

## Aspects of *How science works* – teacher guidance

This strand is about helping pupils to develop some of the more challenging aspects of the practical *How science works* skills. While many pupils can draw graphs well, fewer understand how to interpret the graphs and the principle of the 'line of best fit'. Variables can remain a mystery to many as they do not understand the interplay between the different types, nor how the choice and range can influence the results of an experiment. How often

### ***Moving from step 1 to step 2***

#### **Step 1 – Pupil characteristics**

Pupils:

- can present work or data as a graph although the scales may be incorrect;
- can identify the pattern shown by the graph and possible anomalous results;
- can identify the key factors to be considered and generally assign sensible values to them;
- can measure a variety of quantities with precision;
- can draw conclusions consistent with the evidence and generally analyse data qualitatively;
- can explain how their planning and implementation could be improved.

#### **Step 2 – Pupil characteristics**

Pupils:

- can choose an appropriate type of graph and scale(s) to display the data effectively;
- can explain what the shape of the graph represents and interpret graphs with a negative scale on one axis;
- identify relevant independent and dependent variables.

<sup>1</sup> Two useful publications are:

Investigations – Getting to grips with graphs (ISBN 086 357 3029)

Investigations – Developing understanding (ISBN 086 357 310X)

have pupils written 'I could of done it better' [sic] or 'I needed to do more readings' [sic] as their evaluation? Pupils need to be able to identify and explain sources of experimental error and to take account of these in their experimental design.<sup>1</sup>

## **Strategies to ensure progression from step 1 to step 2**

### **Graphical skills**

#### **A) Model how to:**

- **assign appropriate scales;**
  - **read a graph;**
  - **describe what a graph is showing, that is, increase, decrease, no change.**
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- Explain to pupils that a graph is not the end point of an investigation. Make it clear that a graph is another way of presenting data, in a way that can make it easier to identify a pattern. Compare tables and graphs for the ease of looking for patterns.
  - Give pupils copies of graphs from past papers or text books and ask them firstly to identify the variables and units and then to give the graph a title.
    - Minibooster 4 activities 1, 2 and 3.

#### **B) Demonstrate how to break line graphs up into discrete sections, read each section and then sequence them to build up the whole story of the graph.**

- Collective memory task.

Prepare a graph but keep it concealed from view. The pupils work in small groups to replicate the graph. Pupils come up in turn and have 10 seconds to view the graph followed by 10 seconds to reproduce it, from memory, for the rest of the group. This is repeated until all members of the group have visited the graph. Pupils compare their own graphs with the original.

This is a good way to encourage pupils to look carefully at the component parts of an image and to consider the strategies they have used to commit them to memory.
- Minibooster 4 activity 5.
- Minibooster 4 – moving to level 6+ activity 3.

**C) Create opportunities to interpret a range of graphs including those with simple negative scales on one axis, for example, change of mass.**

- Present pupils with a number of less common graphs, that is, not straight lines that begin at or near the origin and slope upwards to the right and ask them to produce a results table from which the graph could have been drawn.
- Minibooster 4 – moving to level 6+ activities 2 and 4.
- Minibooster 4 – moving to level 6+ activity 9.

**Variables, reliability and accuracy**

**A) Support pupils in using the correct language when talking about variables.**

- Minibooster 5 activity 1.
- Minibooster 6 activity 1.

**B) Demonstrate how the choice and range of variables might affect the quality of the investigation, for example, pupils carry out the same investigation using different ranges and numbers of variables and compare results.**

- Minibooster 3 activity 1.
- Minibooster 6 activities 2 and 3.

### **Analysis and evaluation**

**A) Explain the use of a table as an organiser within the experimental plan as well as a way of presenting data in a report.**

- Discuss with pupils how tables can be used as an important part of the planning of an investigation and that they may construct suitable tables before carrying out the work. They may use other tables to summarise data after an investigation or from research.
- Minibooster 4 activity 4.
- Minibooster 5 activity 3.
- Minibooster 4 – moving to level 6+ activity 6.

**B) Create the opportunities for pupils to:**

- compare the relative advantages and disadvantages of presenting results as tables or graphs;
- predict the design of an experiment from the table or graph;
- organise data into different tables and compare them.
- Make it explicit to pupils why the numeric independent variable should change in equal steps. They can compare it to looking for patterns in tables where the independent variables change in equal and unequal steps.
- Minibooster 5 activities 5 and 6.

**C) Model how to interpret patterns in graphs and tables and to be aware of the limitations of the data.**

- Minibooster 2 activity 1.
- Minibooster 5 activity 2.
- Use *Pattern or not?*

**D) Model how to identify possible sources of experimental error in the planning and implementation.**

- Minibooster 2 activities 2 and 4.
- Minibooster 7 activities 1, 2 and 3.
- Minibooster 2 – moving to level 6+ activities 3 and 4.

## **Moving from step 2 to step 3**

### **Step 2 – pupil characteristics**

Pupils:

- choose an appropriate type of graph and scale(s) to display the data effectively;
- explain what the shape of the graph represents and interpret graphs with a negative scale on one axis;
- identify relevant independent and dependent variables;
- choose an appropriate range, number and value for each variable;
- make enough measurements, observations and comparisons for the task;
- draw conclusions consistent with evidence and use scientific knowledge and understanding to explain them;
- explain how planning and implementation could be improved and how this could help overcome experimental error.

### **Step 3 – pupil characteristics**

Pupils:

- use lines of best fit appropriately;
- make allowances for anomalous results in their graphs;
- explain what the shape of the graph represents and interpret this correctly;
- manipulate and transform data to represent negative changes, for example, osmosis, exothermic or endothermic reactions;
- identify and manipulate relevant independent and dependent variables and recognise that some cannot be controlled;
- plan for accuracy through the choice of equipment and technique;
- consider whether the data they have collected is sufficient for conclusions to be drawn;
- explain how they have made a numerical prediction based on the trend or pattern in results;
- evaluate their planning and implementation and explain how this could account for errors and anomalies.

## Strategies to ensure progression from step 2 to step 3

### Graphical skills

#### **A) Model how incorrect plotting or inappropriate scales can change or distort the pattern of the graph.**

- Give pupils a copy of a graph without the labels on the y-axis; for example, use a graph showing the growth of a plant over a number of weeks. Then secretly give each group of pupils a set of different scales to add to the graph, such as 0–20 g, 0–100 g, 0–4 kg. Ask them to use the graph to answer questions such as: 'How much mass did the plant gain in the first three weeks?' Ask pupils to work out why the answers are different and why labelling the axis, with the correct scale, is important.
- Use activity 'Problems with scales' from *Getting to grips with graphs* which shows the same set of results plotted on axes marked with different scales and the effect on the pattern presented.
- Minibooster 6 – moving to level 6+ activity 3.

#### **B) Create a number of opportunities to represent data through a range of complex graphs. This should include drawing graphs with negative scales.**

- Pupils work in pairs. Each pupil is given a different graph and five minutes to write down all the important information from it. They swap information and then use this to recreate each other's graphs.
- Minibooster 4 – moving to level 6+ activities 1 to 10.

#### **C) Model how to decide whether a line of best fit is needed and how to draw it correctly and whether it should go through the origin. Help pupils to realise that any point on a graph is only ever an approximation.**

- Discuss and establish some rules about lines of best fit, for example, they do not always go through all the points; they are not always straight lines; they do not have to go through the origin; there may be more than one possible line of best fit on the same graph.
- Pupils work in pairs using a table of results that has three repeat readings and an average value of all three, that is, four columns of results. One of the pair plots a graph using the mean values only and the other pupil plots all three readings (omitting the means) on the same graph. Pupils compare their lines and discuss why they are different and whether a point on a graph is exact or approximate.

- Present pupils with some graphs with pre-drawn lines of best fit that go through the origin. Check that they are clear about what the origin represents. Ask them to discuss and explain if it makes sense for the line to go through the origin.
- Minibooster 4 moving to level 6+ activity 5.

**D) Create experimental opportunities to calculate negative values, for example, mass before and after; temperature change during reactions.**

### **Variables, reliability and accuracy**

**A) Create opportunities for pupils to identify the key variables in scientific newspaper articles or adverts.**

- Minibooster 1 – moving to level 6+ activity 1.
- Minibooster 4 – moving to level 6+ activity 1.

**B) Demonstrate how accuracy can be affected by the choice of equipment or technique, for example, pupils carry out the same investigation using different equipment and compare results.**

- Minibooster 1 activities 1 and 2.
- Minibooster 2 activity 3.
- Minibooster 1– moving to level 6+ activity 1.
- Minibooster 2 – moving to level 6+ activity 1.
- Minibooster 2– moving to level 6+ activity 7.
- Minibooster 6 – moving to level 6+ activity 1.
- Ask pupils to justify why they chose to use a particular measuring instrument.

**C) Explain the differences between categoric, ordered and continuous variables and require pupils to assign the correct classification to different investigations.**

- Explain to pupils that independent, dependent and control variables all have values but the values might be:
  - **categories** (for example type of metal) or
  - **ordered** (for example small, medium, large, very large) or
  - **continuous**, which are numeric. This could give nine possible combinations. Either present a number of tables for pupils to practise deciding the type of variable or ask them to think of examples for each space on the table on the next page.

Independent	Dependent		
	Categoric	Ordered	Continuous
Categoric			
Ordered			
Continuous			

- Minibooster 3 – moving to level 6+ activity 1.

### Analysis and evaluation

#### A) Create opportunities for pupils to:

- identify mathematical trends or patterns and use these to make a prediction;
- devise criteria to decide whether the evidence is valid.

#### B) Create opportunities for pupils to assess each other's experimental designs and explain where they see possible sources of error.

- Minibooster 3 activity 1.
- Minibooster 2 – moving to level 6+ activity 5.
- Minibooster 7 – moving to level 6+ activity 3.

#### C) Discuss with pupils the range of errors associated with taking measurements.

- Minibooster 2 – moving to level 6+ activity 2.

### **Moving from step 3 to step 4**

#### **Step 3 – pupil characteristics**

Pupils:

- use lines of best fit appropriately;
- make allowances for anomalous results in their graphs;
- explain what the shape of the graph represents and interpret this correctly;
- manipulate and transform data to represent negative changes, for example, osmosis, exothermic/endothermic reactions;



- identify and manipulate relevant independent and dependent variables and recognise that some cannot be controlled;
- plan for accuracy through the choice of equipment and technique;
- consider whether the data they have collected is sufficient for conclusions to be drawn;
- explain how they have made a numerical prediction based on the trend or pattern in results;
- evaluate their planning and implementation and explain how this could account for errors and anomalies.

#### **Step 4 – pupil characteristics**

Pupils:

- interpolate and extrapolate with accuracy;
- explain and suggest reasons for anomalous results in their graphs;
- identify key factors in complex contexts and in contexts where variables are not easily controlled;
- plan for reliability through trial runs, repeat readings and accurate practical techniques;
- identify and suggest reasons for anomalous results and allow for these when drawing graphs;
- explain how the selective presentation of data can bias the conclusion drawn;
- evaluate their planning and implementation and explain how this could account for errors and anomalies and the subsequent impact on the conclusion drawn.

### **Strategies to ensure progression from step 3 to step 4**

#### **Graphical skills**

**A) Create opportunities for pupils to explain how they have made numerical predictions from the interpolation or extrapolation of graphical readings.**

- Model this process for pupils making the steps in your thinking explicit.
- Ask some groups of pupils to make predictions from the table of results and others to make predictions from the graph and to discuss and compare their answers.

**B) Demonstrate the effect of insufficient readings and/or anomalous results on the graphical representation of data.**

- Minibooster 4 – moving to level 6+ activity 7.

### Variables, reliability and accuracy

**A) Discuss with pupils investigations where not all variables can be controlled and ask pupils to explain how to account for this in their experimental design.**

- Minibooster 6 – moving to level 6+ activities 4, 5, 6 and 7.

**B) Demonstrate how to increase reliability through repeat readings, use of a control and trial runs; create opportunities for pupils to develop these techniques.**

- Minibooster 1 activities 4 and 5.
- Give pupils the opportunity to carry out some short trial runs of simple investigations to generate some preliminary data that they could use to make decisions about appropriate range, degree of accuracy and number of repeats.
- Ask pupils to justify why they chose a particular number of repeat readings or the use of a control group.
- Minibooster 2 – moving to level 6+ activity 6.

### Analysis and evaluation

**A) Discuss with pupils how and why bias in the evaluation of evidence might arise.**

- Use the table *Recognising the pitfalls* from **Developing critical and creative thinking** to alert pupils to possible sources of bias and look for examples of this in newspaper articles or on Internet sites.
- Minibooster 3 activities 3 and 4.
- Minibooster 3 – moving to level 6+ activities 3 and 4.

**B) Model for pupils how a change in experimental parameters can alter the validity of the data.**

- Minibooster 7 – moving to level 6+ activities 1 and 6.

**C) Create opportunities for pupils to assess each other's experimental designs and conclusions to identify and explain inconsistencies between the two.**

- Minibooster 7 – moving to level 6+ activity 4.