Lesson Four

Scientific Investigations: Design

Aims

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

- understand how to design a scientific investigation

Context

This lesson introduces you to the way in which scientists work.

Oxford Home Schooling

Introduction

Scientists have worked out a way of discovering things which they all share. We are going to call this a **scientific investigation**, or an "investigation" for short. People often also call it "doing experiments".

A scientific investigation involves three main stages:

1. Design: planning what to do.
2. Carrying out: doing the practical work and recording the results.
3. Interpreting: working out what the results mean.

In the first three modules we shall look at these in turn, starting in this lesson with Design. Later on, you will be doing your own investigations.

Designing Investigations

All investigations start off with a problem or a question, something we are unsure about and want to know about.

In this lesson we shall design an investigation into the following problem:

"I wonder how fast things fall?"

This is interesting, but it needs licking into shape before we can do anything with it. In fact it needs taking through the following four steps.

1. Put the question in a testable form

In this stage we sharpen up the question, and put it in a form involving things we can actually measure.

Either of the following would be a testable form of our problem:

- What happens to the speed of a falling object as it falls for a longer time? Does it get faster or slower?

- What happens to the time taken for a falling object to hit the ground, as the distance it has to fall gets further and further?

In each case there are things we can measure (distance, time, speed) to reach an answer to our question.

We will use the second one for now, because we know how to measure distance and time.

2. Make a prediction

Next we make a **prediction** – an informed guess - as to what the answer to our question will be. The guess doesn't need to be right, but it does need to be sensible. That means it must fit in with what we know about science and the world already.

Here are three possible predictions:

1. If things fall twice as far, they will only take half as long to fall

2. If things fall twice as far, they will take twice as long to fall

3. If things fall twice as far, they will take 1.5 times as long to fall

The first prediction is *not* sensible, because we know from experience that things take longer to fall bigger distances.

The second prediction is better. But we also know from experience that things *speed up* as they fall, so they should take *less than* twice as long to fall twice as far.

The third prediction is sensible, because it fits in with what we already know. Actually it will turn out to be wrong, but that doesn't matter – it is a good prediction!

3. Consider the variables and make it a fair test

A **variable** in an investigation is something that does, or can, change or vary. Variables come in three main sorts.

First, there is the thing we are deliberately changing, to see its effect. This is called the **independent variable**. In this investigation we are deliberately changing the distance the object falls, so distance is the independent variable.

Secondly, there is the thing whose change we want to discover. This is called the **dependent variable**. In this investigation we want to discover how the time of fall changes, so time is the dependent variable.

To summarize:

- independent variable: distance
- dependent variable: time

Thirdly, there are other possible variables which, if they changed, might well affect the time of fall. These include:

- the mass of the object (heavy or light)
- the material it is made from (e.g. steel or feathers)
- the wind speed
- the direction of fall (straight down or at an angle).

These are called **control variables**. They must be kept constant throughout the investigation so that they do not affect the time of fall. If this is done, we can be confident that any change in the time of fall *is due to a change in the distance, not to some other factor.*

To keep the control variables constant in this way makes our investigation **a fair test**.

Activity 1	Suggest how changes in each of the control variables listed in the four bullet points above might affect the time taken for the object to fall.

4. Detailed planning

Lastly, we need to decide precisely what to do. This includes deciding about:

- The equipment or **apparatus** we will need
- Exactly what we will **measure**
- The **range of readings** (what heights will we drop the object from?)
- Any **safety issues** (so that no-one gets hurt)

We are then ready to go!

Activity 2	1. Make a complete list of the apparatus needed for this investigation. 2. Write down exactly what will need to be measured. 3. Say what you think is the most important safety issue to think about.

Keywords

Investigation	**Control variable**
Prediction	**Fair test**
Variable	**Control variable**
Independent	**Fair test**
variable	**Apparatus**
	Dependent variable

Suggested Answers to Activities

Activity 1

- You might have guessed that a heavier object will take less time to fall. However, experiments show that the mass of the object has no effect on the time.

- A less dense material will take a longer time to fall. (This is because it has greater air resistance slowing it up compared to the force of gravity pulling it down.)

- It depends on the direction of the wind. An upward wind would make the time longer, a downward wind would make the time shorter. A sideways wind should have no effect (because of the next point).

- Provided you measure the distance covered as straight up and down, any extra sideways motion of the object should have no effect on its time of fall.

Activity 2

1. Object to drop, stopwatch, ruler/tape measure. It is <u>not</u> necessary to list things like paper and pen, or a house to carry out the investigation in.

2. You will need to measure the independent and the dependent variables, that is
   - the distance dropped
   - the time taken to drop

3. Perhaps ways to avoid hitting someone on the head with a heavy falling object!

Lesson Eight

Scientific Investigations: Carrying out

Aims

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

- understand how to carry out a scientific investigation and record the results.

Context

This lesson continues the work started in Lesson Four. It is completed in Lesson Twelve.

Oxford Home Schooling

Introduction

In the last module, we learned about scientific investigations and how to design them. It would be very useful to review that work before starting the present lesson.

In this lesson we continue with the same investigation, the one into how fast things fall. If you remember, we made the following prediction:

If things fall twice as far, they will take 1.5 times as long to fall.

Now it is time to see how a scientist would carry out the practical work to test this prediction. As when designing the investigation, there are several different things to watch out for.

1. Accuracy

The scientist needs to use their apparatus carefully so that they can trust the results they get are close to the real values. The real values are the ones they "should have got" if they'd done everything perfectly. If their results are close to the real values, they are **accurate**.

In our investigation this includes things like:

- Starting the stopwatch at the exact time the object is dropped, not some time later because they were looking out of the window instead of paying attention
- Lining the ruler up carefully when measuring the distance, instead of waving it about in vaguely the right place.

2. Precision

They also need to take the measurements finely enough – distances to the nearest centimetre instead of the nearest metre, and times to the nearest 0.1s, not the nearest second. Doing this gives their results **precision**.

3. Reliability

They also need to repeat each reading several times, to make sure they didn't make a mistake with it the first time. This is known as doing **replicates**, and it ensures that their results are **reliable**.

If they do replicates, they can also take an average of their recorded times for each distance dropped. This average is likely to be more **accurate** – closer to the true value – than any individual reading.

Get it right! Notice that "accurate", "precise" and "reliable" mean three different things. Try not to mix them up.

Activity 1

While doing this investigation, scientist A got time readings of 0.23s, 0.37s, 0.13s and 0.40s, while scientist B got time readings of 0.2s, 0.3s, 0.2s and 0.3 s for the same distance. If the real value for the time was 0.24s:

(a) which scientist had the more accurate readings?
(b) which scientist had the more precise readings?

Explain your answer in each case.

4. Table of Results

Once the scientist has got their results (readings), they almost always record them in a **table**, which should be drawn up before the practical work starts.

Designing tables is more difficult than it looks, and there a number of mistakes to avoid. Here is a suitable table for our investigation with the results filled in:

Distance / m	**Time / s**
0.00	0.0
1.00	0.4
2.00	0.9
3.00	0.8
4.00	0.9
6.00	1.1
8.00	1.2

Notice the following points:

- The heading is ruled off from the body of the table containing the numbers

- The units are written in the heading and not repeated after each number in the table.

The numbers in each column are quoted to the same number of decimal places, and this is related to the precision claimed for the results, i.e. distance to the nearest 0.01m (1cm), and time to the nearest 0.1s.

In this table, only one time for each distance is recorded. It is a good idea instead to record all the **raw data**, i.e. all the times for each distance, plus an average time for each distance.

Activity 2

Here is a student's table of results for a different investigation. Can you spot four errors they have made in their table?

Temperature (°C)	Mass	Length
36.8	156g	17
37	158g	18
39.25	163g	19
40	165g	20

1.

2.

3.

4.

5. Anomalous Results

Once you have recorded all data in a table, you can then spot any **anomalous results**.

An anomalous result is one that doesn't fit in with the pattern shown by the rest of the results. It was probably produced by a mistake in carrying out the practical work.

In the first table above, the time of 0.8s for a drop of 2m is an anomalous result – in every other case the time is getting longer as the distance is getting greater.

When a scientist gets an anomalous result they will go back and repeat the reading. If this is not possible they will ignore the anomalous reading when working out their averages, so that it does not ruin the accuracy of the results.

Activity 3

A student was measuring the time taken for a 1.5m drop. They did it five times. Here are their results: 0.63s, 0.67s, 1.13s, 0.63s and 0.64s.

1. Which is the anomalous result?

2. Assuming they were not able to take any more readings, calculate their average time for the 1.5m drop.

Keywords

Accurate
Precision
Reliable
Replicate
Table
Raw data
Anomalous result

Suggested Answers to Activities

Activity 1

1. Scientist B – their average time (0.25s) is closer to the real value of 0.24s than was the average of Scientist A (0.28s).

2. Scientist A – they were measuring to the nearest 0.01s, where Scientist B was only measuring to the nearest 0.1s.

Activity 2

1. They did not rule off after the heading.
2. They missed out the units for length completely.
3. They wrote the units of mass after each number, instead of in the heading.
4. They quoted their temperature readings to different numbers of decimal places.

Activity 3

1. 1.13s
2. 0.64s

Note well: (i) You shouldn't include the anomalous result when you calculate the average (ii) Your calculator reading for the answer was 0.6425. However, you should *not* write 0.6425s for the answer, because this looks like you are confident that your answer is accurate to the nearest 1/10,000th of a second!

Lesson Twelve

Scientific Investigations: Interpreting

Aims

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

- understand how to interpret results from a scientific investigation.

Context

This lesson completes the work started in Lesson Four and continued in Lesson Eight.

Oxford Home Schooling

Introduction

In Modules One and Two we learned how to design and carry out scientific investigations. It would be very useful to review that work before starting the present lesson.

In this lesson we continue with the same investigation, the one into how fast things fall. If you remember, we made the following prediction:

If things fall twice as far, they will take 1.5 times as long to fall.

and we obtained the following results:

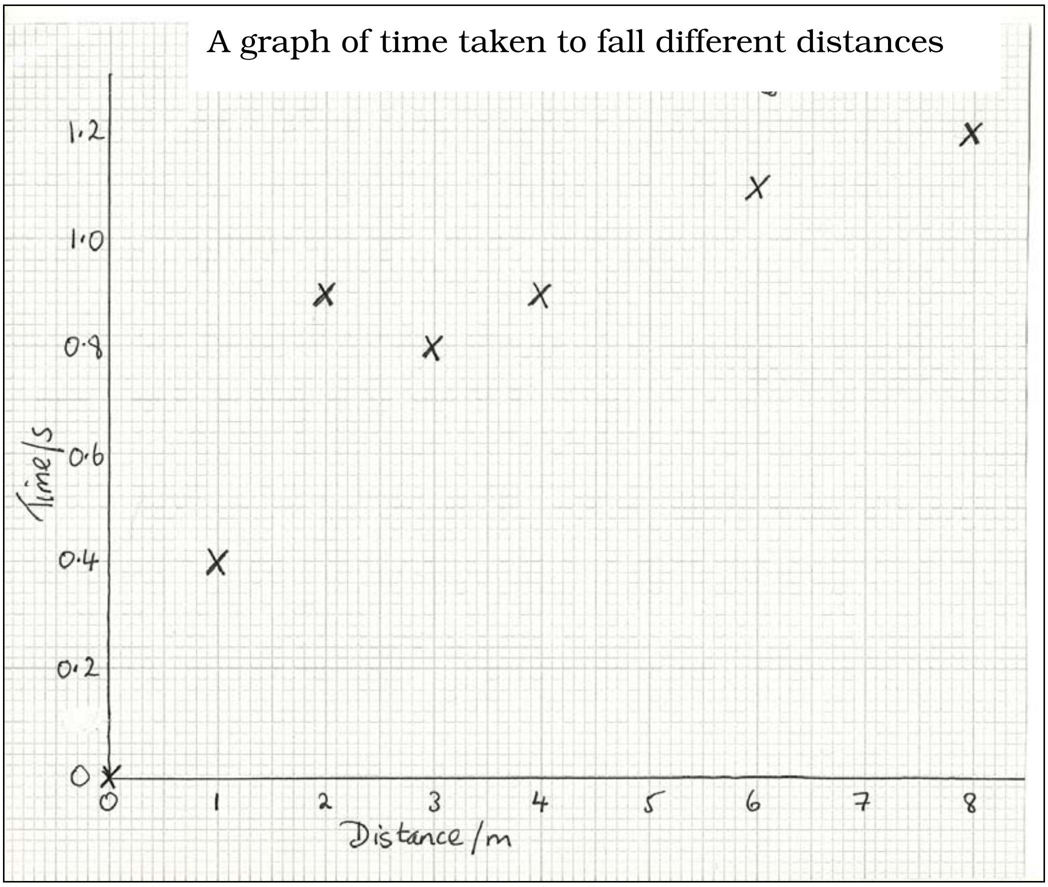
Distance / m	Time / s
0.00	0.0
1.00	0.4
2.00	0.9
3.00	0.8
4.00	0.9
6.00	1.1
8.00	1.2

Now it is time to see how a scientist would interpret these results. As when designing and carrying out the investigation, there are several different things to watch out for.

1. Presentation: Graphs

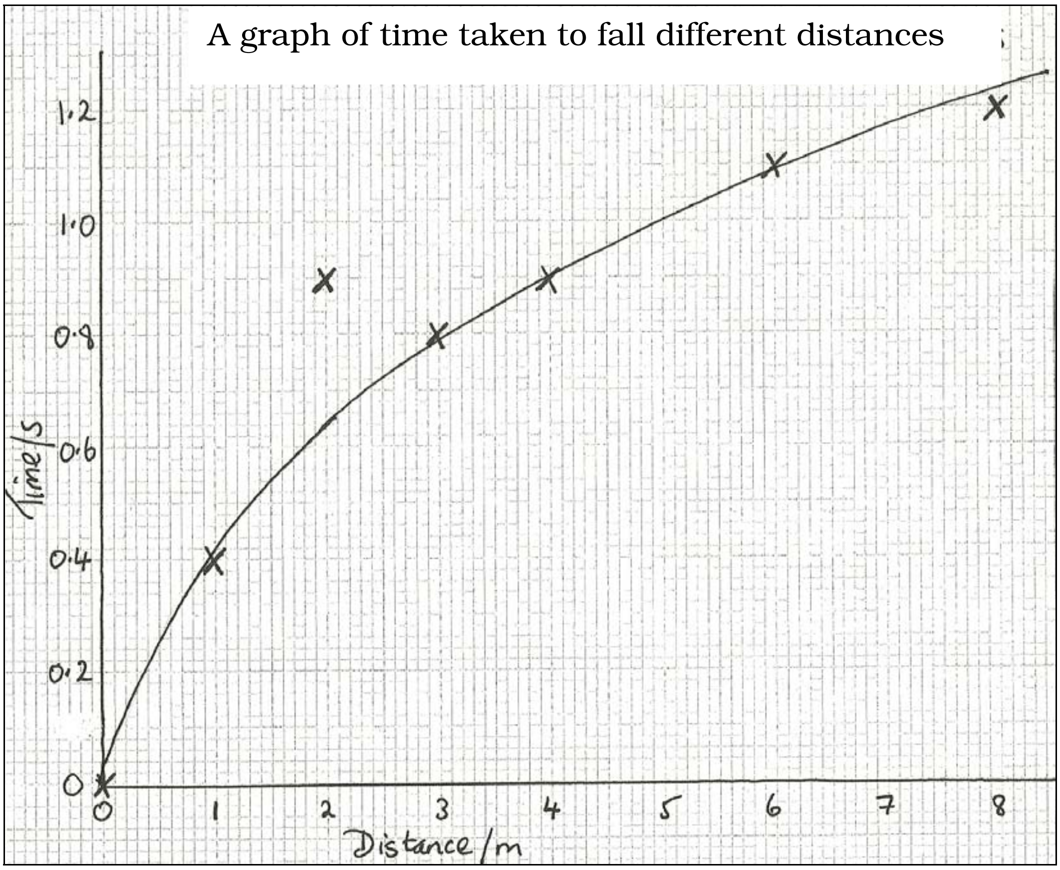
The first is to present the results in a form which helps us see better what is going on. This often means drawing a **graph**.

There is a lot to learn about drawing graphs in science, and we shall come back to this later on. In this case, both of our sets of readings are in numbers, so we can draw a **line graph**. In science, the independent variable always goes along the bottom of the graph and the dependent variable up the side. So, if you sketch the graph, it will look like this.



Notice how strange the **anomalous result** at 2m looks – it is clearly out of line with the rest of the results.

The graph is completed by drawing a **line of best fit**. This is line which ignores the anomalous result completely and does not necessarily go exactly through all the other points. It leaves approximately the same number of points slightly on either side so as to get a smooth curve:



2. Identifying Patterns

We then look at the graph to see if we can spot any patterns. There are several:

1. As the distance dropped increases the time taken also increases (as we expected).

2. The graph is a curve, flattening off as it goes on, not a straight line. This means as we double the distance the time is less than doubled (also as we expected).

3. Now compare the times for 2m, 4m and 8m, using the line not the points. They are about 0.64s, 0.90s, and 1.24s. Each time is about 1.4 times bigger than the one before. That is: if we double the distance the time is multiplied by about 1.4 times.

Activity 1	Read off the graph the times taken to fall 1.5m, 3m and 6m. Do they fit pattern 3 discovered above?

3. Reaching a Conclusion

We now compare the patterns we have spotted with the prediction made at the Design stage. It turns out our prediction was wrong, but only slightly. We predicted that doubling the distance would increase the time by 1.5 times, but in fact the time increased by about 1.4 times. This is the **conclusion** to our investigation.

If we are able to, we now suggest possible reasons why this might be the case. Unfortunately, we don't know enough Physics at present to do this. (As you will learn much later on, if you double the distance the time is increased by the "square root" of 2, i.e. by about 1.4 times.)

Get it right! Proving your original prediction wrong is just as valuable as showing it was right. The investigation has still succeeded. In fact, most real advances in science occur when scientists' predictions are proved wrong, because that forces them to re-examine their theories!

4. Evaluation

The final step in any investigation is to **evaluate** it. This means to criticise it and work out how it could be done better next time.

In this investigation:

- It was difficult to drop the object and start the stopwatch at the same time – the results would be more accurate if you had an assistant to help you.

- The times were not measured precisely enough. It would be better to use an electronic timer, so we could record the times to the nearest 1/100th of a second.

- Air resistance might be slowing the object up as it moves faster. Perhaps the investigation could be repeated in a vacuum?

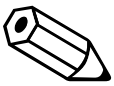
All these points could lead to improvements in any future investigation on the same topic.

Activity 2

What do you think about these criticisms of the investigation?

1. The distance should have been measured to the nearest millimetre instead of the nearest centimetre.

2. I often wasn't paying attention, so didn't stop the stopwatch when the object hit the ground.



Activity 3 Extension

The earliest experiments on falling objects were done by the scientist Galileo at Pisa in Italy. If you go to YouTube at www.youtube.com, and enter "Galileo falling objects video" into the search box, you can find out more about his life and work.

Keywords

Line graph

Line of best fit

Evaluation

Suggested Answers to Activities

Activity 1

The times are about 0.54s (for 1.5m), 0.78s (for 3m) and 1.08s (for 6m). These also fit pattern 3 quite closely.

Activity 2

1. This increased precision in distance would not make our results any better unless the measurement of the time was *much* more precise.

2. This is probably true, but it is an "avoidable error", rather than something built in to the design of the experiment itself!

Lesson Sixteen

Student Investigation: Design

Aims

By the end of this lesson you should have:

- chosen a puzzle to investigate
- designed an investigation to solve the puzzle

Context

This lesson uses the work we did on the design of investigations in Lesson Four. It continues in Lessons 20 and 24.

Oxford Home Schooling

Introduction

Way back in Lesson Four we saw how scientists design investigations. You will shortly be designing your own investigation, so it would be helpful to revise Lesson Four now before continuing.

You will be given a list of four possible investigations. You will need to choose one of the four, and then work through all the four stages in the design process.

Investigations to choose from

Think about these four questions and, if possible, discuss them with someone else. Choose one which:

- you find interesting,
- you have an idea about how to investigate, and
- you have, or can buy or find, the apparatus you will need.

Here are the four:

1. "When a rubber band stretches, does it obey Hooke's law?"

   You will find Hooke's Law in Lesson Fifteen, in the discussion about stretching springs.

2. "Does the size of an ice cube affect how fast it melts?"

   Melting is discussed in Lesson Six.

3. "What most affects how fast sugar dissolves in water?"

   Dissolving is also discussed in Lesson Six.

4. What effect does the weight of an object have on the friction between it and the ground?

   Friction is discussed in Lesson Fifteen.

Designing your Investigation

Before doing each stage, look back to the corresponding section in Lesson Four.

1. Put the question in a testable form

Sharpen up your question, and put it in a form involving things you can actually *measure*.

2. Make a prediction

Make a prediction – an informed guess - as to what the answer to your question will be. The guess doesn't need to be *right*, but it does need to be *sensible*. That means it must fit in with what you know about science and the world already.

3. Consider the variables and make it a fair test

A variable in an investigation is something that does, or can, change or vary.

Decide what will be your independent and dependent variables. Then make a list of the control variables that you have to keep the same to make your investigation a fair test.

4. Detailed planning

Lastly, decide precisely what to do. This includes deciding about:

- The equipment or **apparatus** you will need
- Exactly what you will *measure*
- The *range* of readings you will take
- Any *safety* issues, so that no-one gets hurt.

Considering your Planning

When you are done, explain what you have written to a responsible adult. In particular, *ask them to check your plan for safety*. If you or they are unsure about what you are planning to do, contact your Tutor for help.

Timing

We will discuss carrying out your investigation in the next module.

However, if you are enthusiastic to get started you can always do it straight after the following TMA, before starting work on the next module. It's up to you.

Lesson Twenty

Student Investigation: Carrying Out

Aims

By the end of this lesson you should have:

- carried out an investigation to solve the puzzle chosen in Lesson Sixteen

Context

This lesson uses the work we did on the carrying out of investigations in Lesson Eight. It continues in Lesson 24.

Oxford Home Schooling

Introduction

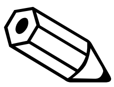
Way back in Lesson Eight we saw how scientists carry out investigations. You will shortly be carrying out the investigation which you designed in Lesson Sixteen. It would be helpful to revise Lessons Eight and Sixteen now before continuing.

Carrying Out your Investigation

Before doing each stage, look back to the corresponding sections in Lesson Eight.

1, 2 and 3. Accuracy, Precision and Reliability

Consider what you need to do in these three areas, and write your answers down below.



4. Table of Results

Draw up the table in which you will record your results while carrying out the practical work.

Once this is done, carry out the work and fill in your results in the table.

5. Anomalous Results

Do you have any anomalous results in your table? If so, record them below, and consider whether it would be a good idea to repeat these readings.

Considering Results

When you are done, show your results table to a responsible adult and ask for their comments. If you or they are unsure about the results obtained, contact your Tutor for help.

Timing

We will discuss interpreting your investigation in the next module.

However, if you are enthusiastic to get started you can always do it straight after the following TMA, before starting work on the next module. It's up to you.

Lesson 24

Student Investigation: Interpreting

Aims

By the end of this lesson you should have:

- interpreted your investigation into the question chosen in Lesson Sixteen and carried out in Lesson Twenty.

Context

This lesson uses the work we did on the carrying out of investigations in Lesson Twelve. It completes the work on your own investigation that was started in Lessons Sixteen and Twenty.

Oxford Home Schooling

Introduction

Way back in Lesson Twelve we saw how scientists interpret investigations. You will shortly be interpreting the investigation which you designed in Lesson Sixteen and carried out in Lesson Twenty. It would be helpful to revise Lessons Twelve and Twenty now before continuing.

Interpreting your Investigation

Before doing each stage, look back to the corresponding sections in Lesson Twelve.

1. Draw a Graph

Use the data from your results table to draw a graph or bar chart. Before starting, consider the answers to the following:

- Should it be a line graph or a bar chart?
- Which quantity should go on the bottom (x) axis, and which on the vertical (y) axis?

Using graph paper, draw and label the axes and plot the points.

Now look at your points:

- Do the points suggest a straight line or a curve?
- Do you have any anomalous results? If so, you will ignore them when drawing your line.

Now draw a line of best fit (straight or curved). Remember that it does not have to go exactly through all the points.

Finally give your graph a title.

Job done!

2. Identify Patterns

What is the connection between the two quantities you chose for your axes? That is:

- As the quantity on the horizontal axes increases, does the one on the vertical axis increase or decrease?

- Are these changes regular or not? For example:

  - If you double the quantity on the horizontal axis, does the one on the vertical axis also double (or halve)? If not, does it more than double or less than double?

  - Does the relationship between the two quantities stay the same throughout? Or does it change? For example, the quantity on the vertical axis might increase at first, then decrease.

3. Reach a Conclusion

Now go back to the prediction you made when you designed your investigation in Lesson Sixteen. Do your findings:

- support your prediction,
- not support your prediction, or
- partly support your prediction?

Stating and explaining this is the **conclusion** to your investigation.

If you are able to, explain the reasons for your findings in terms of the Science you know: *why* did you find the patterns you did?

4. Evaluation

Finally, evaluate your investigation. Just how good was it at finding the answer to the question that interested you? Don't say: “It was brilliant!” And don't just say “Measure everything much more accurately.” Instead, think of specific ways:

- it could be *improved* if you did it again

- it has *unavoidable* errors built into it that you just can’t eliminate

A good investigation is *not* one that is perfect. It is one that was quite good, but the scientist has reached a realistic appreciation of the problems with it and is ready to improve.

Your investigation is now finally finished. Celebrate quietly, and then go off and discuss it with someone.

This is the end of your Year 7 Science course. We hope you have enjoyed it, and we look forward to seeing you again at the start of year 8!