Research skills – teacher guidance

This strand is about helping pupils to develop information-processing skills so that they can use and interpret a wide selection of information. Pupils nee d to be able to:

- undertake some experimental or preliminary research;
- plan how to identify and select the most appropriate or valid sources of information or data;
- transform information into the most appropriate form for the task and audience;
- use criteria to decide on appropriate information to support a conclusion or argument;
- critically evaluate both the pieces of information used and the process for selecting the evidence;
- appreciate that their conclusion is a 'best fit' and be able to consider the validity of alternative explanations;
- develop a range of skills allowing them to transform information into the most appropriate format.

Information-processing skills

These enable pupils to locate and collect relevant information, to sort, classify, sequence, compare and contrast and to analyse partial or whole relationships.

In science pupils need to be able to access, use and interpret a wide selection of information and data; sort, select and prioritise information that is relevant; group and classify observations and findings to determine patterns. This is an essential aspect that underpins pupils' understanding about the ways in which scientists work and being a scientist. Using these skills can be an important early stage in developing language for learning in science

In science teachers should plan for pupils to:

- locate and collect relevant information; for example, researching the nature of planets in the solar system, or using a habitat, such as the school playing field or local pond, to collect biotic and abiotic information using both dataloggers and observation notes;
- sort, classify and sequence; for example, ordering the planets in the solar system in relation to their relative sizes, or identifying the organisms and classify them and/or use them to construct possible food chains and webs;
- compare and contrast; for example, comparing the sizes and gravitational forces on the different planets, comparing the various invertebrates in terms of movement, nutrition and reproduction;
- analyse partial or whole relationships; for example, predicting how the mass of the planet will affect the relative size of the gravitational force on it, or identifying producers and consumers and recognising their role in the maintenance of the ecosystem of the pond.

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Moving from step 1 to step 2

Step 1 – Pupil characteristics

Pupils:

- can identify a few data items or evidence linked, but not always relevant, to a task;
- have limited note-taking skills that do not include identifying the main ideas; they struggle to translate the original language into their own words;
- recognise that sources of information and data exist in several forms, for example, graphical as well as textual.

Step 2 – Pupil characteristics

Pupils:

- can link the selected data items or evidence to reach a suitable conclusion;
- can produce notes that identify the main ideas and have a clear purpose but do not question the 'authority' of written texts;
- can plan how to collect relevant information and data from a variety of sources, both primary and secondary.

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Strategies to ensure progression from step 1 to step 2

A) Create opportunities for pupils to classify information based on concrete and then, if appropriate, abstract categories using a range of, for example, mysteries, odd one out and relational diagrams.

- Use the mystery 'Why did the dinosaurs die out?' to help pupils make links between pieces of information that may seem disparate and unconnected.

  Pupils may have to read between the lines and decide whether the information is relevant or not. Help pupils differentiate between inductive and deductive approaches[1]. The pupils' thinking is physically evident as they move slips of paper around. This helps them to share their thinking and allows the teacher a unique opportunity for diagnostic assessment. It also gives much opportunity for the development of creative thinking as pupils can generate their own hypotheses or suggest alternate explanations.

  When designing mysteries it is important to start with a topic where there is the opportunity for uncertainty and ambiguity. There need to be 15–30 data items, some of which can be red herrings.

[1] To explain this and deductive-inductive – Bacon promoted the study of science from a position of gathering data and then, by inference or inductive reasoning to come to conclusions. In inductive reasoning the initial premises may support the conclusion, but do not ensure that the conclusion is correct. We can 'infer' from the premises that something is correct. For example take a traveller making many observations of sheep on farms in the Welsh countryside, all the observed sheep are white, therefore the traveller may infer that all sheep are white. The more observed white sheep he records the stronger the inference and the conclusion he or she makes. The conclusion, however, is not taken to be true. The conclusion can be tested by making more observations. If, on another journey the traveller observes a black sheep, then the conclusion would be shown to be false and a new idea for sheep colour would be needed. The more observations (premises) that you base your conclusion on the stronger your inductive reasoning. The above example is an example of strong induction. There are also weak inductive arguments, often made from weak premises. Deductive- Deductive reasoning starts with known facts or 'premises' these, by necessity, lead to conclusions that must be correct. For example; an eagle is a bird; all birds have wings; therefore an eagle has wings. In this case the 'known fact' is that an eagle is a bird (the major premise). That all birds have wings is also a 'known fact' (the minor premise) and leads us to the conclusion that eagles have wings. This is an example of valid deductive reasoning. It does not follow that deductive reasoning will always give a valid conclusion. Take the following example; a bird has wings; a bat has wings. Therefore a bat is a bird. This is an example of invalid deductive reasoning. The Major premise is true, as is the minor premise but the conclusion does not have to be true and in this case it is not. What is happening here is that we are using what we know to be true as a substitute for the logic of the statement. We need to be sure that we do not make linked assertions that seem reasonable, but in fact are logically incorrect.

Share the question with the pupils and then say that they will be given a set of cards with information on them, which they can sort to help them decide on an answer. You may choose to tell them that some of the cards are red herrings, or you might like to leave it up to them to decide. Alternatively, you might decide to use it as a prompt question during the activity, if appropriate.

After 15–30 minutes stop the task and explain to pupils that they need to come up with an explanation for their answer. Give them a short time to do this and share the responses with the class to see if there is agreement or a range of answers. Then ask the pupils to evaluate how they did the task and what were the important things that they learnt. Again share these responses with the whole class.

It may be appropriate to split the work so that pupils begin the mystery in one lesson with time to generate some questions that they then can research for homework. They continue the mystery in the next lesson as above.

Background information

Quite a few possible theories have been suggested at different times as to why dinosaurs died out – often based on rather flimsy evidence. These include:

- Meteors hitting the Earth, increasing levels of dust, radiation, pollution and decreasing levels of light.
- Volcanic eruption on a grand scale, increasing levels of dust, radiation, pollution and decreasing levels of light.
- Issues relating to diet, for example, increase in numbers of mammals and competition for food sources.
- Issues relating to reproduction, for example, increased temperature could have resulted in more female dinosaurs because the determination of sex is temperature dependent; some chemicals or pollution can decrease fertility or make egg shells thinner.
- Increased radiation, for example, from solar flares and meteorites, can cause mental problems through a reduction in brain size. As dinosaurs already had small brains this could have affected how well they responded to environmental factors. Increased radiation could also cause cancer, infertility and the death of dinosaur embryos.
- Changes to levels of oxygen in the air, for example, high oxygen levels may have increased the metabolic rate of some animals leading to an increased demand for food with the result that many of the larger animals could not find enough food to enable them to survive.

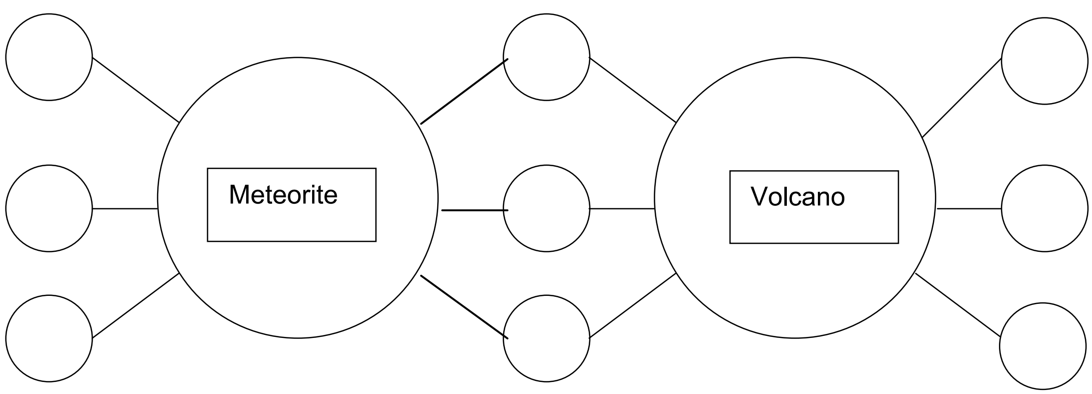
- The evolution of plants resulted in more flowering species, many of which contained toxic alkaloids that may have been lethal to animals. This may have been exacerbated if dinosaurs ate large numbers of plants – see point above.

If pupils find this difficult you can use fewer cards or suggest some headings for the cards.

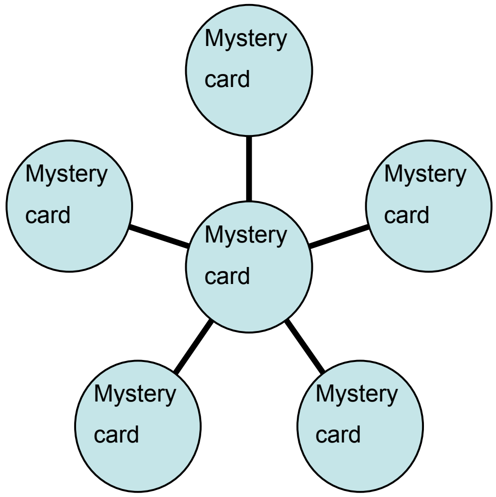
- The mystery cards can also be used in different ways:
  i) Put pupils into groups of three or four. One member of the group mixes up the mystery cards and then deals four cards to each pupil in the group, placing the rest of the cards face-down on the table. The object of the game is for pupils to collect a set of cards that supports only one theory of why the dinosaurs died out, by discarding and picking up cards from the pile in turn. Once they have a complete set they have to explain the link to the others in the group.

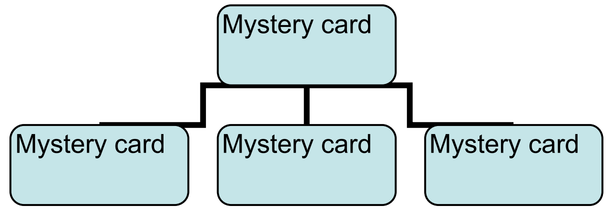
  In both activities ii) below it is not the placing of the cards that is important but pupils' ability to articulate their reasons based on scientific knowledge and understanding. Good questioning by the teacher is vital and it is worth planning some key questions before the lesson.

  ii) Use the cards to construct a graphic organiser diagram. One example is given below in which the circles in the centre will contain points or issues common to both. The circles on either end are for the points that are not similar.



There are a number of different graphic organisers (sometimes thinking maps) that can be used to organise information and two are shown below.



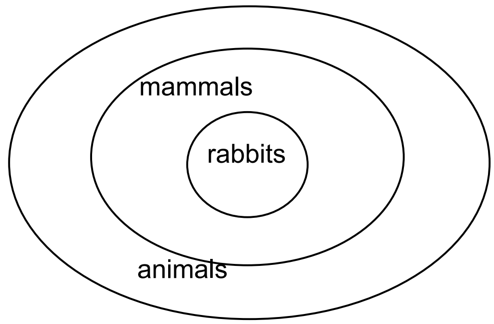


Some suggested questions:

- How did the graphic organiser help you to process, sort or classify the information?
- Was this a good graphic organiser to use? Why?
- Could you adapt the organiser to make it more fit for purpose?
- Could you add some questions to your organiser to clarify or to fill gaps in understanding?
- Could you add links in a different colour to other information or ideas that you know about?

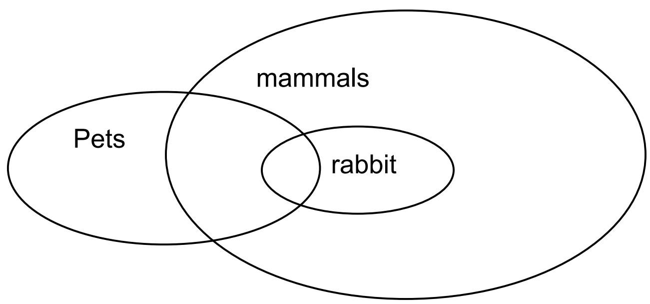
- Relational diagrams can help pupils understand the similarities and differences between terms. This is a useful link to classification as relational diagrams allow pupils to show whether NONE, SOME or ALL of a particular group of things belong to one category. Pupils can be asked to annotate the boundaries to show what distinguishes one area from another.

In many cases there is a correct version of the diagram, based on the recognised definition of terms that may be restricted by pupils' current level of knowledge. In some cases the task may be divergent and different diagrams could be defended on the basis of the interpretation of terms or opinions, for example, some terms could have everyday meanings that are different to the scientifically-accepted ones. This could be tried with terms such as health, safety, risk, hazard or stem cells, embryo, clone, disease.
It is important to model the process for pupils using a simple example of animals, mammals and rabbits.



This shows how a diagram can demonstrate simple relationships between groups and subgroups.

This could be extended by using the categories of rabbits, pets, and mammals and asking pupils to show the relationship as overlapping/non-overlapping circles. Pupils need to consider the relative sizes of the diagrams.



It is the discussion about the organisation of the diagram that is important not the diagram itself. Pupils may have used this type of diagram in other subjects, for example, mathematics which could be useful practice to draw on.

(i) Use the photosynthesis and respiration cards to construct a relational diagram.

One group of pupils presents its diagram to the class and the other groups have a few minutes to discuss it before asking questions

or;

pupils share their diagram with another group to identify and discuss the reasons for any differences.

(ii) Present pupils with a completed diagram and ask them to decide why they agree or not with the placing of the cards or whether they can construct a better diagram.

Some suggested questions

- How did you decide where to put things?
- Has the drawing helped you sort out the meanings of the terms and their relationships?
- Is this more helpful than looking words up in a dictionary?
- Did you need to change your diagram?

B) Model how to change information from one form to another, for example, DARTS activities; turning scientific development into a timeline.

- DARTS (directed activities related to text) are a useful way to ensure that pupils engage with text in a way that promotes understanding.

  These activities are **directed** because pupils are told why they are reading and what they should gain from the experience before they start. They are **active** because they make pupils think and make decisions.

  Handouts from the *Literacy in science* unit are available in the Handouts for developing DARTS. The activities can be used with any written sources of material and are effective in helping pupils make sense of information from text books, newspapers or the Internet.

  - DARTS are useful to encourage pupils to read a text carefully and in detail, to go beyond literal comprehension and to think about what they read.
  - They are popular with pupils as they have a game-like quality.
  - Learning may be implicit and may need to be made explicit.
  - Pupils need to realise that sometimes reading can be demanding and is not a clear-cut task.

  It is important that the technique and purpose match. For example, a long passage about digestion could be used to complete a diagram but it might be more effective if pupils had sequenced the stages beforehand.

- Use the handout Supporting the writing of a conclusion, which contains a number of sheets from the *Literacy in science* unit to support the class or groups of pupils in writing better conclusions.

C) Support pupils in using different thinking grids and organisers to make links between pieces of information.

There are many examples of concept maps, mind maps and graphic organisers that can be used to help pupils make links between pieces of information. Use some of the examples from the Developing critical and creative thinking in science guide.

Moving from step 2 to step 3

Step 2 – Pupil characteristics

Pupils:

- can link the selected data items or evidence to reach a suitable conclusion;
- can produce notes that identify the main ideas and have a clear purpose but do not question the 'authority' of written texts;
- can plan to collect relevant information and data from a variety of sources, both primary and secondary.

Step 3 – Pupil characteristics

Pupils:

- can use criteria to judge the relevance and validity of data items or evidence and use this to support or negate an argument;
- can adopt the most appropriate format for note-taking to represent the information for specific purposes;
- can recognise the potential for bias within sources of information and data.

Strategies to ensure progression from step 2 to step 3

A) Model how to use criteria to decide if particular pieces of evidence are appropriate and to what extent they support or negate the hypothesis.

- Use the Dark Suckers Theory to model for pupils how to use the Evidence decision maker sheet to make choices about whether a piece of evidence is appropriate to the question being asked in terms of reliability and validity. Then pupils use the *Evidence decision maker* to assess a range of conclusions, for example, pupils' own investigations, newspaper articles, Internet sites, television reports, to decide if these are valid conclusions.

- Use the Plate tectonics card sort which is arranged into three groups for this task. The statements may be printed onto different coloured cards. The activity can also be used as a further mystery. Ask pupils to select nine cards at random from the 15 red plate tectonic cards. Then they rank these cards as a diamond nine and draft a suitable conclusion, based on the evidence they have in front of them. Pupils should then have access to each other's work and should discuss why the evidence card at the top of the diamond is where it is, giving some justification for their choice. This could be with another group or to the whole class. It is important that pupils appreciate that the same evidence-base may lead people to form different conclusions.

B) Discuss with pupils the features of particular sources of information that make it appropriate to particular audiences, for example, newspaper and magazine articles for different age groups or professions.

Writing in science can be effective when the writing expectations and purposes are made clear at the start. By considering audience and purpose pupils can become more imaginative in writing about science and develop persuasive, interpretive and argumentative writing.

- Liaise with the English department to see what skills pupils already have in writing for different audiences and purposes.
- Discuss with pupils what constitutes an audience, for example, people of a particular age, from a particular group, or with common interests and what constitutes a purpose, for example, to entertain, inform, explain, persuade and serve a practical need or decorative function.
- Use some of the examples below for pupils to discuss and:
    - agree the criteria for designing a leaflet for parents about why they should stop smoking and use agreed criteria to evaluate the leaflets;
    - review the appropriateness of different graphs for presenting different data sets, for example, line graph, bar chart, histogram, pie chart, scattergraph;
    - match different diets to different people, for example, diabetic, coeliac, pregnant woman, long distance runner, body builder, or energy resources to particular environments and justify the choice;
    - identify the key features of an explanation for a younger pupil on how to carry out a procedure or investigation;

- decide which of a set of given scientific poems is most suitable as an explanation, for example, explaining to a class of six-year-olds how to care for the environment;
- compare how advertisements about a given issue would be different, for example, to persuade people to buy less salty foods if it were aimed respectively at pensioners, parents of young children, teenagers and people with a history of heart disease in the family;
- present both sides of an argument, for example, to a group of mothers with young babies about whether they should use the MMR vaccine or to a supermarket chain about whether they should sell genetically-modified food.

C) Explore with pupils effective ways to make notes from different sources of information.

- Use the handout on Note-taking strategies and ask pupils to identify where they have already used some of the techniques in other subjects and how useful the technique was using a RAG (red, amber, green) rating.
- Model any techniques that pupils have not tried and give them opportunities to try and evaluate these for themselves during lessons.

Moving from step 3 to step 4

Step 3 – Pupil characteristics

Pupils:

- can use criteria to judge the relevance and validity of data items or evidence and use their findings to support or negate an argument;
- can adopt the most appropriate format for note-taking to represent the information for specific purposes;
- can recognise the potential for bias within sources of information and data.

Step 4 – Pupil characteristics

Pupils:

- can evaluate the reliability and validity of others' research, hypotheses and conclusions;
- can transform information into textual, visual and diagrammatic notes that have clarity of purpose and demonstrate critical reflection of ideas;
- can explain why they selected or discarded sources of information or data.

Strategies to ensure progression from step 3 to step 4

A) Create opportunities for pupils to evaluate the appropriateness of a piece of research, theory or other pupils' work and to make valid comments about the conclusion the research or work came to.

- Allow pupils, working in small groups, to decide on three appropriate criteria for evaluating a piece of work or theory. Let them share these with another group and agree three final criteria to share with the class. Agree a class set of criteria to use with some samples of work.
- Present pupils with a number of alternative theories and a short summary about each. Ask them to support or refute the theory using information sources to construct their argument. Possible alternative theories could include:
  - spontaneous generation
  - phlogiston theory
  - the flat Earth
  - the Earth is the centre of the Universe
  - the Lamarck theory of the inheritance of acquired characteristics
  - we see because light rays travel from our eyes to the objects.

All the class could work on the same theory or each group could be given a different theory.

B) Model the part of the scientific process where data is used to develop theories and then build pupils' confidence in being able to adapt or change conclusions in light of new evidence.

- Use the plate tectonic cards.
  Either give pupils the red tectonic plate cards and ask them to draw a conclusion based on that evidence. They may want to use the Evidence decision maker. Now introduce the amber cards and ask whether they need to amend or change the conclusion and if so in what way. Now give them the green cards and repeat the process.
  Or give groups different sets of cards (pupils do not know this at this stage) and ask them to draw a conclusion. Ask groups with different cards to join up and share their conclusions. Ask them to discuss why they have different conclusions and then to use all available evidence to reach a consensus.
- Use the PowerPoint™ presentation Drawing conclusions from graphs as a model to explain to pupils how new evidence can change the shape and therefore the 'story' of the graph. Ask pupils to discuss where this is a good analogy and where it has weaknesses.

- **Pineapple jelly**.

  The purpose of this activity is to improve pupils' understanding of:

  - how scientists work today, including the roles of experimentation, evidence and creative thought in the development of scientific ideas;
  - the importance of testing explanations by using them to make predictions;
  - checking if evidence matches the predictions.

This is a simple context that allows pupils to come up with a range of testable explanations. Some explanations are seen to be implausible following further evidence gleaned by asking questions, for example, real scientists would research journals, talk to colleagues, etc. Scientists only seek evidence by experiment when they have decided that an explanation is supported by all known facts.

The approach below is an example of how to manage the task, but teachers will choose their own strategies with their classes.

Background information

Pineapple jelly made with tinned pineapple sets readily whereas pineapple jelly made with fresh fruit stays runny. The reason for this is that fresh pineapple (in common with some other fruits) contains pectinase that 'digests' the gelatine, preventing the jelly from setting. Tinned pineapple is heat-treated, which destroys the enzyme function.

Stage 1

Towards the end of a lesson, pupils observe small pots of jelly being assembled. Use ordinary edible jelly and make one batch as described on the packet. You will need two containers for each working group (100 ml beakers are suitable).

You will need to have some pineapple pieces from a can and some pieces cut from a whole pineapple. The pieces should be on the same large dish (so as not to give away any clues to the pupils) although the two varieties should be kept slightly separated to avoid pectinase in the fresh fruit contaminating the tinned variety.

Add the fruit to the jelly in the pots. Ensure that half the pots have tinned pineapple and the rest have fresh pineapple.

Safety note: There should be no opportunity for or suggestion that the jelly or pineapple could be eaten. If you wish the pupils to eat the jelly, then transfer the class to a food room for the whole of the activity.

Stage 2

In the next lesson pupils are given the pots of jelly to observe. Make a drama out of the strange mystery that half the pots are still liquid and half are set. Ask the groups to think of some possible explanations. Likely explanations include:

- They were not all kept in the same conditions of, for example, temperature.
- Someone added extra water to some of the pots.
- Some of the pots were not clean and have 'gone off' (germs have got to the jelly).
- Some of the pineapple pieces were old and allowed germs in (many pupils equate liquefying with rotting).
- There was some kind of chemical in some of the pots.

Ask pupils to say how they would find evidence to support their explanation. Tell them that they will be able to ask you and the technician questions about the experiment in a courtroom-style interrogation. They can only ask about what you did, not what you think. They need to construct their questions to ensure they get evidence to support their idea.

Stage 3

The pupils are informed (how this is done is up to the imagination of the teacher) about the two sources of the pineapple. It is, of course, possible that some pupils will have considered this possibility and asked the question.

Pupils are asked to reconsider their explanations in the light of this new evidence.
Likely explanations include:

- The tinned pineapple jellies did set because the tinning process uses chemicals.
- The fresh pineapple jellies did not set because there is bacteria or germs on fresh pineapple that stop the setting process.

Stage 4

After about five minutes, two new pieces of information are introduced. The pupils are told:

- the canning process involves strongly heating the pineapple but not the addition of chemicals;
- jelly is a short name for a protein called gelatine.

Again groups are asked to reconsider their explanations.
This would be a good time to take some feedback. Encourage the pupils to say how they would collect evidence to support their explanation.

Stage 5

The last piece of evidence is introduced as a story (perhaps as a remembered newspaper article):

- Pineapple juice is used to tenderise meat – hence the traditional combination of gammon and pineapple.
- Some people get very sore mouths when eating fresh pineapple.

Groups are asked to come up with their final explanation and suggest how they would gather evidence to support it. Use a whole-class discussion about the range of explanations and tests to model how scientists work. Groups should defend their ideas, explaining their reasoning.

There are possibilities for some challenging debates. For example, some groups will have now decided that the explanation involves enzymes in the pineapple and to test this they may want to heat the fresh pineapple to denature the enzyme as part of a test. However, this will also have the effect of killing ‘germs’ so this approach does not support one explanation over another.

Stage 6

If there is time, pupils set up their tests; alternatively this could be a homework exercise.

Plenary

Discuss how this task has modelled some of the work of scientists.

- There is a phenomenon to be explained.
- Several explanations are suggested based on knowledge and theories.
- Some explanations can be dismissed as further knowledge (evidence) is gained through reading and discussion.
- Evidence is sought to support the most plausible explanations.

- Sometimes it is hard to design an experiment that supports one explanation and refutes another.

C) Transform the same piece of information into various forms and evaluate the purpose and effectiveness of each.

- Use articles from newspapers, text books or produced by pupils and ask different groups of pupils to transform the same piece of information into another suitable form such as:
  - a table
  - a flowchart
  - a spider diagram
  - a picture diagram
  - a cartoon
  - a poem.

  Pupils present their information, in revised form, to the class and then collectively discuss and evaluate which forms are most effective for which purpose.

