Lesson Three

Investigative Skills A - Design

Aims

By the end of this lesson you should be able to:

- understand the principles of experimental design in biology
- be able to apply these in new situations
- know and understand some new technical vocabulary

Context

Investigative skills are not given a separate section in the "Biology content" section of the Specification. However, you will see from the "Assessment objectives and weightings" section on page 51 that these form the whole of the third assessment objective, called AO3. These skills will be tested in both of your exam papers and carry 19-21% of the total marks.

There will be three lessons early in your course devoted to investigative skills. This, the first, looks at the design of investigations. The later two will look at the carrying out and interpretation of investigations.

Edexcel International GCSE (9-1) Biology Student Book, pages 303 and 305-307.

Introduction

A biological **investigation**, or experiment, or practical, is a piece of practical work done to find something out. However, it will only achieve this aim if it is designed correctly before starting work. This lesson looks at the various components of a good design.

Rather than talking in general, we will start by adapting one of the investigations described in your textbook. Before carrying on, read Activity 5 on page 17 of the textbook called "Demonstration of diffusion in a jelly". We will adapt this experiment to investigate how temperature affects the rate of diffusion, something we discussed in the last lesson.

Hypothesis and Prediction

Any good investigation starts with an idea of what *might* be going on, based on scientific understanding, called a **hypothesis**. In this investigation, a good hypothesis might be:

"Diffusion of acid particles through agar will occur faster at higher temperatures than lower temperatures, because at higher temperatures the acid particles move around faster."

Notice that the hypothesis is not just a blind guess; it is developed from relevant scientific knowledge.

A hypothesis can be used to generate a **prediction** of what will happen in a specific situation. Here we might predict that:

"The higher the temperature, the faster acid particles will diffuse to the centre of the agar block, so the less time will be taken for the block to lose all its colour."

A prediction is something that we can verify or disprove by carrying out a practical procedure.

Activity 1	(a) The incidence of skin cancer has increased greatly in England in recent years. Formulate (make) a hypothesis to account for this fact. (b) Make a prediction, based on this hypothesis, which could be used to test it.
	

Method

The next thing needed is an outline plan of how to do the practical work. This is called the **method**.

In the textbook experiment, the method is outlined in the third, fifth and sixth paragraphs. We need to adapt this method as follows:

- use beakers with acid kept at different temperatures
- drop the coloured blocks into these beakers and time how long it takes for the colour to completely disappear.

Apparatus

Any equipment or materials used in an investigation is called the **apparatus**. It is useful to write a list of this, specifying the numbers of each item needed.

In this experiment the acid is contained in a piece of glassware called a **beaker**. You would need three beakers if you decided to use three different temperatures for the acid. You would also need at least one **thermometer** to measure the temperature of the acid, and a **stopwatch** to measure the time taken for the colour to disappear.

Safety

You need to specify any important hazards involved in the practical work and how you would minimize the risk involved with each. Doing this process is known as undertaking a **risk assessment**.

The most important risk in this practical work is the dilute hydrochloric acid. This is pretty harmless if it gets on your skin, provided you wash it off promptly, but it is very dangerous if it gets in your eyes. So you would specify:

- Use safety goggles
- Wash any acid off skin promptly using cold water

Activity 2	(a) How would you adapt the method to investigate the effect of acid concentration on the rate of diffusion into agar? (b) What extra apparatus would you need for your investigation? (c) Carry out a risk assessment for your new investigation.
	

Variables

Things which can change during the course of an investigation are called **variables**. We want to find out the effect of temperature on the time taken for the blocks to change colour, so both **temperature** and **time** are variables in our investigation.

In any investigation, there is one variable that you change deliberately so that you can observe the effect of doing so. This is called the **independent variable**. There is also another variable whose changes you want to discover. This is called the **dependent variable**. In our investigation, temperature is the independent variable and time is the dependent variable.

Variables can be **categoric** or **continuous**. A categoric variable is one that is best described by a label, like blue or brown eyes in humans. A continuous variable is one that can be measured by an instrument and described using numbers, like the speed of a moving car.

In our investigation, temperature and time could both be categoric or continuous variables:

- If we predict that 'the block will change colour quickly in hot acid but slowly in cold acid' we are using categoric variables.

- If we predict that 'the higher the temperature of the acid the shorter will be the time taken for the block to change colour' we are using continuous variables.

Whereas 'hot', 'cold', 'quickly' and 'slowly' do not imply the use of numbers measured using a stopwatch or thermometer, 'higher temperature' and 'shorter time' do.

In general, an investigation that uses continuous variables is more informative than one using categoric variables, and should be chosen if possible.

Validity

The temperature of the acid is not the only factor which will affect how long it takes for the blocks to completely change

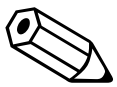
colour. Three other factors are also likely to affect the time taken:

- the volume (size) of the blocks
- the shape of the blocks
- the concentration of the acid

We will need to keep these other factors **constant** so they do not also affect the time taken. Only in this way can we be sure that the variation in the time we observe is due to the different temperatures of the acid, not some other factor.

Keeping other relevant factors, or potential variables, constant is to design a **fair test.** It would be unfair to handicap our block in the cold acid by also making it larger! Potential variables which we deliberately keep constant in this way, like the size and shape of the blocks, are called **control variables**. Relevant variables which we fail to keep constant are called **uncontrolled variables**.

Our investigation will only be **valid** if we design it as a fair test, eliminating all relevant uncontrolled variables. Otherwise we may unwittingly be measuring the effect of something else, not temperature, on the rate of diffusion!

Activity 3	Return to the skin cancer investigation in Activity 1. Assume that you are going to investigate the effect of hours of sunbathing on the incidence of skin cancer. (a) What are the dependent and independent variables in your investigation?
	(b) Think of several other variables, apart from hours of exposure to sunlight, which might be responsible for the increase in skin cancer. (c) To what extent could you control these variables to make your investigation valid?

Activity 4	A student made the following prediction: "The final grade that a student gets in their IGCSE Biology examination will be determined by the number of hours of study that they undertake". What are the potentially uncontrolled variables in this student's investigation?
	

Reliability

Once we have completed our investigation, we want to be *sure* that we have discovered the right answer - that our conclusion is **reliable**. The best way to ensure this is to repeat all of our readings several times. This is known as doing **replicates**.

One reason is: it is so easy to make a mistake while carrying out practical work. We could misread a stopwatch, for example, or make a mess of mixing acid. Another reason is: we could accidentally be studying an organism which is abnormal in some way. If we only do the procedure once, we will not spot this. But if we do it several times, the problem will show up immediately.

For example, if we had six time readings for the same acid concentration like this:

25.2 24.7 26.3 35.9 25.0 24.8

we could straight away see that the fourth reading was suspect. A reading like this is called an **anomalous result** – one that is an exception to the pattern show by the rest of the readings. Such a reading should be repeated, or ignored when interpreting our data later on.

The other advantage of doing replicates is that we can take an **average** of our readings (eliminating any anomalous results first). The average of the five good readings above comes to 25.2, which a more reliable answer than any of the individual readings.

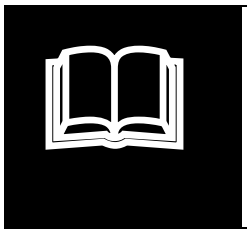
Activity 5	What steps could you take to make your survey from Activity 3 as reliable as possible?
	

Accuracy and Precision

An **accurate** measurement is one which is close to the true value. A **precise** measurement is one which is quoted to a lot of decimal places.

For example, let's say a student doing our investigation used a stopwatch that measured to the nearest $1/100^{th}$ of a second. If he recorded a time reading as 26.73 seconds, that would be a very precise measurement of the time taken. It might, however, be hopelessly inaccurate. If the true value for the time was 36.2 seconds, a reading of 35 seconds would be much more accurate (closer to the true value) even though much less precise.

In biology, accuracy is more important than precision. In general, you should only quote your readings with a degree of precision you feel your investigation is achieving. So, if you feel you are really only able to spot the time when the colour finally disappears from the block to the nearest 5 seconds, you should record your reading as 25 seconds, even if your stopwatch reads 26.73 seconds.



Now is the time to read *Edexcel International GCSE (9-1) Biology Student Book,* pages 303 and 305-307. This covers the same topics as this lesson, so will add to your understanding of the material.

Keywords

Investigation
Hypothesis
Prediction
Method
Apparatus
Variables
Valid
Accurate
Replicates
Dependent variable
Continuous variable
Control variable
Uncontrolled variable
Fair test
Reliable
Precise
Anomalous result

Summary

Lesson Three: Investigative Skills A - Design

INVESTIGATION ---------- hypothesis ---- prediction

---------- method ----- apparatus ---- safety

---------- variables ------ independent and dependent

------- control variables

--------- replicates

What you need to know

- the meaning of the technical terms in **bold** print in this lesson

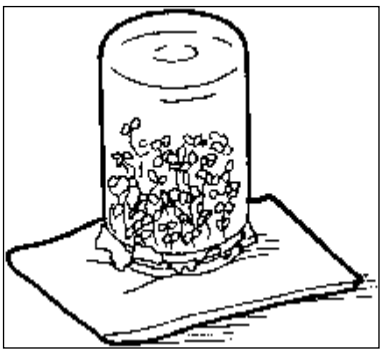
What you might be asked to do

- design a valid investigation, using the principles and technical terms described in this lesson, ensuring that your results are reliable

- criticise inadequately designed investigations, especially in terms of uncontrolled variables and lack of reliability, and suggest how to improve them

Self-Assessment Test: Lesson Three

An IGCSE student carried out the following experiment, using mung beans to grow bean sprouts. She wanted to find the best conditions in which to grow mung beans and predicted that the beans would grow best in warm conditions.



Into each of five jam jars were placed 20g of soaked mung beans. The top of each jar was covered with gauze and each jar was placed upside down on some kitchen paper as shown in the diagram.

The jars were placed in five different positions around the house as follows:

1. on a shelf in the refrigerator

2. on a shelf in the airing cupboard

3. on a window sill

4. under the bed

5. in the garage

Each morning and evening the jars of beans were washed in water, drained through the gauze and replaced in position. At midday each day the beans were removed from their jars, blotted dry with clean paper and had their mass measured on an accurate balance.

The following results were obtained:

Jar	Mass on day 1 (g)	Mass on day 3 (g)	Mass on day 5 (g)	Mass on day 7 (g)
1	20.13	20.12	21.36	22.08
2	20.42	26.93	24.27	39.86
3	20.35	22.57	23.23	24.07
4	20.09	25.16	29.00	34.73
5	20.22	21.03	22.95	24.24

(a) What was the student's dependent variable?

(b) What was the student's independent variable?

(c) (i) What is the most significant uncontrolled variable in the student's design?

(ii) Suggest any other uncontrolled variables that might be significant.

(d) (i) What is the most significant factor that the student has failed to measure?

(ii) How could this be rectified?

(e) The student concluded that mung beans grow best in warm conditions.

(i) Is her conclusion valid?

(ii) How reliable is her conclusion?

(iii) How could her investigation be made more reliable?

(f) Were there any anomalous results in the student's data?

(g) Comment on the precision of the student's data.

(h) How would you redesign the student's investigation to make it more satisfactory?

Suggested Answers to Activities

Activity 1

(a) The increase in skin cancer is due to increased exposure to ultra-violet light from sunbathing.

(b) Unfortunately, it would be wrong and illegal to expose people to extra ultraviolet to see if they contracted cancer! However, you could use survey evidence to test this prediction, or one like it: "The more hours per year a person sunbathes, the more chance they have of contracting skin cancer by the age of 50."

Activity 2

(a) Have several different beakers, each with acid of a different concentration, all kept at the same temperature. Apart from the mixing of the acids, the rest of the procedure would be the same.

(b) A **measuring cylinder** to measure out volumes of water and acid accurately.

(c) If you intended to use more concentrated acid, it would be harmful to the skin as well as the eyes. Consider using plastic gloves.

Activity 3

(a) Dependent variable: the number of people, per thousand of the population, who have contracted skin cancer by the age of 50.

Independent variable: the number of hours per year, on average, a person sunbathes.

(b) Several! Some are: increased use of sunlamps, decay of the ozone layer that shields us from ultraviolet light, increase in holidays to places where the sun is stronger, increased exposure to chemicals that cause skin cancer.

(c) Very difficult! You could, for example, restrict your survey to people who only took holidays in the UK, never used sunlamps, and were not exposed to cancer-causing chemicals in their work.

Activity 4

Potentially uncontrolled variables include: age of student, sex of student, motivation of student, health of student, when the study time was used, other IGCSEs studied at the same time, quality of teaching – and many more!

Activity 5

You could use a very large sample size, and repeat the survey in several different countries in the world who also reported a rise in skin cancer rates.

Suggested Answers to Self-Assessment Test: Lesson Three

(a) The mass of the beans.

(b) The warmth (temperature) of the surroundings.

(c) (i) Some of the beans were in the light and some in the dark. As plants need light for growth, the amount of light might well be determining the rate of growth as well as (or instead of) the temperature.

(ii) No really important ones. The jars started with slightly different masses of beans, which is not ideal.

(d) (i) The temperature.

(ii) Use one or more thermometers.

(e) (i) No, because the light was an important uncontrolled variable.

(ii) Not reliable, because she tested each condition only once.

(iii) Do replicates, e.g. ten jars in each of the tested conditions. Change the jar locations so that all were either in light or in dark.

(f) Jar 2 on day 5 – because its mass went down, contrary to the trends in all of the other jars.

(g) Her results suggest accuracy to the nearest 0.01g. This is far too optimistic, given the way the investigation is done. She should quote the masses to the nearest gram, or nearest 0.1g at best. This is particularly true given that the starting masses differed by 0.3g.

(h) Use the living room, garage and fridge to give three different temperatures. Measure the actual temperatures regularly using thermometers. Black out all of the jars with black paper so all the beans were growing in darkness. Put ten jars into each of the three conditions.