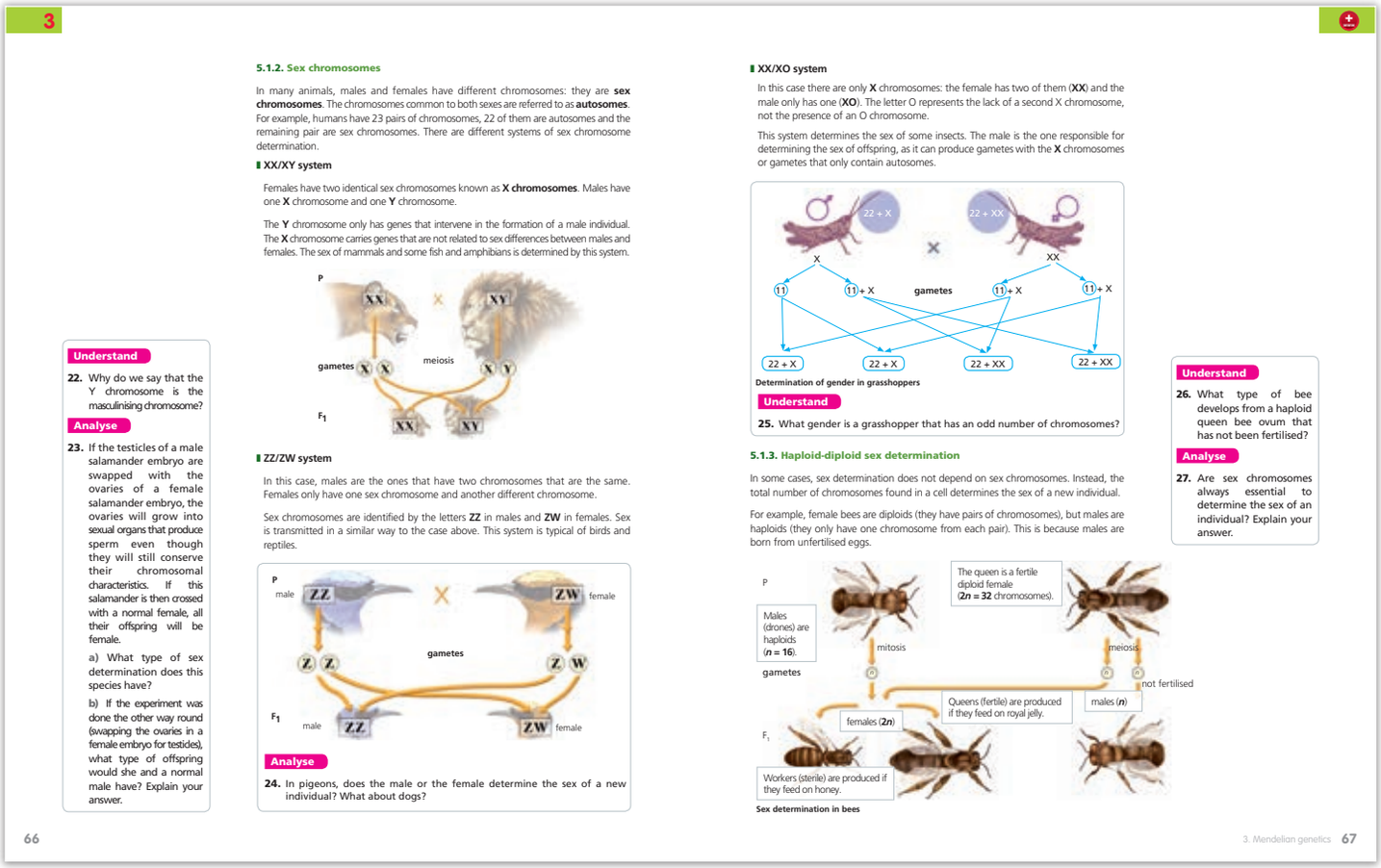
False, it also studies characteristics that are not related to sex but their transmission is different in males and females.

b) Sexual reproduction is possible because the individuals of a particular species are of two different kinds: male and female.

True

c) Genetic determination is common in animals.

False, it is common in plants.



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5.1.2. Sex chromosomes

In many animals, males and females have different chromosomes: they are **sex chromosomes**. The chromosomes common to both sexes are referred to as **autosomes**. For example, humans have 23 pairs of chromosomes, 22 of them are autosomes and the remaining pair are sex chromosomes. There are different systems of sex chromosome determination.

XX/XY system

Females have two identical sex chromosomes known as **X chromosomes**. Males have one **X** chromosome and one **Y** chromosome.

The **Y** chromosome only has genes that intervene in the formation of a male individual. The **X** chromosome carries genes that are not related to sex differences between males and females. The sex of mammals and some fish and amphibians is determined by this system.

ZZ/ZW system

In this case, males are the ones that have two chromosomes that are the same. Females only have one sex chromosome and another different chromosome.

Sex chromosomes are identified by the letters **ZZ** in males and **ZW** in females. Sex is transmitted in a similar way to the case above. This system is typical of birds and reptiles.

Analyse

24. In pigeons, does the male or the female determine the sex of a new individual? What about dogs?

Understand

22. Why do we say that the Y chromosome is the masculinising chromosome?

Analyse

23. If the testicles of a male salamander embryo are swapped with the ovaries of a female salamander embryo, the ovaries will grow into sexual organs that produce sperm even though they will still conserve their chromosomal characteristics. If this salamander is then crossed with a normal female, all their offspring will be female.

a) What type of sex determination does this species have?

b) If the experiment was done the other way round (swapping the ovaries in a female embryo for testicles), what type of offspring would she and a normal male have? Explain your answer.

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XX/XO system

In this case there are only **X** chromosomes: the female has two of them (**XX**) and the male only has one (**XO**). The letter O represents the lack of a second X chromosome, not the presence of an O chromosome.

This system determines the sex of some insects. The male is the one responsible for determining the sex of offspring, as it can produce gametes with the **X** chromosomes or gametes that only contain autosomes.

Determination of gender in grasshoppers

Understand

25. What gender is a grasshopper that has an odd number of chromosomes?

5.1.3. Haploid-diploid sex determination

In some cases, sex determination does not depend on sex chromosomes. Instead, the total number of chromosomes found in a cell determines the sex of a new individual.

For example, female bees are diploids (they have pairs of chromosomes), but males are haploids (they only have one chromosome from each pair). This is because males are born from unfertilised eggs.

Sex determination in bees

Understand

26. What type of bee develops from a haploid queen bee ovum that has not been fertilised?

Analyse

27. Are sex chromosomes always essential to determine the sex of an individual? Explain your answer.

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5.1.2. Sex chromosomes

Students listen to and read the first paragraph. Ask:

- *Which chromosomes are different in many animals?*

  Many species of animals have different sex chromosomes for male and females.

- *What are autosomes?*

  Autosomes are chromosomes that are common to both sexes.

To study the different systems, put students in 6 groups of five students each. Each group is responsible for studying one system of sex chromosome determination (XX/XY, ZZ/ZW or XX/XO) and creating a short two-minute presentation explaining how it works. This means that there will be two presentations for each of the sex determination systems.

Students should explain the different letters used in each system and who determines the sex of offspring (male or female). They could also add a simple diagram, like the one found in the Student's book, to show why the male or the female is responsible for determining the sex of offspring.

Students can use the information in their Student's book as well as the following link to complete their presentations.

Weblink 6: **SEX DETERMINATION**
This web page has a lot of information about the different systems of sex determination.

You might also want to show **Video 4** again as it provides students with a general introduction to how animals determine their gender. In groups, students take notes that they can then use for their oral presentations.

Groups give their presentations to the class. As they are presenting, ask key questions that will help them later to complete the activities in this double spread. For example: *Who has two different sex chromosomes? Who determines the sex of offspring then?*

Students complete Activities 22 and 24 individually. Use their answers for assessment purposes. Then complete Activity 23 in open class.

5.1.3. Haploid-diploid sex determination

Students listen to and read the two paragraphs in this section. Ask:

- *What determines the sex in a haploid-diploid sex determination system?*

  The number of chromosomes determines the sex: males have one chromosome from each pair (they are haploid) and females have a pair of each chromosome (they are diploid).

Students complete Activity 25 in mixed-ability pairs. Prompt students by asking them to look at the number of chromosomes the male and female in the diagram **Determination of gender in grasshoppers** have. They compare their answers with another pair, then discuss in open class.

Then, still in their pairs, they complete Activity 26. Discuss the meaning of haploid and diploid if necessary and discuss their answers in open class. Students complete Activity 27 individually. Use their answers for assessment purposes.

Finally, to help students remember key vocabulary and summarise the key concepts of the lesson, ask students to add any new

vocabulary to their Quizlet set of cards, or alternatively to their graphic organisers, and ask volunteer students to prepare the A4 posters of new vocabulary to hang up on the wall.

EXTRA RESOURCES

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Answer Key

Understand

22. Why do we say that the Y chromosome is the masculinising chromosome?

Chromosome Y only has genes that intervene in the formation of a male.

Analyse

23. If the testicles of a male salamander embryo are swapped with the ovaries of a female salamander embryo, the ovaries will grow into sexual organs that produce sperm even though they will still conserve their chromosomal characteristics. If this salamander is then crossed with a normal female, all their offspring will be female.

a) What type of sex determination does this species have?

XX/XY system

b) If the experiment was done the other way round (swapping the ovaries in a female embryo for testicles), what type of offspring would she and a normal male have? Explain your answer.

They would be 1/3 female and 2/3 male. YY individuals are not possible.

24. In pigeons, does the male or the female determine the sex of a new individual? What about dogs?

Pigeons, like all birds, follow the ZZ/ZW system, in which the female determines the sex of the offspring. Dogs, like all mammals, follow the XX/XY system, in which the sex is determined by males.

Understand

25. What gender is a grasshopper that has an odd number of chromosomes?

It is a male, given that they have 23 chromosomes and females have 24 chromosomes.

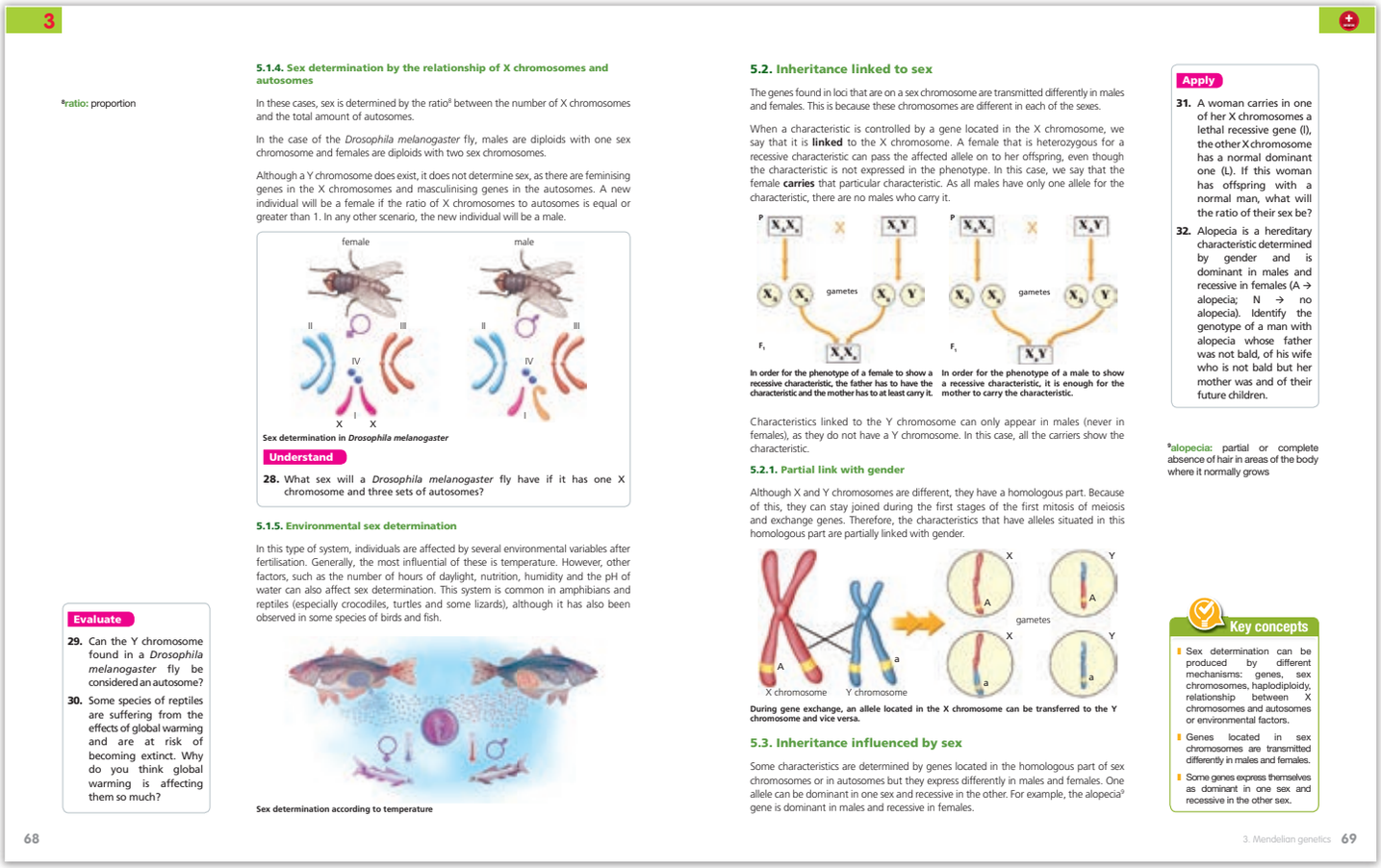
26. What type of bee develops from a haploid queen bee ovum that has not been fertilised?

Unfertilised ova will result in the formation of a male. This is why it is said that male bees do not have fathers.

Analyse

27. Are sex chromosomes always essential to determine the sex of an individual? Explain your answer.

Sex chromosomes are not essential to determine the sex of an individual. For example, the sex of bees is determined by the number of chromosomes and the sex of crocodiles and turtles is determined by the environment.



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[a]ratio: proportion

5.1.4. Sex determination by the relationship of X chromosomes and autosomes

In these cases, sex is determined by the ratio[a] between the number of X chromosomes and the total amount of autosomes.

In the case of the *Drosophila melanogaster* fly, males are diploids with one sex chromosome and females are diploids with two sex chromosomes.

Although a Y chromosome does exist, it does not determine sex, as there are feminising genes in the X chromosomes and masculinising genes in the autosomes. A new individual will be a female if the ratio of X chromosomes to autosomes is equal or greater than 1. In any other scenario, the new individual will be a male.

Sex determination in *Drosophila melanogaster*

Understand

28. What sex will a *Drosophila melanogaster* fly have if it has one X chromosome and three sets of autosomes?

5.1.5. Environmental sex determination

In this type of system, individuals are affected by several environmental variables after fertilisation. Generally, the most influential of these is temperature. However, other factors, such as the number of hours of daylight, nutrition, humidity and the pH of water can also affect sex determination. This system is common in amphibians and reptiles (especially crocodiles, turtles and some lizards), although it has also been observed in some species of birds and fish.

Evaluate

29. Can the Y chromosome found in a *Drosophila melanogaster* fly be considered an autosome?

30. Some species of reptiles are suffering from the effects of global warming and are at risk of becoming extinct. Why do you think global warming is affecting them so much?

Sex determination according to temperature

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5.2. Inheritance linked to sex

The genes found in loci that are on a sex chromosome are transmitted differently in males and females. This is because these chromosomes are different in each of the sexes.

When a characteristic is controlled by a gene located in the X chromosome, we say that it is **linked** to the X chromosome. A female that is heterozygous for a recessive characteristic can pass the affected allele on to her offspring, even though the characteristic is not expressed in the phenotype. In this case, we say that the female **carries** that particular characteristic. As all males have only one allele for the characteristic, there are no males who carry it.

In order for the phenotype of a female to show a recessive characteristic, the father has to have the characteristic and the mother has to at least carry it.

In order for the phenotype of a male to show a recessive characteristic, it is enough for the mother to carry the characteristic.

Characteristics linked to the Y chromosome can only appear in males (never in females), as they do not have a Y chromosome. In this case, all the carriers show the characteristic.

5.2.1. Partial link with gender

Although X and Y chromosomes are different, they have a homologous part. Because of this, they can stay joined during the first stages of the first mitosis of meiosis and exchange genes. Therefore, the characteristics that have alleles situated in this homologous part are partially linked with gender.

During gene exchange, an allele located in the X chromosome can be transferred to the Y chromosome and vice versa.

5.3. Inheritance influenced by sex

Some characteristics are determined by genes located in the homologous part of sex chromosomes or in autosomes but they express differently in males and females. One allele can be dominant in one sex and recessive in the other. For example, the alopecia[a] gene is dominant in males and recessive in females.

Apply

31. A woman carries in one of her X chromosomes a lethal recessive gene (l), the other X chromosome has a normal dominant one (L). If this woman has offspring with a normal man, what will the ratio of their sex be?

32. Alopecia is a hereditary characteristic determined by gender and is dominant in males and recessive in females (A → alopecia; N → no alopecia). Identify the genotype of a man with alopecia whose father was not bald, of his wife who is not bald but her mother was and of their future children.

[a]alopecia: partial or complete absence of hair in areas of the body where it normally grows

Key concepts

- Sex determination can be produced by different mechanisms: genes, sex chromosomes, haplodiploidy, relationship between X chromosomes and autosomes or environmental factors.
- Genes located in sex chromosomes are transmitted differently in males and females.
- Some genes express themselves as dominant in one sex and recessive in the other sex.

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5.1.4. Sex determination by the relationship of X chromosomes and autosomes

Students listen to and read the three paragraphs in this section. When they have finished ask:

- *How many sex chromosomes do male fruit flies have?*

  They have one sex chromosome.

- *How many sex chromosomes do female fruit flies have?*

  They have two sex chromosomes.

- *Why does the Y chromosomes not determine sex in fruit flies?*

  Because they are feminising genes in the X chromosomes and masculinising genes in autosomes, not the Y chromosomes. The ratio of X chromosomes to autosomes determines if the offspring is male or female.

Sex determination in *Drosophila melanogaster* is quite complicated. However, if you want to explore it further, write the following table on the board. In it, we can see the relationship between the chromosomal constitution and the sex type in fruit flies.

CHROMOSOME X	SETS OF AUTOSOMES N	RATIO X:N	SEX
3	2	1.5	Metafemale
4	3	1.33	Metafemale
4	4	1	Female
3	3	1	Female
2	2	1	Female
3	4	0.75	Intersex
2	3	0.66	Intersex
1	2	0.5	Male
1	3	0.33	Metamale

Students complete Activity 28 in mixed-ability pairs. If they need help, encourage them to look at the ratio (in this case one X chromosome: 3 autosomes, which means it will be a male.) Then, still in their pairs, they complete Activity 29. Before they start, remind students that autosomes are common chromosomes for both males and females. Students compare their answers for Activities 28 and 29 with another pair, then discuss in open class.

5.1.5. Environmental sex determination

Students listen to and read this section to find out the environmental factors that can influence sex determination. Ask:

- *Which environmental factor is the most influential when determining sex?*

  Temperature

- *Which other environmental factors can determine sex?*

  The number of hours of daylight, nutrition, humidity and the pH of water can all influence sex determination.

Remind students that in **Video 4** they saw how temperature determines the sex of certain turtles. Then students complete Activity 30 in mixed-ability pairs. Discuss their answers in open class.

5.2. Inheritance linked to sex

Students listen to and read the first paragraph. Ask:

- *Why are certain genes transmitted differently in males and females?*

  This is because the genes are located on a sex chromosome and as a result they are transmitted differently in males and females.

Now, students listen to and read the second paragraph and study the diagram to visualise why recessive characteristics will not be present in a female's genotype unless her father has the characteristic and her mother carries the same characteristic. This occurs when the characteristic is present in the X chromosomes of both parents.

Use the following video in order to help students further understand the concept of inheritance linked to sex.

Video 5: **GENETICS-XLINKED**
This short video, part of TED-Ed, has a good explanation of how inheritance linked to the X chromosome works. It is then applied to a typical genetics problem involving colour blindness. There are activities which will help students understand and internalise the information.

Students listen to and read the last paragraph in this section. Ask:

- *Why are characteristics linked to the Y chromosome only present in males?*

  Because only males have a Y chromosome, so if their descendants were female, they would not have the characteristic.

Students complete Activity 31 in mixed-ability pairs. Encourage them to use a Punnett square. Discuss their answers in open class.

5.2.1. Partial link with gender

Students listen to and read this section. You might want to remind students about the process of linked genes with recombination (page 63 of the Student's book): homologous chromosomes exchange part of their chromatids during prophase I of meiosis.

This will help students understand how characteristics located in either the X or Y chromosome can be exchanged. Study the illustration at the bottom of the section carefully.

5.3. Inheritance influenced by sex

This type of inheritance occurs when characteristics are expressed differently in males and females (heterozygous individuals). Students listen to and read this section. Another example you might want to mention is the presence or absence of horns in bovine species. Students complete Activity 32 in mixed-ability pairs. Use their answers for assessment purposes

Finally, to help students remember key vocabulary and summarise the key concepts of the lesson, ask students to add any new vocabulary to their Quizlet set of cards, or alternatively to their graphic organisers, and ask volunteer students to prepare the A4 posters of new vocabulary to hang up on the wall.

EXTRA RESOURCES
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Answer Key

Understand

28. What sex will a *Drosophila melanogaster* fly have if it has one X chromosome and three sets of autosomes?

The resulting fruit fly would be a male.

Evaluate

29. Can the Y chromosome found in a *Drosophila melanogaster* fly be considered an autosome?

Autosomes are chromosomes that are common to both sexes. The chromosome Y does not determine sex in fruit flies, however it is exclusive to males, so it cannot be considered an autosome. It is a sex cell.

30. Some species of reptiles are suffering from the effects of global warming and are at risk of becoming extinct. Why do you think global warming is affecting them so much?

Sex determination in some reptiles is dependent on temperature. Their eggs will develop into males or females depending on the temperature in the nest. If temperatures continue to increase, only one sex will be formed, meaning they won't have partners who to reproduce with later on, slowly causing their extinction.

Apply

31. A woman carries in one of her X chromosomes a lethal recessive gene (l), the other X chromosome has a normal dominant one (L). If this woman has offspring with a normal man, what will the ratio of their sex be?

$X^L X^l \times X^L Y$

1/3 $X^L X^L$; 1/3 $X^L X^l$; 1/3 $X^L Y$

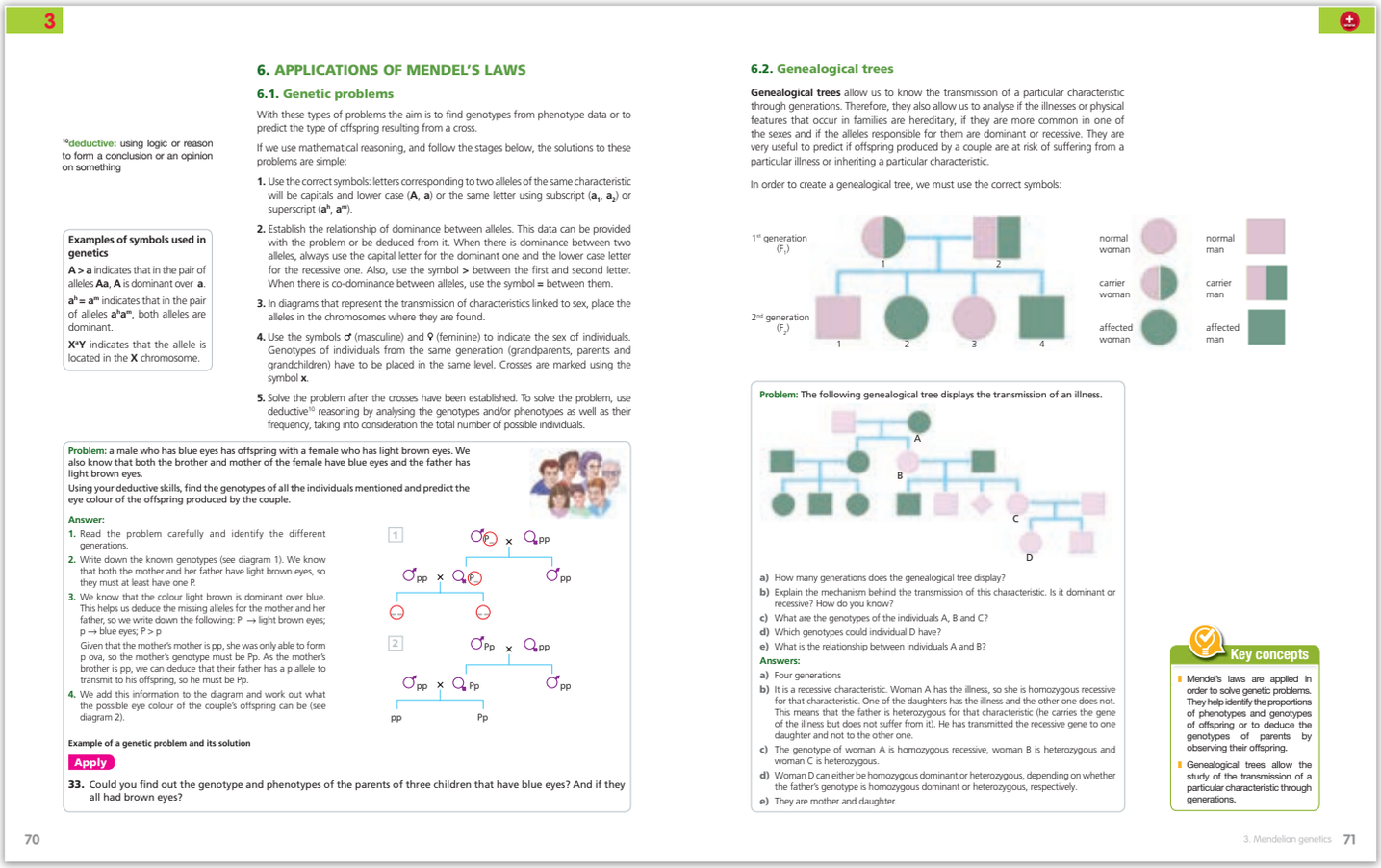
2/3 women

1/3 men

32. Alopecia is a hereditary characteristic determined by gender and is dominant in males and recessive in females (A è alopecia; N è no alopecia). Identify the genotype of a man with alopecia whose father was not bald, of his wife who is not bald but her mother was and of their future children.

Both individuals being crossed are heterozygous: the man has inherited gene N from his father (NN) and the woman has inherited gene A from her mother (AA).

Males that have AA and AN genotypes will be bald, but only the females with the genotype AA will be bald. As a result 3/4 of male offspring will be bald and just 1/4 of female offspring will be bald.



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6. APPLICATIONS OF MENDEL'S LAWS

6.1. Genetic problems

With these types of problems the aim is to find genotypes from phenotype data or to predict the type of offspring resulting from a cross.

If we use mathematical reasoning, and follow the stages below, the solutions to these problems are simple:

1. Use the correct symbols: letters corresponding to two alleles of the same characteristic will be capitals and lower case (**A**, **a**) or the same letter using subscript (a_1, a_2) or superscript (a^h, a^m).
2. Establish the relationship of dominance between alleles. This data can be provided with the problem or be deduced from it. When there is dominance between two alleles, always use the capital letter for the dominant one and the lower case letter for the recessive one. Also, use the symbol **>** between the first and second letter. When there is co-dominance between alleles, use the symbol **=** between them.
3. In diagrams that represent the transmission of characteristics linked to sex, place the alleles in the chromosomes where they are found.
4. Use the symbols ♂ (masculine) and ♀ (feminine) to indicate the sex of individuals. Genotypes of individuals from the same generation (grandparents, parents and grandchildren) have to be placed in the same level. Crosses are marked using the symbol **x**.
5. Solve the problem after the crosses have been established. To solve the problem, use deductive[10] reasoning by analysing the genotypes and/or phenotypes as well as their frequency, taking into consideration the total number of possible individuals.

[10]deductive: using logic or reason to form a conclusion or an opinion on something

Examples of symbols used in genetics

A > a indicates that in the pair of alleles **Aa**, **A** is dominant over **a**.

$a^h = a^m$ indicates that in the pair of alleles $a^h a^m$, both alleles are dominant.

$X^a Y$ indicates that the allele is located in the **X** chromosome.

Problem: a male who has blue eyes has offspring with a female who has light brown eyes. We also know that both the brother and mother of the female have blue eyes and the father has light brown eyes.

Using your deductive skills, find the genotypes of all the individuals mentioned and predict the eye colour of the offspring produced by the couple.

Answer:

1. Read the problem carefully and identify the different generations.
2. Write down the known genotypes (see diagram 1). We know that both the mother and her father have light brown eyes, so they must at least have one P.
3. We know that the colour light brown is dominant over blue. This helps us deduce the missing alleles for the mother and her father, so we write down the following: P → light brown eyes; p → blue eyes; P > p

   Given that the mother's mother is pp, she was only able to form p ova, so the mother's genotype must be Pp. As the mother's brother is pp, we can deduce that their father has a p allele to transmit to his offspring, so he must be Pp.
4. We add this information to the diagram and work out what the possible eye colour of the couple's offspring can be (see diagram 2).

Example of a genetic problem and its solution

Apply

33. Could you find out the genotype and phenotypes of the parents of three children that have blue eyes? And if they all had brown eyes?

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6.2. Genealogical trees

Genealogical trees allow us to know the transmission of a particular characteristic through generations. Therefore, they also allow us to analyse if the illnesses or physical features that occur in families are hereditary, if they are more common in one of the sexes and if the alleles responsible for them are dominant or recessive. They are very useful to predict if offspring produced by a couple are at risk of suffering from a particular illness or inheriting a particular characteristic.

In order to create a genealogical tree, we must use the correct symbols:

1st generation (F_1)
2nd generation (F_2)
normal woman
carrier woman
affected woman
normal man
carrier man
affected man

Problem: The following genealogical tree displays the transmission of an illness.

a) How many generations does the genealogical tree display?
b) Explain the mechanism behind the transmission of this characteristic. Is it dominant or recessive? How do you know?
c) What are the genotypes of the individuals A, B and C?
d) Which genotypes could individual D have?
e) What is the relationship between individuals A and B?

Answers:

a) Four generations
b) It is a recessive characteristic. Woman A has the illness, so she is homozygous recessive for that characteristic. One of the daughters has the illness and the other one does not. This means that the father is heterozygous for that characteristic (he carries the gene of the illness but does not suffer from it). He has transmitted the recessive gene to one daughter and not to the other one.
c) The genotype of woman A is homozygous recessive, woman B is heterozygous and woman C is heterozygous.
d) Woman D can either be homozygous dominant or heterozygous, depending on whether the father's genotype is homozygous dominant or heterozygous, respectively.
e) They are mother and daughter.

Key concepts

- Mendel's laws are applied in order to solve genetic problems. They help identify the proportions of phenotypes and genotypes of offspring or to deduce the genotypes of parents by observing their offspring.
- Genealogical trees allow the study of the transmission of a particular characteristic through generations.

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6. Applications of Mendel's laws

6.1. Genetic problems

Students listen to and read the guidelines for solving genetic problems. Discuss the meaning of the symbols in the box **Examples of symbols used genetics**.

As you are reading, write a simplified set of instructions on the board. For example:

1. Use the correct notation and symbols.
2. Determine the relationship between alleles.
3. Relating to the transmission of characteristics linked to sex, put alleles in the chromosomes where they are found.
4. Carry out the crosses and use Punnett squares in order to solve the problem.

Solve the problem provided as an example in open class (students have their Student's book closed). This will reinforce students' understanding of how to solve genetic problems.

Then put students into mixed-ability groups. Each group creates and solves their own genetic problem. When they have finished, solve all the problems in open class. Groups could read their problems aloud and solve them on the board for the rest of the class to see and assess.

Still in their groups, students complete Activity 33. Discuss their answers in open class. Make sure that they understand that the information given in Activity 33 is not enough to determine the genotypes and phenotypes.

Science experiment: IDENTIFY THE PERCENTAGE OF RECESSIVE PHENOTYPES

The aim of this practical activity is to identify the percentage of students with recessive phenotypes for detecting phenylthiocarbamide in class.

6.2. Genealogical trees

Students listen to and read the first paragraph. Ask:

- *What are genealogical trees for?*

  Genealogical trees allow us to know the transmission of a particular characteristic through generations.
- *Why are they useful?*

  They are useful because they allow us to predict if offspring are at risk of suffering from an illness or inheriting a particular characteristic.

Ask students to look at the symbols used to represent: normal, carrier and affected men and women. Give students one or two minutes to analyse the symbols and memorise them. Then, ask them to close their Student's book. Ask:

- *Which symbol represents a carrier woman?*

  Two semicircles of different colours that form a circle.
- *Which symbol represents a carrier man?*

  Two rectangles of different colours that form a square.

Repeat the process with similar questions, as this will reinforce the memorisation of correct symbols.

To further consolidate their knowledge, draw some symbols (unlabelled) on the board. Students work in pairs to decide what they represent.

Read the example problem in open class but do not read the solution (students can cover it with a piece of paper). Students work in their pairs to solve it, then compare their answers with the answers in the Student's book. Discuss the solution to the problem in open class.

If laptops are available, students could use the following link to continue practising how to solve genetic problems. Alternatively, you could display the problems on the interactive whiteboard and solve them in open class.

Weblink 7: **DRAG AND DROP PEDIGREE**

This fantastic interactive resource provides student with a range of genetic problems involving the use of genealogical trees to find out how characteristics such as tongue rolling, diabetes, hypertension and eye colour are passed onto offspring.

Finally, to help students remember key vocabulary and summarise the key concepts of the lesson, ask students to add any new vocabulary to their Quizlet set of cards, or alternatively to their graphic organisers, and ask volunteer students to prepare the A4 posters of new vocabulary to hang up on the wall.

EXTRA RESOURCES

AUDIO

TALKING BOOK

PDF

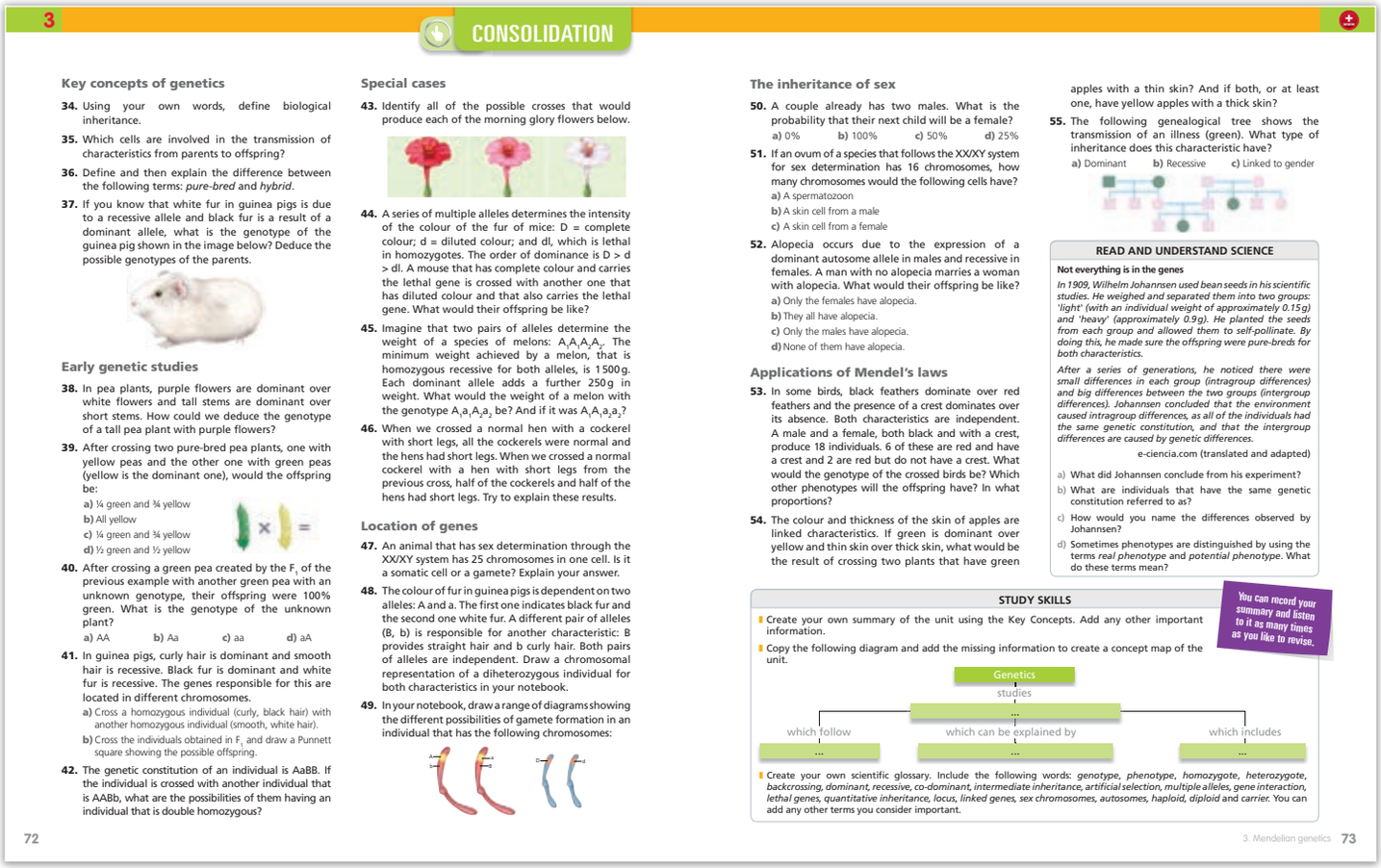
INTERACTIVE ACTIVITIES

Answer Key

Apply

33. Could you find out the genotype and phenotypes of the parents of three children that have blue eyes? And if they all had brown eyes?

- Knowing only that the three children have blue eyes does not allow us to find out the parents' phenotypes. With regards to the parents' genotype, we can only confidently say that they both have the recessive allele p.
- Knowing that three children have brown eyes only indicates that one of the parents had the same eye colour.



3 CONSOLIDATION

Key concepts of genetics

34. Using your own words, define biological inheritance.

35. Which cells are involved in the transmission of characteristics from parents to offspring?

36. Define and then explain the difference between the following terms: *pure-bred* and *hybrid*.

37. If you know that white fur in guinea pigs is due to a recessive allele and black fur is a result of a dominant allele, what is the genotype of the guinea pig shown in the image below? Deduce the possible genotypes of the parents.

Early genetic studies

38. In pea plants, purple flowers are dominant over white flowers and tall stems are dominant over short stems. How could we deduce the genotype of a tall pea plant with purple flowers?

39. After crossing two pure-bred pea plants, one with yellow peas and the other one with green peas (yellow is the dominant one), would the offspring be:

a) ¼ green and ¾ yellow
b) All yellow
c) ¼ green and ¾ yellow
d) ½ green and ½ yellow

40. After crossing a green pea created by the F_1 of the previous example with another green pea with an unknown genotype, their offspring were 100% green. What is the genotype of the unknown plant?

a) AA b) Aa c) aa d) aA

41. In guinea pigs, curly hair is dominant and smooth hair is recessive. Black fur is dominant and white fur is recessive. The genes responsible for this are located in different chromosomes.

a) Cross a homozygous individual (curly, black hair) with another homozygous individual (smooth, white hair).
b) Cross the individuals obtained in F_1 and draw a Punnett square showing the possible offspring.

42. The genetic constitution of an individual is AaBB. If the individual is crossed with another individual that is AABb, what are the possibilities of them having an individual that is double homozygous?

Special cases

43. Identify all of the possible crosses that would produce each of the morning glory flowers below.

44. A series of multiple alleles determines the intensity of the colour of the fur of mice: D = complete colour; d = diluted colour; and dl, which is lethal in homozygotes. The order of dominance is D > d > dl. A mouse that has complete colour and carries the lethal gene is crossed with another one that has diluted colour and that also carries the lethal gene. What would their offspring be like?

45. Imagine that two pairs of alleles determine the weight of a species of melons: $A_1A_1A_2A_2$. The minimum weight achieved by a melon, that is homozygous recessive for both alleles, is 1500 g. Each dominant allele adds a further 250 g in weight. What would the weight of a melon with the genotype $A_1a_1A_2a_2$ be? And if it was $A_1A_1a_2a_2$?

46. When we crossed a normal hen with a cockerel with short legs, all the cockerels were normal and the hens had short legs. When we crossed a normal cockerel with a hen with short legs from the previous cross, half of the cockerels and half of the hens had short legs. Try to explain these results.

Location of genes

47. An animal that has sex determination through the XX/XY system has 25 chromosomes in one cell. Is it a somatic cell or a gamete? Explain your answer.

48. The colour of fur in guinea pigs is dependent on two alleles: A and a. The first one indicates black fur and the second one white fur. A different pair of alleles (B, b) is responsible for another characteristic: B provides straight hair and b curly hair. Both pairs of alleles are independent. Draw a chromosomal representation of a diheterozygous individual for both characteristics in your notebook.

49. In your notebook, draw a range of diagrams showing the different possibilities of gamete formation in an individual that has the following chromosomes:

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The inheritance of sex

50. A couple already has two males. What is the probability that their next child will be a female?

a) 0% b) 100% c) 50% d) 25%

51. If an ovum of a species that follows the XX/XY system for sex determination has 16 chromosomes, how many chromosomes would the following cells have?

a) A spermatozoon
b) A skin cell from a male
c) A skin cell from a female

52. Alopecia occurs due to the expression of a dominant autosome allele in males and recessive in females. A man with no alopecia marries a woman with alopecia. What would their offspring be like?

a) Only the females have alopecia.
b) They all have alopecia.
c) Only the males have alopecia.
d) None of them have alopecia.

Applications of Mendel's laws

53. In some birds, black feathers dominate over red feathers and the presence of a crest dominates over its absence. Both characteristics are independent. A male and a female, both black and with a crest, produce 18 individuals. 6 of these are red and have a crest and 2 are red but do not have a crest. What would the genotype of the crossed birds be? Which other phenotypes will the offspring have? In what proportions?

54. The colour and thickness of the skin of apples are linked characteristics. If green is dominant over yellow and thin skin over thick skin, what would be the result of crossing two plants that have green apples with a thin skin? And if both, or at least one, have yellow apples with a thick skin?

55. The following genealogical tree shows the transmission of an illness (green). What type of inheritance does this characteristic have?

a) Dominant b) Recessive c) Linked to gender

READ AND UNDERSTAND SCIENCE

Not everything is in the genes

In 1909, Wilhelm Johannsen used bean seeds in his scientific studies. He weighed and separated them into two groups: 'light' (with an individual weight of approximately 0.15 g) and 'heavy' (approximately 0.9 g). He planted the seeds from each group and allowed them to self-pollinate. By doing this, he made sure the offspring were pure-breds for both characteristics.

After a series of generations, he noticed there were small differences in each group (intragroup differences) and big differences between the two groups (intergroup differences). Johannsen concluded that the environment caused intragroup differences, as all of the individuals had the same genetic constitution, and that the intergroup differences are caused by genetic differences.

e-ciencia.com (translated and adapted)

a) What did Johannsen conclude from his experiment?
b) What are individuals that have the same genetic constitution referred to as?
c) How would you name the differences observed by Johannsen?
d) Sometimes phenotypes are distinguished by using the terms *real phenotype* and *potential phenotype*. What do these terms mean?

STUDY SKILLS

You can record your summary and listen to it as many times as you like to revise.

- Create your own summary of the unit using the Key Concepts. Add any other important information.
- Copy the following diagram and add the missing information to create a concept map of the unit.

Genetics
studies
...
which follow ... | which can be explained by ... | which includes ...

- Create your own scientific glossary. Include the following words: *genotype, phenotype, homozygote, heterozygote, backcrossing, dominant, recessive, co-dominant, intermediate inheritance, artificial selection, multiple alleles, gene interaction, lethal genes, quantitative inheritance, locus, linked genes, sex chromosomes, autosomes, haploid, diploid* and *carrier*. You can add any other terms you consider important.

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Key concepts of genetics

34. Using your own words, define biological inheritance.

Open answer. When cells or organisms reproduce, they transmit their biological information to their offspring. This includes basic information to perform biological functions as well as the specific characteristics of that cell or organism.

35. Which cells are involved in the transmission of characteristics from parents to offspring?

Gametes

36. Define and then explain the difference between the following terms: *pure-bred* and *hybrid*.

- Pure-bred individuals for a particular characteristic are those that have the same alleles in their homologous chromosomes. They are also known as homozygotes.
- Hybrid individuals for a particular characteristic are those that have different alleles in their homologous chromosomes. They are also known as heterozygotes.

37. If you know that white fur in guinea pigs is due to a recessive allele and black fur is a result of a dominant allele, what is the genotype of the guinea pig shown in the image below? Deduce the possible genotypes of the parents.

The phenotype of the guinea pig is white fur. The genotype of the guinea pig is nn. This means that the parents could have been black (Nn) or white (nn), but they must both carry at least one n gene.

Early genetic studies

38. In pea plants, purple flowers are dominant over white flowers and tall stems are dominant over short stems. How could we deduce the genotype of a tall pea plant with purple flowers?

We can do so by carrying out a backcrossing with a recessive homozygote for both characteristics. If the offspring have a recessive phenotype for any of the characteristics, this means that the plant was heterozygous for that characteristic.

39. After crossing two pure-bred pea plants, one with yellow peas and the other one with green peas (yellow is the dominant one), would the offspring be:

a) ¼ green and ¾ yellow
b) All yellow
c) ¾ green and ¼ yellow
d) ½ green and ½ yellow

b) All yellow

40. After crossing a green pea created by the F_1 of the previous example with another green pea with an unknown genotype, their offspring were 100 % green. What is the genotype of the unknown plant?

a) AA b) Aa c) aa d) aA

b) Aa

41. In guinea pigs, curly hair is dominant and smooth hair is recessive. Black fur is dominant and white fur is recessive. The genes responsible for this are located in different chromosomes.

a) Cross a homozygous individual (curly, black hair) with another homozygous individual (smooth, white hair).

RRNN x rrnn

RrNn

b) Cross the individuals obtained in F_1 and draw a Punnett square showing the possible offspring.

	RN	Rn	rN	rn
RN	RRNN	RRNn	RrNN	RrNn
Rn	RRNn	RRnn	RrNn	Rrnn
rN	RrNN	RrNn	rrNN	rrNn
rn	RrNn	Rrnn	rrNn	rrnn

9/16 curly, black hair

3/16 curly, white hair

3/16 smooth, black hair

1/16 smooth, white hair

42. The genetic constitution of an individual is AaBB. If the individual is crossed with another individual that is AABb, what are the possibilities of them having an individual that is double homozygous?

The probability of having dominant double homozygous offspring (AABB) is 25 %. However the probability of producing recessive double homozygous individuals (aabb) is 0 %.

Special cases

43. Identify all of the possible crosses that would produce each of the morning glory flowers below.

In morning glory flowers, the inheritance of petal colour follows intermediate inheritance. This means that the genotype of the flower on the right is rr and the one on the left is RR. As a result, the possible crossings that could lead to the formation of a white flower (rr) are:

- pink (Rr) × pink (Rr)
- pink (Rr) × white (rr)
- white (rr) × white (rr)

The possible crossings that could lead to the formation of a red flower (RR) are:

- red (RR) × red (Rr)
- red (RR) × pink (Rr)
- pink (Rr) × pink (Rr)

44. A series of multiple alleles determines the intensity of the colour of the fur of mice: D = complete colour; d = diluted colour; and dl, which is lethal in homozygotes. The order of dominance is D > d > dl. A mouse that has complete colour and carries the lethal gene is crossed with another one that has diluted colour and that also carries the lethal gene. What would their offspring be like?

Ddl × ddl

- 1/3 Dd complete colour
- 1/3 Ddl complete colour
- 1/3 ddl diluted colour

45. Imagine that two pairs of alleles determine the weight of a species of melons: $A_1A_1A_2A_2$. The minimum weight achieved by a melon, that is homozygous recessive for both alleles, is 1 500 g. Each dominant allele adds a further 250 g in weight. What would the weight of a melon with the genotype $A_1a_1A_2a_2$ be? And if it was $A_1A_1a_2a_2$?

- $A_1a_1A_2a_2$ would be 2 000 g.
- $A_1A_1a_2a_2$ would also be 2 000 g.

46. When we crossed a normal hen with a cockerel with short legs, all the cockerels were normal and the hens had short legs. When we crossed a normal cockerel with a hen with short legs from the previous cross, half of the cockerels and half of the hens had short legs. Try to explain these results.

It is a recessive characteristic linked to sex (zp). In birds, females are the heterogametic sex, so the crossings would be:

- (cockerel) ZpZp × ZW (hen)
- ZpZ (normal cockerel); ZpW (short-legged hens)

	Zp	Z
Zp	ZpZp (short-legged cockerels)	ZpZ (normal cockerels)
W	ZpW (short-legged hens)	ZW (normal hens)

Location of genes

47. An animal that has sex determination through the XX/XY system has 25 chromosomes in one cell. Is it a somatic cell or a gamete? Explain your answer.

It is a gamete (a sex cell) because 25 is an odd number and the diploid number is always even.

48. The colour of fur in guinea pigs is dependent on two alleles: A and a. The first one indicates black fur and the second one white fur. A different pair of alleles (B, b) is responsible for another characteristic: B provides straight hair and b curly hair. Both pairs of alleles are independent. Draw a chromosomal representation of a diheterozygous individual for both characteristics in your notebook.

The chromosomal representation might look like this:

49. In your notebook, draw a range of diagrams showing the different possibilities of gamete formation in an individual that has the following chromosomes:

- If genetic recombination does not occur, the gametes will be AbD, Abd, aBD and aBd.
- If recombination occurs there will be more possible combinations: AbD, Abd, aBD, aBd, ABD, abD, ABd y abd.

The inheritance of sex

50. A couple already has two males. What is the probability that their next child will be a female?

a) 0 % b) 100 % c) 50 % d) 25 %

c) 50 %

51. If an ovum of a species that follows the XX/XY system for sex determination has 16 chromosomes, how many chromosomes would the following cells have?

a) A spermatozoon

7 + X or 7 + Y

b) A skin cell from a male

14 + XY

c) A skin cell from a female

14 + XX

52. Alopecia occurs due to the expression of a dominant autosome allele in males and recessive in females. A man with no alopecia marries a woman with alopecia. What would their offspring be like?

a) Only the females have alopecia.

b) They all have alopecia.

c) Only the males have alopecia.

d) None of them have alopecia.

c) Only the males have alopecia.

Applications of Mendel's laws

53. In some birds, black feathers dominate over red feathers and the presence of a crest dominates over its absence. Both characteristics are independent. A male and a female, both black and with a crest, produce 18 individuals. 6 of these are red and have a crest and 2 are red but do not have a crest. What would the genotype of the crossed birds be? Which other phenotypes will the offspring have? In what proportions?

The proportions would be the following:

- 9/16 black with a crest (NNCC, NNCc, NnCc, NnCC).
- 3/16 black without a crest (NNcc, Nncc).
- 3/16 red with a crest (nnCC, nnCc).
- 1/16 red without a crest (nncc).

54. The colour and thickness of the skin of apples are linked characteristics. If green is dominant over yellow and thin skin over thick skin, what would be the result of crossing two plants that have green apples with a thin skin? And if both, or at least one, have yellow apples with a thick skin?

Parents: _ _ _ _ X vvff and _ _ _ _ X vvff

Plants that are crossed: VvFf × VvFf

Gametes: VF, Vf, vF, vf and VF, Vf, vF, vf

Offspring:

	VF	Vf	vF	vf
VF	VVFF green & thin	VVFf green & thin	VvFF green & thin	VvFf green & thin
Vf	VVFf green & thin	VVff green & thick	VvFf green & thin	Vvff green & thick
vF	VvFF green & thin	VvFf green & thin	vvFF yellow & thin	vvFf yellow & thin
vf	VvFf green & thin	Vvff green & thick	vvFf yellow & thin	vvff yellow & thick

The proportion of phenotypes of offspring follows Mendel's laws: 9/16 green and thin, 3/16 green and thick, 3/16 yellow and thin and 1/16 yellow and thick

55. The following genealogical tree shows the transmission of an illness (green). What type of inheritance does this characteristic have?

a) Dominant b) Recessive c) Linked to gender

b) Recessive

READ AND UNDERSTAND SCIENCE

a) What did Johannsen conclude from his experiment?

That intragroup differences were caused by the environment, as all of the individuals had the same genetic constitution, and that the intergroup differences were caused by genetic differences.

b) What are individuals that have the same genetic constitution referred to as?

Clones

c) How would you name the differences observed by Johannsen?

Johannsen observed the effect of the interaction between genotype and environment, which is referred to as phenotype.

d) Sometimes phenotypes are distinguished by using the terms *real phenotype* and *potential phenotype*. What do these terms mean?

The potential phenotype is the one that is expressed according to the genetic information, so the genes determine it. However, the environment can influence certain genes. The real phenotype is the one that is finally expressed after its interaction with the environment.

Study skills

Open answer

EXTRA RESOURCES

PDF
COMPETENCE TEST
CONCEPT MAP
EXTENSION WORKSHEET
UNIT TESTS
INTERACTIVE ACTIVITIES
PRESENTATION

3 WORK AND EXPERIMENTATION TECHNIQUES

Study of the distribution of a quantitative characteristic

Several pairs of alleles that have an additive effect intervene in quantitative inheritance. As a result, they produce a high number of phenotypes with small variations between them.

The interaction between genotypes and the environment can increase the amount of variations by modifying the expression of some genes.

Materials

- 100 beans
- A vernier caliper

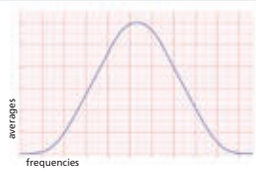
Procedure

1. Place a bean in the vernier caliper and measure its length.
2. Write down the measurement in a table. Make sure that you include in the heading the magnitude (length of the seed), the unit of measurement (mm) and the measurement uncertainty (± minimum unit that your vernier caliper can measure).
3. Repeat the process with the remaining 99 beans.
4. Create a table. Make sure the number of intervals is sufficient and that none contain more than ten values.

Length of the seeds (mm ± 0.1)		Frequencies
Intervals	Averages	
[8.1 – 8.5]	8.3	2
[8.6 – 9.0]	8.8	4
[9.1 – 9.5]	9.3	0
[9.6 – 10.0]	9.8	7

5. Next to each interval, write down the averages.
6. Record the frequency each interval has (the number of seeds that have measurements between both extremes of the intervals).

1. Calculate the range of your data.
2. Calculate the median, mode and mean from your averages.
3. Create a graph and represent the frequency values for each interval.
4. Describe how the characteristic (length) is expressed amongst the population of beans.



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FINAL TASK

How do we find out the type of inheritance a characteristic has?

In order to find out if the inheritance of a specific characteristic follows Mendel's laws or if it is a special case, we must look at the phenotypes of offspring and from them work out the genotypes of their parents.

In this research task, you are going to identify the type of inheritance the colour of minks' fur has. To do this, you must analyse the data obtained from several crosses.

Minks can have black, platinum (silvery-white) or sapphire (light blue) fur. Several crosses were carried out in a farm that breeds minks. The following data was obtained:

Parents	Offspring
black x sapphire	all black
black x sapphire	½ black and ½ sapphire
black x sapphire	½ black and ½ platinum
sapphire x sapphire	all sapphire
platinum x sapphire	½ platinum and ½ sapphire

When a mink with platinum fur is crossed with a mink with black fur: ½ of their offspring will have black fur, ¼ of them will have sapphire fur and ¼ will have platinum fur. Apart from identifying the type of inheritance the colour of minks' fur has, you are also going to make the genealogical tree for this cross.

1. Research

a) Which is the dominant colour?
b) Does the colour of the minks' fur follow Mendel's laws?
c) How can you explain the results of these crosses?

2. Presentation

Write a report that includes the genealogical tree of the cross carried out in the farm as well as the reasoning behind your hypothesis. Make sure you explain how the data obtained has lead you to your hypothesis and how it has helped you discard other possible hypotheses. You may follow the structure below:

Research question	Alternative hypotheses
Your hypothesis	Arguments against alternative hypotheses:
Evidence	

Procedure

In order to complete this task, you should carry out the following steps:

Search for information

- Identify the dominant phenotype.
- Identify the relationship of dominance between the three phenotypes.

Organise the information

- Based on your observations, create a hypothesis that explains the results of the crosses.
- Give each characteristic a letter.
- Carry out example crosses to check your hypothesis.
- Create the genealogical tree of the cross mentioned above to check your hypothesis.

Draw conclusions and check your results

- Check that the values obtained are the same as the results predicted in your hypothesis.
- Make sure the genealogical tree confirms your hypothesis.

SELF-ASSESSMENT

Answer the following questions to evaluate your work:

1. Have you identified the type of inheritance the colour of minks' fur has?
2. Can the type of inheritance explain the data obtained in each of the different crosses?
3. Have you represented the cross mentioned at the top of the page in a genealogical tree?
4. Give your report and genealogical tree a score from 1 to 5.

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Study of the distribution of a quantitative characteristic

In this activity, students will study the phenotypic variability of a characteristic: the length of seeds in a bean population. The main aim of this activity is to get students to understand the concept of phenotypic variability and familiarise them with the treatment of data during an experiment.

Students will have to collect data about the length of the seeds of 100 beans and create their own frequency table.

Bean	Length (mm ±0.1)
1	12.1
2	12.0
3	12.0
4	12.5
5	12.3
6	12.0
…	…

Length of beans (mm ±0,1)		
Midpoint	Intervals	Frequency
11.3	[11.1-1.5]	0
11.8	[11.6-12.0]	8
12.3	[12.1-12.5]	14
12.8	[12.6-13.0]	21
13.3	[13.1-13.5]	0
…	....	…

Read through the procedure section with students. You might want to have a pair of students demonstrating how to carry out the study. Put students into mixed-ability groups of four or five and provide them with vernier calipers and beans. As students are completing their frequency table, make sure that they are being accurate.

By doing this activity, students will develop the following key competences:

- Mathematical competence and basic competences in science and technology (MCST)
- Digital competence (DC)
- Linguistic comunications (LC)
- Sense of initiative and entrepreneurship (SIE)

Answer key

1. Calculate the range of your data.

Open answer. The range is obtained by finding the difference between the minimum and maximum values.

2. Calculate the median, mode and mean from your averages.

Open answer.

- Mean: the value obtained by adding all of the measurements and dividing it by the number of beans.
- Mode: the most repeated value.
- Median: after putting the measurements in ascending order the value in the middle is the median. Since there are 100 beans and it is an even number, there would not be a number exactly in the middle. In this case two numbers will represent the median.

3. Create a graph and represent the frequency values for each interval.

Open answer.

4. Describe how the characteristic (length) is expressed amongst the population of beans.

The size of beans will most probably be evenly distributed. This means that most of them will be a similar size to the median.

How do we find out the type of inheritance a characteristic has?

During this task, students will study a particular inheritance case, as well as answer all of the questions asked (**Research** and **Self-Assessment** sections). Students usually solve genetic problems in a mechanical way. The aim of this task is that students give reasons for their solutions.

In this section, students can find a detailed explanation of how to carry out their research, as well as some tips on how to write their reports. Read the information as a whole class, allowing students to ask any questions they might have.

- The **Research** section outlines the questions that the students should try to answer.
- The **Presentation** section outlines the steps to be followed as the students carry out the project. It gives them tips on how to search for information, formulate their hypothesis and present their results.
- The **Procedure** section sets out the steps students should follow in order to complete the research.
- The **Self-assessment** section helps students evaluate their work and think about the development of the final task.

The learning outcome that will be reinforced during this task is:

- 6.1 Solves practical problems crossing one or two characteristics (MCST, DC, SIE).

Below is a sample report you could show students once they have finished to help them self-assess their own work.

Research question What type of inheritance does the colour of minks' fur follow?	**Alternative hypothesis** It follows Mendelian genetics, but given that there are three possible phenotypes, it could be a case of intermediate inheritance.
Your hypothesis The data obtained does not follow Mendel's third law.. The characteristic is controlled by three alleles: B, S, P, which B>P>S	**Arguments against alternative hypothesis** The second crossing (black × sapphire = black), sapphire is compatible with intermediate inheritance (BB × BS = BB and BS), however: **1.** In the first crossing: black × sapphire = all black, means that black dominates over sapphire. **2.** The third crossing of black × sapphire originates black and platinum, but not sapphire. Platinum could be a recessive characteristic, but that does not follow intermediate inheritance.
Evidence **1.** The colour black dominates over sapphire. When the colour sapphire is obtained, it is because the parents were heterozygous: - BB × SS = BS (black) - BS × SS = BS; SS; so ½ black; and ½ sapphire) **2.** In crossing number 3, the colour platinum is recessive. The crossing could be: - BP × SS = BS; PS; so ½ black and ½ platinum if platinum dominates over sapphire. - BB × PS = BP; BS; so they would all be black if sapphire dominates over platinum. Only the first case is compatible with the results obtained. **3.** When platinum and sapphire are crossed in crossing number 5: - PS × SS = PS; SS; so/½ platinum and ½ sapphire if platinum is dominant, - PP × SP = /½ platinum and ½ sapphire if sapphire is dominant. The second option is not compatible with the results obtained, so the order of dominance is: B>P>S	

An example of how to assess the final task is shown below:

0 = not handed in 1 = very basic 2 = well done 3 = excellent

	0	1	2	3
REPORT				
The report has the right structure and format.				
It includes a bibliography and /or webography.				
It answers all of the questions related to the task.				
Uses adequate terminology and the writing makes sense.				
Uses adequate information.				

LEARNING OUTCOMES RUBRIC

Evaluable learning outcomes	Assessment tools	Excellent 3	Satisfactory 2	In process 1	Not achieved 0	Score
1.1. Defines and differentiates the fundamental concepts of genetics.	1, 2, 32, 33, 34, 35, 36, 37	Defines and differentiates the main concepts.	Defines and differentiates the main concepts making a few mistakes.	Defines and differentiates the main concepts making many mistakes.	Answers incorrectly or does not answer.	
2.1. Recognises the basic principles of Mendelian genetics.	3, 4, 5, 6, 7, 8, 9, 36, 37, 38, 39, 40, 41, 42	Recognises all of the basic principles.	Recognises almost all of the basic principles.	Recognises some of the basic principles.	Answers incorrectly or does not answer.	
3.1. Identifies the causes of exceptions to Mendelian proportions in the inheritance of some characteristics.	10, 11, 12, 13, 14, 15, 16, 43, 44, 45, 46, Work and Experimentation techniques	Differentiates the processes and identifies facts correctly.	Differentiates the processes and identifies facts making a few mistakes.	Differentiates the processes and identifies facts making many mistakes.	Answers incorrectly or does not answer.	
4.1. Identifies the cause of the formation of different types of gametes depending on the location of genes on chromosomes.	17, 18, 19, 20, 47, 48, 49	Interprets observations correctly.	Interprets observations making a few mistakes.	Interprets observations making many mistakes.	Answers incorrectly or does not answer.	
5.1. Differentiates between different types of sex determination systems.	22, 23, 24, 25, 26, 27, 29, 30, 51	Relates the main concepts correctly.	Relates the main concepts making a few mistakes.	Relates the main concepts making many mistakes.	Answers incorrectly or does not answer.	
5.2. Solves practical problems about inheritance of sex and sex-linked inheritance.	28, 31, 32, 50, 52	Solves all activities correctly.	Solves all activities making a few mistakes.	Solves all activities making many mistakes.	Answers incorrectly or does not answer.	
6.1. Solves practical problems crossing one or two characteristics.	33, 53, 54, 55, Final task	Solves all activities correctly.	Solves all activities making a few mistakes.	Solves all activities making many mistakes.	Answers incorrectly or does not answer.	

Objectives, contents and methodology

TYPES OF RESOURCES AND METHODOLOGY USED TO MEET OBJECTIVES	
●	Interactive activities. Elaboration and verification of a hypothesis.
❍	Search for information on the Internet.
▶	Watch videos.
❑	Analyse images.
■	Analyse texts (news articles, scientific articles...).

SECTIONS	OBJECTIVES AND CONTENTS	METHODOLOGY	
Genotype and phenotype	Understand the concepts phenotype and genotype.	●	❍
	Analyse how the genotype influences the phenotype.	●	
	Concepts: Genotype, phenotype and environmental factors.		
Key concepts of genetics	Understand key concepts of genetics.	●	❍
	Analyse the different types of inheritance.	●	❍
	Concepts: Gene, allele, dominant allele, recessive allele, co-dominance, dominant inheritance, intermediate inheritance, homozygous and heterozygous.		
Dominant inheritance	Analyse scenarios related to dominant inheritance.	●	
	Concepts: Dominant inheritance.		
Intermediate inheritance and co-dominance	Differentiate between intermediate inheritance and co-dominance.	●	
	Analyse scenarios related to intermediate inheritance and co-dominance.	❍	
	Concepts: Intermediate inheritance and co-dominance.		
Final task	Identify the inheritance of a particular characteristic and create a geological tree for a specific cross.	●	

1. Define the terms pure-bred and hybrid.

- Pure-bred individuals for a particular characteristic are those that have the same allele in the homologous chromosomes.
- Hybrid individuals for a particular characteristic are those that that have different alleles in the homologous chromosomes.

2. Homozygous plants with blue flowers are crossed with homozygous plants with white flowers. All of the descendants have blue flowers, so we can establish that:

a) Inheritance is a result of the genes.

b) Blue colour dominates over white colour.

c) White colour dominates over blue colour.

d) They are both dominant.

b) Blue colour dominates over white colour.

3. Identify all of the possible parents that resulted in each of the following pure-bred pea seeds: wrinkled and green as well as round and yellow.

- The genotype of the wrinkled, green seed is aall, so its parents must have had the alleles a and l: AaLl, Aall, aaLl or aall.
- The genotype of the round, yellow seed is AALL, so its parents must have had the alleles A and L: AALL AALl AaLL AaLl.

4. The genetic constitution of an individual is AaBB. If the individual is crossed with another individual that is AABb, what are the possibilities of them having an individual that is double homozygous?

The probability of having dominant double homozygous offspring (AABB) is 25 %. However, the probability of producing recessive double homozygous individuals (aabb) is 0 %.

5. In Andalusian chickens, the combination of heterozygote alleles (one for white feathers and the other for black feathers) create blue feathers. What would the offspring of a blue chicken be if it was crossed with another blue chicken?

B = black

W = white

BW = blue

Parents: BW × BW

Gametes: B and W × B and W

	B	**B**
B	BB	WB
B	BW	WW

25 % white; 50 % blue and 25 % black

6. In certain rabbits, the colour of their fur presents the following phenotypes according to their dominance: colour > chinchilla > Himalaya > albino. What type of inheritance is displayed by that characteristic?

Multiple alleles

7. Let's imagine that two pairs of alleles $A_1A_1A_2A_2$ are responsible for increasing the weight of chickens from 500 grams to 1 100 grams. Each of the alleles contributes 150 grams. If we cross a cockerel that is 1 100 grams and a chicken that is 650 grams, what would the phenotypes and genotypes of the offspring be?

If each allele A_1 or A_2 contributes 150 g over 500 grams, the parents' genotypes would be:

- $A_1A_1A_2A_2$ = 1 100 g
- $A_1a_1a_2a_2$ = 650 g

Parents: $A_1A_1A_2A_2 \times A_1a_1a_2a_2$

Gametes: $A_1A_2 \times A_1a_2$ and a_1a_2

	A_1a_2	**a_1a_2**
A_1A_2	$A_1A_1A_2a_2$	$A_1a_1A_2a_2$

50 % would weigh 950 g and the other 50 % would be 800 g.

8. If the ova of a species that follows the chromosomal XX/XY sex determination system have 16 chromosomes, how many chromosomes would the following cells have?

a) A spermatozoon

16 chromosomes

b) A cell from the skin of a male

32 chromosomes

c) A cell from the skin of a female

32 chromosomes

9. A woman carries a recessive lethal gene in one of her X chromosomes. In the other one, she carries a normal, dominant L. What would the proportion of males and females be if this woman had offspring with a normal man?

Parents: XLXl × XY

Gametes:XL and Xl × X and Y

	XL	**Xl**
X	XXL	XXl
Y	XLY	~~XlY~~

Males carrying the lethal gene would die, so the proportion would be:

Female: 100 % normal, but 50 % are carriers of the gene (2/3).

Male: 100 % normal (1/3)

10. What does the term locus mean?

The term locus refers to the space an area occupies in a chromosome.

1. What type of inheritance shows a phenotype that is a combination of both pure-bred parents?

   Co-dominance

2. A grey mouse is crossed with a white mouse. If the offspring are 50 % white and 50 % grey, what would the genotype of their parents be?

   a) AA and aa

   b) AA and BB

   c) Aa and aa

   d) Aa and bb

   c) Aa and aa

3. The dominant gene (M) leads to myopia and the recessive gene (m) leads to normal sight. The descendants of two people, one who suffers from myopia and one with normal sight (both homozygous) would be:

   a) ¾ would suffer from myopia and ¼ would have normal sight.

   b) ½ would suffer from myopia and ½ would have normal sight.

   c) 100 % would have normal sight.

   d) 100 % would suffer from myopia.

   d) 100 % will suffer from myopia.

4. Identify the genotypes that could be obtained if a dominant double homozygous individual is crossed with an individual diheterozigous for two linked characteristics, after recombination has occurred.

	AB	Ab	aB	ab
AB	AABB	AABb	AaBB	AaBb

5. The sex of fruit flies is determined by the relationship of X chromosomes and autosomes. The colour of their eyes is determined by a gene that is linked to the X chromosome (red is dominant over white). If two flies that have red eyes (their fathers had white eyes and their mothers red eyes) are crossed, what would their offspring be like? What would all of their genotypes be?

   R = red eyes

   r = white eyes

   Parents: XRXr × XrY

   Gametes: XR and Xr × Xr and Y

	XR	Xr
Xr	XrXR female with red eyes	XrXr female with red eyes
Y	YXR male with red eyes	YXr male with white eyes

   50 % of the males would have red eyes and 50 % would have white eyes.

   100 % of the females would have red eyes.

6. The colour red of tomato pulp depends on the presence of a dominant R allele over the allele r, which leads to yellow pulp. The normal size of a tomato plant depends on allele N, which is dominant over allele n (dwarf size). A plant that has red pulp and a normal size is crossed with a normal sized plant that has yellow pulp. The following offspring are obtained: 30 normal red plants, 31 normal yellow plants, 9 dwarf red plants and 10 dwarf yellow plants. What are the genotypes of the original plants that were crossed? Check the result by performing the crossing.

   R = red

   r = yellow

   N = normal

   n = dwarf

   Parents: RrNn × rrNn

   Gametes: RN, Rn and Rn × rn, rN and rn

	RN	Rn	rN	rn
rN	RrNN	RrNn	rrNN	rrNn
rn	RrNn	Rrnn	rrNn	rrnn

   - 3/8 normal red
   - 1/8 dwarf red
   - 3/8 normal yellow
   - 1/8 dwarf yellow

7. What does the term quantitative inheritance mean? Give an example.

   In quantitative inheritance, several pairs of alleles that have an additive effect intervene. The final result is the addition of all the individual effects. Examples of quantitative inheritance in humans are eye colour, height or skin colour.

8. Identify the genotype of a bald man that had a father who was not bald, the genotype of woman who had a mother who was bald and the genotypes of their future children.

   BB = Bald

   Bb = bald men and normal women

   Parents: Bb × Bc

   Gametes: B and b × B and b

	B	b
B	BB	Bb
b	Bb	bb

   - Men: 75 % bald and 25 % not bald
   - Women: 75 % not bald and 25 % bald

9. What are linked genes?

   Linked genes are genes that are found in the same chromosome.

10. In a species of insect we find that females are diploids whilst males are haploids. How would you explain this major difference?

    This is a case of haploid-diploid sex determination. Females originate from fertilised gametes (diploids), whilst the males originate from unfertilised gametes (haploids).