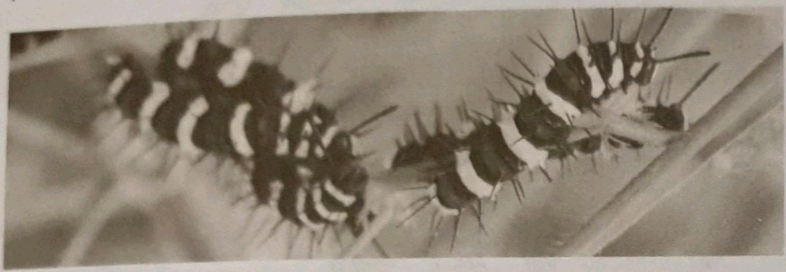
2 Hypotheses and Predictions

Key Idea: A hypothesis is a tentative, testable explanation for an observed phenomenon. An assumption is something that is accepted as true but is not tested.

Scientific hypotheses are tentative testable explanations for observed phenomena. A hypothesis leads to one or more predictions about the way a system will behave so a **research hypothesis** is often written to include a testable prediction, i.e if X is true, then the effect of Y will be Z. For every hypothesis, there is a corresponding **null hypothesis**: a hypothesis of no difference or no effect. A null hypothesis allows a hypothesis to be tested statistically and can be rejected if the experimental results are statistically significant. Hypotheses are not static, but may be modified as more information becomes available.

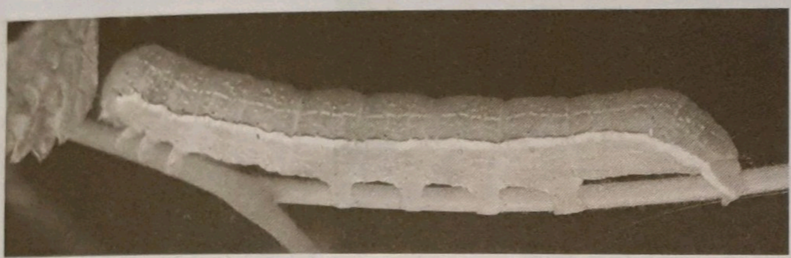
Observations, hypotheses, and predictions

Observation is the basis for formulating hypotheses and making predictions. An observation may generate a number of plausible hypotheses, and each hypothesis will lead to one or more predictions, which can be tested by further investigation.



Observation 1: Some caterpillar species are brightly coloured and appear to be conspicuous to predators such as insectivorous (insect-eating) birds.

Predators appear to avoid these species. These caterpillars are often found in groups, rather than as solitary animals.



Observation 2: Some caterpillar species are cryptic in their appearance or behaviour.

Their camouflage is so convincing that, when alerted to danger, they are difficult to see against their background. Such caterpillars are often found alone.

Assumptions

Any biological investigation requires you to make assumptions about the system you are working with. Assumptions are features of the system (and investigation) that you assume to be true but do not (or cannot) test. Possible assumptions about the biological system described above include:

- insectivorous birds have colour vision;
- caterpillars that look bright or cryptic to us, also appear that way to insectivorous birds; and
- insectivorous birds can learn about the palatability of prey by tasting them.

1. Study the example above illustrating the features of cryptic and conspicuous caterpillars, then answer the following:

   (a) Generate a hypothesis to explain the observation that some caterpillars are brightly coloured and conspicuous while others are cryptic and blend into their surroundings:

   Hypothesis: ______________________________

   (b) State the null form of this hypothesis: ______________________________

   (c) Describe one of the **assumptions** being made in your hypothesis: ______________________________

   (d) Based on your hypothesis, generate a **prediction** about the behaviour of insectivorous birds towards caterpillars:

3 Types of Data

Key Idea: Data is information collected during an investigation. Data may be quantitative, qualitative, or ranked.

Data is information collected during an investigation and it can be quantitative, qualitative, or ranked (below). When planning a biological investigation, it is important to consider the type of data that will be collected. It is best to collect quantitative data, because it is mathematically versatile and easier to analyse it objectively (without bias).

Types of data

Quantitative (interval or ratio)

Characteristics for which measurements or counts can be made, e.g. height, weight, number.
Summary measures: mean, median, standard deviation.

- **Discontinuous (discrete)**
  e.g. Number of children in a family (3, 0, 4)
- **Continuous**
  e.g. Height of children in a family (1.5 m, 0.8 m)

Qualitative (nominal)

Non-numerical and descriptive, e.g. sex, colour, viability (dead/alive), presence or absence of a specific feature.
Summary measures: frequencies and proportions

e.g. Sex of children in a family (male, female)

Ranked (ordinal)

Data are ranked on a scale that represents an order, although the intervals between the orders on the scale may not be equal, e.g. abundance (abundant, common, rare). Summary measures: frequencies and proportions

e.g. Birth order in a family (1, 2, 3)

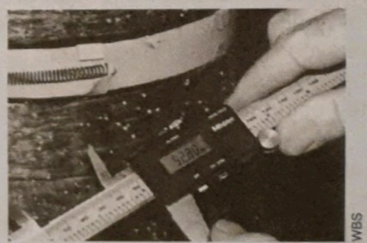
Discontinuous or discrete data:
The unit of measurement cannot be split up (e.g. can't have half a child).

Continuous data:
The unit of measurement can be a part number (e.g. 5.25 kg).

1. For each of the photographic examples A-C below, classify the data as quantitative, ranked, or qualitative:

A: Skin colour

B: Eggs per nest



C: Tree trunk diameter

(a) Skin colour: ______________________

(b) Number of eggs per nest: ______________________

(c) Tree trunk diameter: ______________________

2. Why is it best to collect quantitative data where possible in biological studies? ______________________

____

____

3. Give an example of data that could not be collected quantitatively and explain your answer: ______________________

____

____

4. Students walked a grid on a football field and ranked plant species present as abundant, common, or rare. How might they have collected and expressed this information more usefully?

____

____

4 Making A Qualitative Investigation

Key Idea: Qualitative data is non-numerical and descriptive. Qualitative data is more difficult to analyse and interpret objectively than quantitative data. It is also more likely to be biased. However, sometimes it is appropriate to collect qualitative data, e.g. when recording colour changes in simple tests for common components of foods. Two common tests for carbohydrates are the iodine/potassium iodide test for starch and the Benedict's test for reducing sugars, such as glucose. These tests indicate the presence of a substance with a colour change. All monosaccharides are reducing sugars as are the disaccharides, lactose and maltose. The monosaccharide fructose is a ketose, but it gives a positive test because it is converted to glucose in the reagent. When a starchy fruit ripens, the starch is converted to reducing sugars.

The aim

To investigate the effect of ripening on the relative content of starch and simple sugars in bananas.

The tests

Iodine-potassium iodide test for starch
The sample is covered with the iodine in potassium iodide solution. The sample turns blue-black if starch is present.

Benedict's test for reducing sugars
The sample is heated with the reagent in a boiling water bath. After 2 minutes, the sample is removed and stirred, and the colour recorded immediately after stirring. A change from a blue to a brick red colour indicates a reducing sugar.

Summary of the method

Two 1 cm thick slices of banana from each of seven stages of ripeness were cut and crushed to a paste. One slice from each stage was tested using the I/KI test for starch, and the other was tested using the Benedict's test.

The colour changes were recorded in a table. Signs (+/–) were used to indicate the intensity of the reaction relative to those in bananas that were either less or more ripe.

Stage of ripeness	Starch-iodine test		Benedict's test	
1	blue-black	+++++	blue clear	–
2	blue-black	++++	blue clear	–
3	blue-black	+++	green	+
4	blue-black	++	yellow cloudy	++
5	slight darkening	+	orange thick	+++
6	no change	–	orangey-red thick	++++
7	no change	–	brick-red thick	+++++

1. Explain why each of the following protocols was important:

   (a) All samples of banana in the Benedict's reagent were heated for 2 minutes: ___

   (b) The contents of the banana sample and Benedict's reagent were stirred after heating: ___

2. Explain what is happening to the relative levels of starch and glucose as bananas ripen: ___

3. Fructose is a ketose sugar (not an aldose with an aldehyde functional group like glucose).

   (a) Explain why fructose also gives a positive result in a Benedict's test: ___

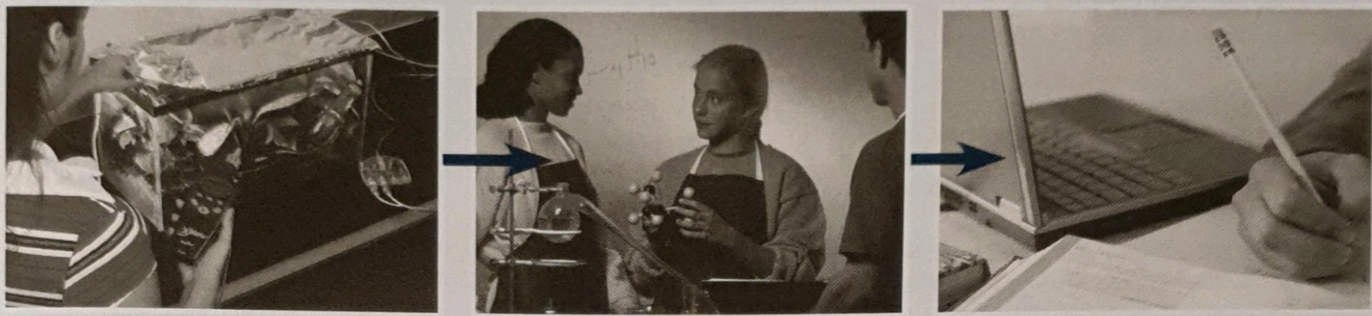
   (b) What could this suggest to you about the results of this banana test? ___

5 Making A Quantitative Investigation

Key Idea: Practical work carried out in a careful and methodical way makes analysis of the results much easier.

The next stage after planning an experiment is to collect the data. Practical work may be laboratory or field based. Typical laboratory based experiments involve investigating how a biological response is affected by manipulating a particular **variable**, e.g. temperature. The data collected for a quantitative practical task should be recorded systematically, with due attention to safe practical techniques, a suitable quantitative method, and accurate measurements to an appropriate degree of precision. If your quantitative practical task is executed well, and you have taken care throughout, your evaluation of the experimental results will be much more straightforward and less problematic.

Carrying out your practical work



Preparation

Familiarise yourself with the equipment and how to set it up. If necessary, calibrate equipment to give accurate measurements.

Read through the methodology and identify key stages and how long they will take.

Execution

Identify any **assumptions** you make about your set up. Assumptions are features of the system that you assume to be true but do not (or cannot) test. Know how you will take your measurements, how often, and to what degree of precision.

Recording

Record your results systematically, in a hand-written table or on a spreadsheet.

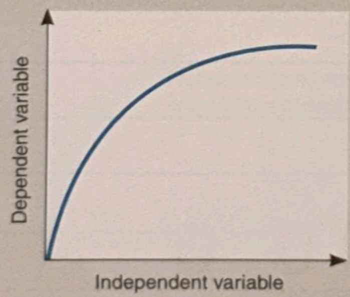
Record your results to the appropriate number of significant figures according to the precision of your measurement.

Identifying variables

A variable is any characteristic or property able to take any one of a range of values. Investigations often look at the effect of changing one variable on another. It is important to identify all variables in an investigation: independent, dependent, and controlled, although there may be nuisance factors of which you are unaware. In all fair tests, only one variable is changed by the investigator.

Dependent variable

- Measured during the investigation.
- Recorded on the y axis of the graph.



Controlled variables

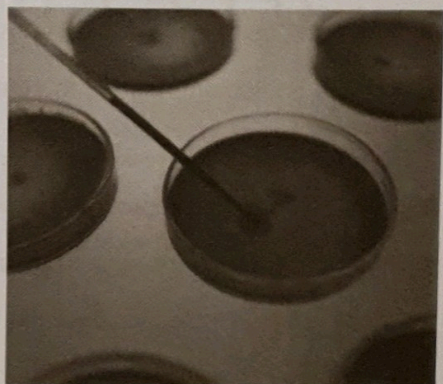
- Factors that are kept the same or controlled.
- List these in the method, as appropriate to your own investigation.

Independent variable

- Set by the experimenter.
- Recorded on the graph's x axis.

Experimental controls

A control refers to standard or reference treatment or group in an experiment. It is the same as the experimental (test) group, except that it lacks the one variable being manipulated by the experimenter. Controls are used to demonstrate that the response in the test group is due a specific variable (e.g. temperature). The control undergoes the same preparation, experimental conditions, observations, measurements, and analysis as the test group. This helps to ensure that responses observed in the treatment groups can be reliably interpreted.



The experiment above tests the effect of a certain nutrient on microbial growth. All the agar plates are prepared in the same way, but the control plate does not have the test nutrient applied. Each plate is inoculated from the same stock solution, incubated under the same conditions, and examined at the same set periods. The control plate sets the baseline; any growth above that seen on the control plate is attributed to the presence of the nutrient.

Examples of investigations

Aim		Variables	
Investigating the effect of varying...	**on the following...**	**Independent variable**	**Dependent variable**
Temperature	Leaf width	Temperature	Leaf width
Light intensity	Activity of woodlice	Light intensity	Woodlice activity
Soil pH	Plant height at age 6 months	pH	Plant height

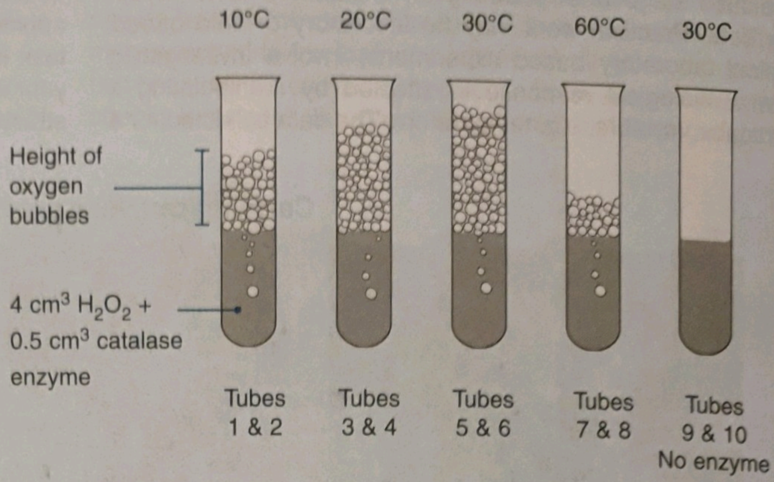
Investigation: catalase activity

$$H_2O_{2\,(l)} \xrightarrow{\text{Catalase}} H_2O_{(l)} + O_{2\,(g)}$$

Catalase is an enzyme that converts hydrogen peroxide (H_2O_2) to oxygen and water.

An experiment to investigate the effects of temperature on the rate of the catalase reaction is described below.

- 10 cm^3 test tubes were used for the reactions, each tube contained 0.5 cm^3 of catalase enzyme and 4 cm^3 of H_2O_2.
- Reaction rates were measured at four temperatures (10°C, 20°C, 30°C, 60°C).
- For each temperature, there were two reaction tubes (e.g. tubes 1 and 2 were both kept at 10°C).
- The height of oxygen bubbles present after one minute of reaction was used as a measure of the reaction rate. A faster reaction rate produced more bubbles than a slower reaction rate.
- The entire experiment was repeated on two separate days.



1. Write a suitable aim for this experiment: ____________________

2. Write an hypothesis for this experiment: ____________________

3. (a) What is the independent variable in this experiment? ____________________

   (b) What is the range of values for the independent variable? ____________________

   (c) Name the unit for the independent variable: ____________________

   (d) List the equipment needed to set the independent variable, and describe how it was used: ____________________

4. (a) What is the dependent variable in this experiment? ____________________

   (b) Name the unit for the dependent variable: ____________________

   (c) List the equipment needed to measure the dependent variable, and describe how it was used: ____________________

5. (a) Each temperature represents a treatment/sample/trial (circle one):

   (b) How many tubes are at each temperature? ____________________

   (c) What is the sample size for each treatment? ____________________

   (d) How many times was the whole investigation repeated? ____________________

6. Which tubes are the control for this experiment? ____________________

7. Identify three variables that might have been controlled in this experiment, and how they could have been monitored:

   (a) ____________________

   (b) ____________________

   (c) ____________________

14 Constructing Tables and Graphs

Key Idea: Tables and graphs provide a way to organise and visualise data in a way that helps to identify trends.

Tables and graphs are ways to present data and they have different purposes. **Tables** provide an accurate record of numerical values and allow you to organise your data so that relationships and trends are apparent. **Graphs** provide a visual image of trends in the data in a minimum of space.

It is useful to plot your data as soon as possible, even during your experiment, as this will help you to evaluate your results as you proceed and make adjustments as necessary (e.g. to the sampling interval). The choice between graphing or tabulation in the final report depends on the type and complexity of the data and the information that you are wanting to convey. Usually, both are appropriate.

Presenting data in tables

An accurate, descriptive title.

Table 1: Length and growth of the third internode of bean plants receiving three different hormone treatments (data are given ± standard deviation).

Treatment	Sample size	Mean rate of internode growth / mm day^{-1}	Mean internode length / mm	Mean mass of tissue added / g day^{-1} ± SD)
Control	50	0.60 ± 0.025	32.3 ± 2.3	0.36 ± 0.025
Hormone 1	46	1.52 ± 0.030	41.6 ± 3.4	0.51 ± 0.030
Hormone 2	98	0.82 ± 0.018	38.4 ± 0.9	0.56 ± 0.028
Hormone 3	85	2.06 ± 0.019	50.2 ± 1.4	0.68 ± 0.020

Independent variable in left column.

Control values (if present) should be placed at the beginning of the table.

Each row should show a different experimental treatment, organism, sampling site etc.

Heading and subheadings identify each set of data and show units of measurement.

Tables can show a calculated measure of data variability (e.g. standard deviation).

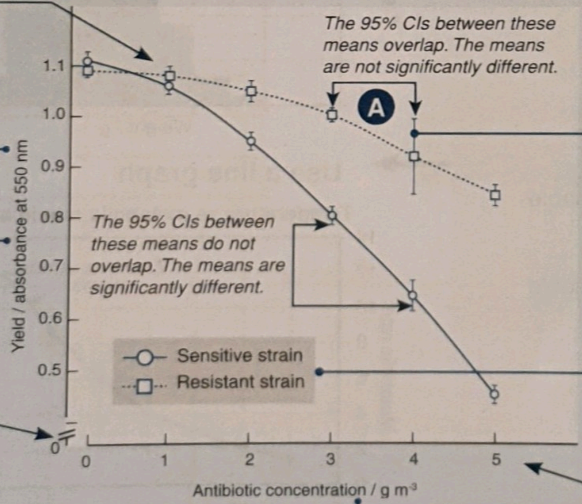
Show values only to the level of significance allowable by your measuring technique.

Columns that need to be compared should be placed alongside each other.

Organise the columns so that each category of like numbers or attributes is listed vertically.

Presenting data in graph format

Fig. 1: Yield of two bacterial strains at different antibiotic levels (± 95% confidence intervals, n= 6)



Plot points accurately. Different responses can be distinguished using different symbols, lines or bar colours.

Label both axes (provide SI units of measurement if necessary).

Place the dependent variable, e.g. biological response, on the vertical (y) axis (if you are drawing a scatter graph it does not matter).

A break in an axis allows economical use of space if there are no data in the "broken" area. A floating axis (where zero points do not meet) allows data points to be plotted away from the vertical axis.

Graphs (called figures) should have a concise, explanatory title. If several graphs appear in your report they should be numbered consecutively.

Measures of spread about the plotted mean value can be shown on the graph. Such measures include standard deviation and 95% confidence intervals (CI). The values are plotted as **error bars** and give an indication of the reliability of the mean value. If the 95% confidence intervals do not overlap between points, then these means will be significantly different.

A key identifies symbols. This information sometimes appears in the title or the legend.

Each axis should have an appropriate scale. Decide on the scale by finding the maximum and minimum values for each variable.

Place the independent variable, e.g. treatment, on the horizontal (x) axis.

1. What can you conclude about the difference (labelled A) between the two means plotted above? Explain your answer:

____

2. Explain the reasons for including both graphs and tables in a final report: ____________________

____

____

____

15 Which Graph to Use?

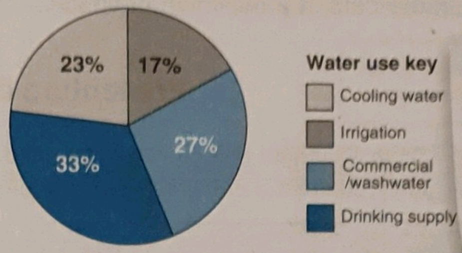
Key Idea: The type of graph you choose to display your data depends on the type of data you have collected.

Before you graph your data, it is important to identify what type of data you have. Choosing the correct type of graph can highlight trends or reveal relationships between variables. Choosing the wrong type of graph can obscure information and make the data difficult to interpret. Examples of common types of graphs and when to use them are provided below.

What type of data have you collected?

- One variable is a category
- One variable is a count

→ **Use a pie graph**

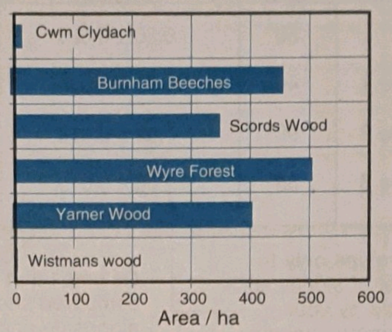


Use to compare proportions in different categories.

- One variable is a category
- One variable is continuous data (measurements)

→ **Use a bar or column graph**

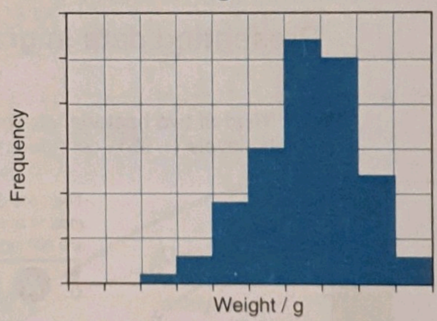
Sizes of various woodlands in Britain



Use to compare different categories (or treatments) for a continuous variable.

- One variable is continuous data (measurements)
- One variable is a count

→ **Use a histogram**

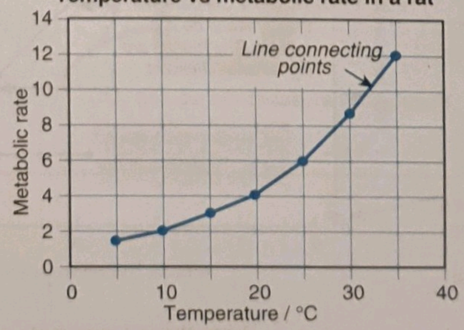


Use to show a frequency distribution for a continuous variable.

- Both variables are continuous
- The response variable is dependent on the independent (manipulated) variable

→ **Use a line graph**

Temperature vs metabolic rate in a rat

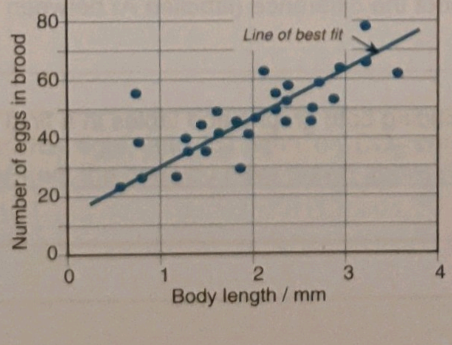


Use to illustrate the response to a manipulated variable.

- Both variables are continuous
- The two variables are inter-dependent but there is no manipulated variable

→ **Use a scatter plot**

Body length vs brood size in *Daphnia*



Use to illustrate the relationship between two correlated variables.

16 Drawing Bar Graphs

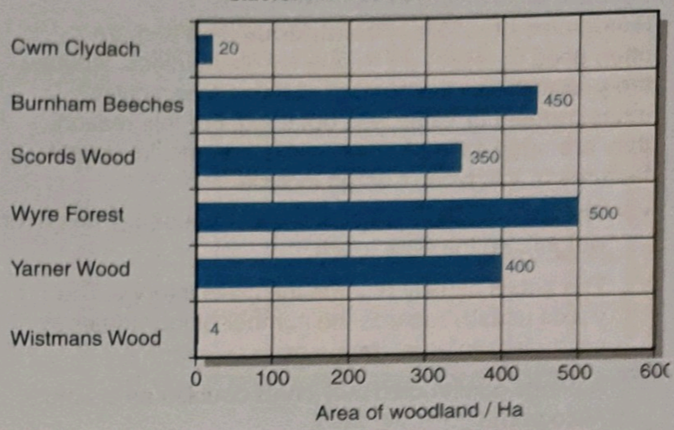
Key Idea: Bar graphs are used to plot data that is non-numerical or discrete for at least one variable.

Guidelines for bar graphs

Bar graphs are appropriate for data that are non-numerical and **discrete** for at least one variable, i.e. they are grouped into categories. There are no dependent or independent variables. Important features of this type of graph include:

- Data are collected for discontinuous, non-numerical categories (e.g. colour, species), so the bars do not touch.
- Data values may be entered on or above the bars.
- Multiple sets of data can be displayed side by side for comparison (e.g. males and females).
- Axes may be reversed so that the categories are on the x axis, i.e. bars can be vertical or horizontal. When they are vertical, these graphs are called column graphs.

Size of various woodlands in Britain



1. Counts of eight mollusc species were made from a series of quadrat samples at two sites on a rocky shore. The summary data are presented here.
   (a) Tabulate the mean (**average**) numbers per square metre at each site in Table 1 (below left).
   (b) Plot a **bar graph** of the tabulated data on the grid below. For each species, plot the data from both sites side by side using different colours to distinguish the sites.

Field data notebook

Total counts at site 1 (11 quadrats) and site 2 (10 quadrats). Quadrats 1 sq m.

	Site 1		Site 2	
	No m^{-2}		No m^{-2}	
Species	Total	Mean	Total	Mean
Ornate limpet	232	21	299	30
Radiate limpet	68	6	344	34
Limpet sp. A	420	38	0	0
Cats-eye	68	6	16	2
Top shell	16	2	43	4
Limpet sp. B	628	57	389	39
Limpet sp. C	0	0	22	2
Chiton	12	1	30	3

Mean abundance of 8 molluscan species from two sites along a rocky shore.

Species	Mean / no. m^{-2}	
	Site 1	Site 2

17 Drawing Histograms

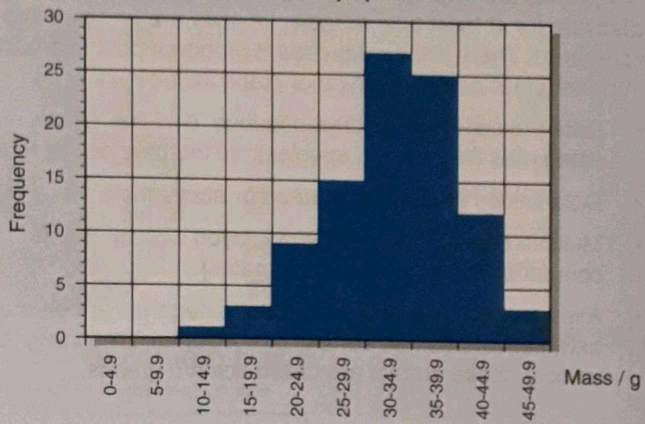
Key Idea: Histograms graphically show the frequency distribution of continuous data.

Guidelines for histograms

Histograms are plots of **continuous** data and are often used to represent frequency distributions, where the y-axis shows the number of times a particular measurement or value was obtained. For this reason, they are often called frequency histograms. Important features of this type of graph include:

- The data are numerical and continuous (e.g. height or weight), so the bars touch.
- The x-axis usually records the class interval. The y-axis usually records the number of individuals in each class interval (frequency).
- A neatly constructed tally chart doubles as a simple histogram.

Frequency of different mass classes of animals in a population



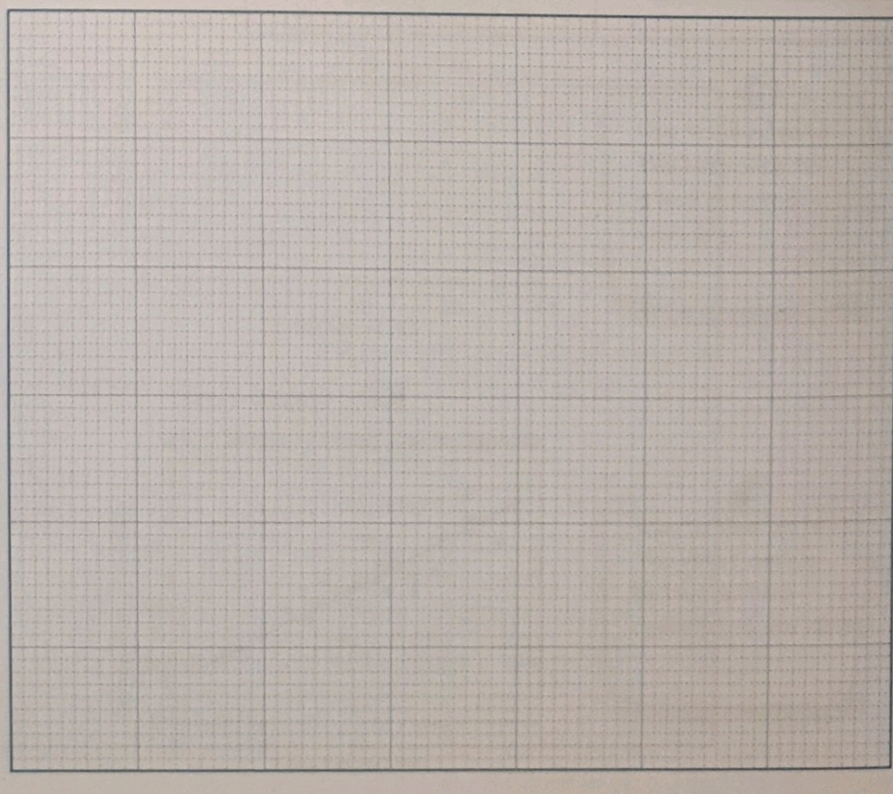
1. The weight data provided below were recorded from 95 individuals (male and female), older than 17 years.
   (a) Create a tally chart (frequency table) in the frame provided, organising the weight data into a form suitable for plotting. An example of the tally for the weight grouping 55-59.9 kg has been completed for you as an example. Note that the raw data values are crossed off the data set in the notebook once they are recorded as counts on the tally chart. It is important to do this in order to prevent data entry errors.
   (b) Plot a **frequency histogram** of the tallied data on the grid provided below.

Weight / kg	Tally	Total
45-49.9		
50-54.9		
55-59.9	卌 ||	7
60-64.9		
65-69.9		
70-74.9		
75-79.9		
80-84.9		
85-89.9		
90-94.9		
95-99.9		
100-104.9		
105-109.9		

Lab notebook

Weight (in kg) of 95 individuals

63.4	81.2	65
~~56.5~~	83.3	75.6
84	95	76.8
81.5	105.5	67.8
73.4	82	68.3
~~56~~	73.5	63.5
60.4	75.2	~~58~~
83.5	63	~~58.5~~
82	70.4	50
61	82.2	92
~~55.2~~	87.8	91.5
48	86.5	88.3
53.5	85.5	81
63.8	87	72
69	98	66.5
82.8	71	61.5
68.5	76	66
67.2	72.5	65.5
82.5	61	67.4
83	60.5	73
78.4	67	67
76.5	86	71
83.4	85	70.5
77.5	93.5	65.5
77	62	68
87	62.5	90
89	63	83.5
93.4	60	73
83	71.5	66
80	73.8	~~57.5~~
76	77.5	76
~~56~~	74	



18 Drawing Line Graphs

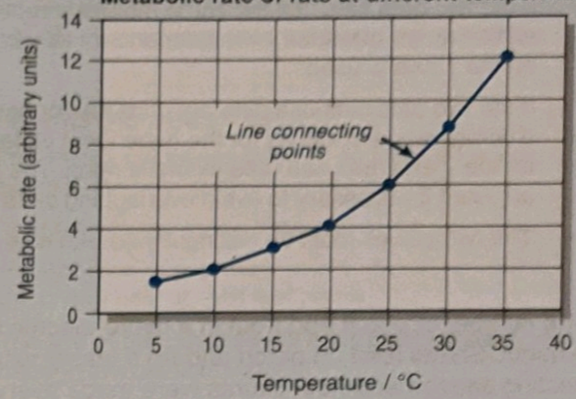
Key Idea: Line graphs are used to plot continuous data in which one variable (the independent variable) directly affects the other (dependent) variable. They are appropriate for data in which the independent variable is manipulated.

Guidelines for line graphs

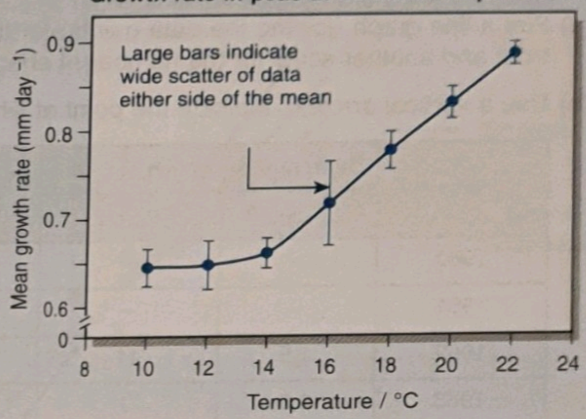
Line graphs are used when one variable (the independent variable) affects another, the dependent variable. Line graphs can be drawn without a measure of spread (top figure, right) or with some calculated measure of data variability (bottom figure, right). Important features of line graphs include:

- The data must be continuous for both variables.
- The dependent variable is usually the biological response.
- The independent variable is often time or experimental treatment.
- The relationship between two variables can be represented as a continuum and the data points are plotted accurately and connected directly (point to point).
- Line graphs may be drawn with measure of error. The data are presented as points (which are the calculated means), with bars above and below, indicating a measure of variability or spread in the data (e.g. standard error, standard deviation, or 95% confidence intervals).
- Where no error value has been calculated, the scatter can be shown by plotting the individual data points vertically above and below the mean. By convention, bars are not used to indicate the range of raw values in a data set.

Metabolic rate of rats at different temperatures



Growth rate in peas at different temperatures



1. The results (shown right) were collected in a study investigating the effect of temperature on the activity of an enzyme.

   (a) Using the results provided (right), plot a line graph on the grid below:

   (b) Estimate the rate of reaction at 15°C: ____________________

Lab Notebook

An enzyme's activity at different temperatures

Temperature / °C	Rate of reaction (mg of product formed per minute)
10	1.0
20	2.1
30	3.2
35	3.7
40	4.1
45	3.7
50	2.7
60	0