DP Biology – D3.2

Inheritance

- What patterns of inheritance are seen in plants and animals?
- What happens at the molecular level to produce these patterns?

SL statements D3.2.1–15. Textbook pp. 725–746.
Image: peas in their pods, Mendel's model organism. Bill Ebbesen, CC BY-SA 3.0.



Objectives for each class

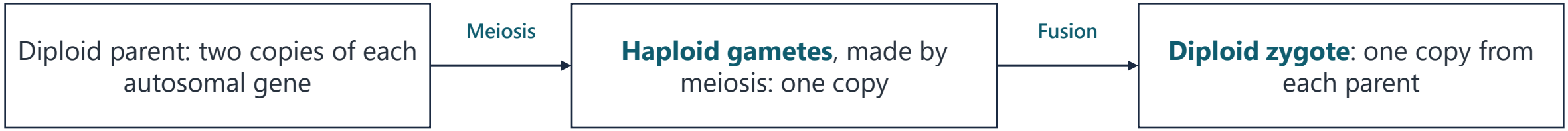
Class	Statements	By the end of the class, you can...
1	D3.2.1–5	Explain inheritance through gametes, carry out plant crosses, and use genotype, phenotype and dominance terms
2	D3.2.6–10	Explain plasticity and phenylketonuria, then multiple alleles, ABO groups, incomplete dominance and codominance
3	D3.2.11–13	Explain sex determination and sex linkage, and deduce patterns from pedigrees
4	D3.2.14–15	Explain continuous variation, and draw a box-and-whisker plot

Overview of this chapter

Part	Statements	What it covers
The basics	D3.2.1–5	Gametes, crosses, genotype, phenotype, dominance
Gene expression and disease	D3.2.6–7	Plasticity, phenylketonuria
Beyond two alleles	D3.2.8–10	SNPs, ABO groups, codominance
Sex and pedigrees	D3.2.11–13	Haemophilia, reading family trees
Continuous traits	D3.2.14–15	Polygenic traits, box-and-whisker plots

Gametes and zygotes: how inheritance works

D3.2.1



- This pattern is common to all eukaryotes with a sexual life cycle
- An **autosomal** gene is a gene on a chromosome other than a sex chromosome
- A diploid cell has two copies of each autosomal gene, and a gamete has one
- So each parent passes on one of its two copies, and that is how inheritance works at the level of molecules

Link

Meiosis (D2.1) explains these patterns: homologous chromosomes separate, so that each gamete receives only one allele of each gene.

Genetic crosses in flowering plants

D3.2.2



Gregor Mendel. Public domain.

- Pollen contains male gametes, and female gametes are in the ovary, so a cross needs **pollination**
- Peas make both types of gamete on one plant, so they can **self-fertilize**
- For a controlled cross, pollen from one chosen plant is moved by hand to another

Term	Meaning
P generation	The parents of the cross
F1 generation	Offspring of the P generation
F2 generation	Offspring of F1 plants crossed or self-fertilized

Why it matters

Crosses are widely used to breed new varieties of crop and ornamental plants. Mendel's work with peas established the first clear laws of inheritance.

Genes, alleles and genotype

D3.2.3

Term	Meaning	Example
Gene	A length of DNA that influences a characteristic	Flower colour
Allele	A version of a gene, at the same position	Purple or white
Genotype	The combination of alleles inherited	Pp
Homozygous	Two identical alleles of a gene	PP or pp
Heterozygous	Two different alleles of a gene	Pp

Common mistake

Gene and allele are not the same. Everyone has the gene for ABO blood group, but people have different alleles of it.

Phenotype: genotype and environment

D3.2.4

- The **phenotype** is what you can observe about an organism, and it depends on both genotype and environment

Genotype only	Environment only	Both together
ABO blood group	A scar from surgery	Height
Haemophilia	A tattoo	Skin colour
Red-green colour blindness	The language you speak	Body mass

Activity

Sort these traits into the three groups: ability to taste bitterness, eye colour, an accent, adult height, a broken bone, type 2 diabetes. Then discuss the traits that you found hardest to place, and why they were hard.

Dominant and recessive alleles

D3.2.5

Genotype	Alleles in the cell	Phenotype
YY	Both produce a working protein	Yellow
Yy	One working allele is enough	Yellow
yy	No working protein	Green

- A **dominant** allele has the same effect whether homozygous or heterozygous
- A **recessive** allele has an effect only when homozygous

Why are YY and Yy the same?

Usually, the dominant allele codes for a working protein, and the recessive allele does not. One copy gives enough protein to produce the same phenotype.

Worked example: a Punnett grid

P: pure-breeding yellow (YY) × green (yy). All of F1 are Yy, and yellow. F1 are then crossed:

Gametes	Y	y
Y	YY: yellow	Yy: yellow
y	Yy: yellow	yy: green

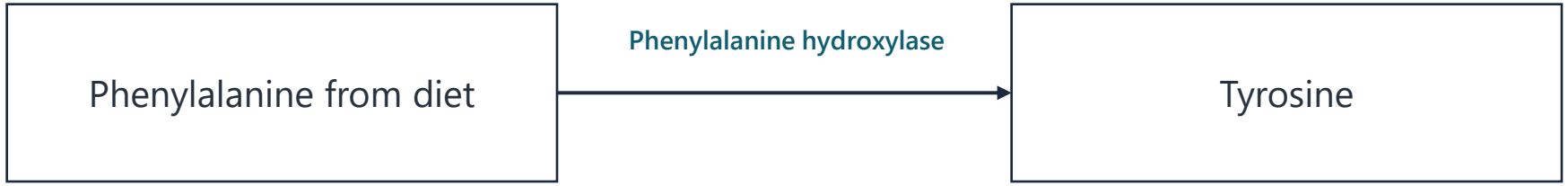
1. Write each parent's gametes on one side of the grid
2. Fill in the genotypes of the offspring
3. Genotype ratio is 1 YY : 2 Yy : 1 yy
4. Phenotype ratio is 3 yellow : 1 green

Activity

In cats, short fur (S) is dominant to long fur (s). Two heterozygous cats have kittens. Draw a Punnett grid, and predict the ratio. Then explain why a litter of four may not show this ratio exactly.

Phenylketonuria: a recessive disease

D3.2.7



- **Phenylketonuria (PKU)** comes from a mutation in an autosomal gene that codes for this enzyme
- Only someone with two copies of the recessive allele has the disease, while a heterozygote is a **carrier**
- Without the enzyme, phenylalanine builds up and can damage the developing brain
- Babies are screened soon after birth, and a low-phenylalanine diet prevents most harm

Key idea

Phenotype depends on environment too. The genotype stays the same, but the diet changes the outcome.

Phenotypic plasticity

D3.2.6



Water flea, which grows a defensive helmet and spine near predators. Paul Hebert, CC BY 2.5.

- **Plasticity**: developing traits suited to the environment, by varying gene expression
- The genotype does not change
- Changes may be reversible during the lifetime of an individual
- Example: muscles grow with training and shrink without it
- Example: skin darkens in sunlight, and fades afterwards

Common mistake

Plasticity is not mutation or adaptation by natural selection. The alleles are unchanged, and what changes is which genes are expressed.

SNPs and multiple alleles

D3.2.8

Allele	Part of base sequence	Change
1	A T G **G** C A T T **C** G	Original
2	A T G **A** C A T T **C** G	SNP at base 4
3	A T G **G** C A T T **T** G	SNP at base 10

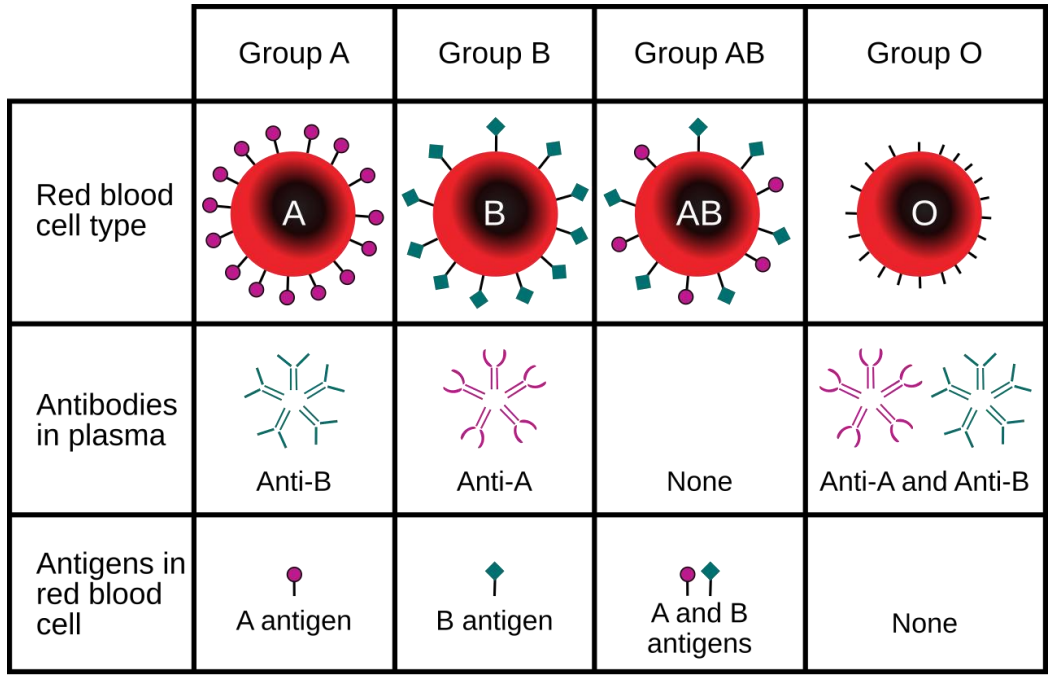
- A **gene pool** is all the alleles of all the genes in a population
- A **SNP** is a position where a base varies, and each gene can have several
- So a gene pool can hold any number of alleles of a gene, but an individual inherits only two

Common mistake

Multiple alleles exist in a population. No individual has them all, because each has only two copies of an autosomal gene.

ABO blood groups: multiple alleles

D3.2.9



ABO blood types. InvictaHOG, public domain.

Genotype	Group	Allele type
$I^A I^A$ or $I^A i$	A	Dominant to i
$I^B I^B$ or $I^B i$	B	Dominant to i
$I^A I^B$	AB	Codominant
i i	O	Recessive

Activity

A woman of group A and a man of group B have a child of group O. Deduce the genotypes of all three. What other blood groups could their later children have?

Incomplete dominance and codominance

D3.2.10



Mirabilis jalapa. Juni from Kyoto, CC BY 2.0.

	Incomplete dominance	Codominance
Heterozygote	Intermediate phenotype	Dual phenotype
Example	Red × white gives pink Mirabilis	I^A I^B gives group AB
What you see	A third, new phenotype	Both phenotypes at once

Worked example

In Mirabilis jalapa, red (C^R C^R) × white (C^W C^W) gives pink F1 (C^R C^W). Crossing F1 plants gives 1 red : 2 pink : 1 white. Phenotype and genotype ratios match, so you can tell every genotype from its colour.

Sex determination and sex chromosomes

D3.2.11



Human male karyotype. National Human Genome Research Institute, public domain.

- Females usually have **XX** and males usually have **XY**
- All eggs carry an X, and half of sperm carry a Y
- So the sex chromosome in the **sperm** determines whether a zygote develops certain male-typical or female-typical characteristics
- The X chromosome carries **far more genes** than the Y

Sex linkage

Genes on the X chromosome show a different pattern of inheritance. A male has only one copy of each, so a single recessive allele affects his phenotype.

Haemophilia: a sex-linked disorder

D3.2.12

Allele for clotting: X^H. Allele for haemophilia: X^h. A carrier mother × an unaffected father:

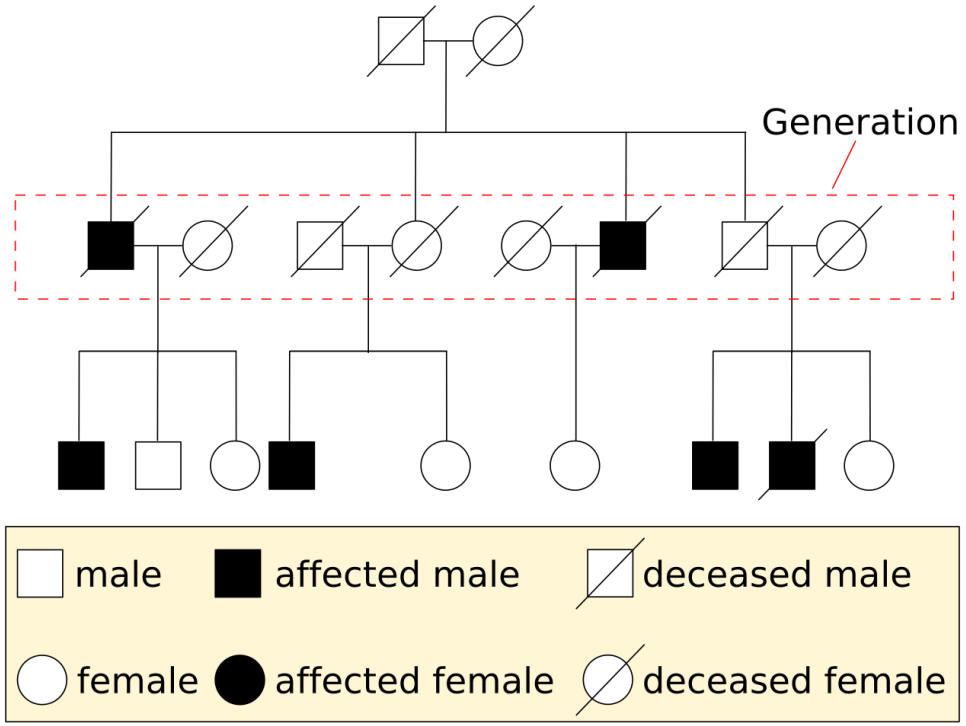
Gametes	X^H	Y
X^H	$X^H X^H$: unaffected girl	$X^H Y$: unaffected boy
X^h	$X^H X^h$: carrier girl	$X^h Y$: affected boy

- A clotting factor is missing, so blood clots slowly
- The allele is recessive and on the X chromosome
- Far more males are affected
- A son inherits his X from his mother, and never from his father

Activity

An affected man and a woman who does not carry the allele have children. Predict the phenotypes of their sons and of their daughters. Show your working using the same notation.

Reading pedigree charts



An example of a pedigree chart. GYassineMrabet, public domain.

- Squares are males and circles are females
- Shading shows an affected person
- Horizontal lines join parents
- Vertical lines lead to children

Activity

Unaffected parents have an affected child. What does this tell you about the allele? How would a chart for an X-linked disorder look different from one for an autosomal disorder?

Deducing the pattern of inheritance

D3.2.13

Pattern	Clues in the pedigree
Autosomal recessive	Unaffected parents can have an affected child, of either sex; both parents are carriers
Autosomal dominant	Every affected person has an affected parent; males and females are about equally affected
X-linked recessive	Mostly males are affected; passed from carrier mothers; never father to son

Close relatives

Close relatives are more likely to carry the same recessive allele, inherited from a shared ancestor. If two carriers have a child, there is a 1 in 4 chance of two copies. This is the genetic basis for rules in many societies that prohibit marriage between close relatives.

Continuous variation

D3.2.14

	Discrete variable	Continuous variable
Values	Separate categories	Any value within a range
Example	ABO blood group	Skin colour, height
Controlled by	Usually one gene	Many genes (polygenic) and environment

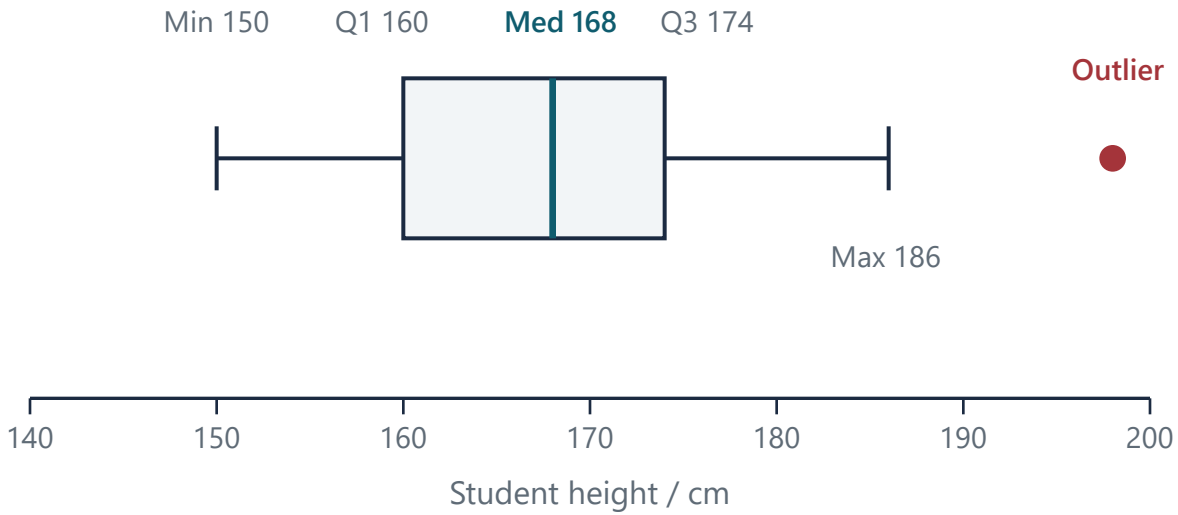
- **Polygenic**: many genes each add a small effect, which gives a bell-shaped distribution
- Skin colour depends on many genes, and on exposure to sunlight
- The centre of a distribution can be described by its **mean**, **median** and **mode**

Worked example

Heights: 158, 160, 160, 164, 168. Mean = 810 / 5 = 162 cm. Median = middle value = 160 cm. Mode = most common value = 160 cm.

Box-and-whisker plots

D3.2.15



Invented values, for practice.

- A plot shows **six things**: outliers, minimum, first quartile, median, third quartile, maximum
- The **interquartile range (IQR)** = Q3 − Q1
- An outlier is more than 1.5 × IQR above Q3 or below Q1

Worked example

IQR = 174 − 160 = 14. 1.5 × 14 = 21. Upper limit = 174 + 21 = 195, and lower limit = 160 − 21 = 139. So a height of 198 cm is an outlier, and the whisker stops at the highest value that is not: 186 cm.

Check that you can explain

1. Gametes, zygotes and autosomal genes
2. P, F1 and F2, and Punnett grids
3. Gene, allele, genotype and phenotype
4. Why YY and Yy look the same
5. Plasticity and phenylketonuria
6. SNPs, gene pools and ABO groups
7. Incomplete dominance and codominance
8. Sex determination and haemophilia
9. How to read a pedigree
10. Continuous variation and box plots

Exit activity: 5 minutes

On your own and without notes. Hand this in as you leave.

1. Two carriers of phenylketonuria have a child. State the probability that the child has the disease.
2. Distinguish between incomplete dominance and codominance.
3. Explain why a son cannot inherit haemophilia from his father.

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