Using self-questioning to promote pupils' process skills thinking

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Pupils can be empowered to direct their own thinking if they know how to ask themselves appropriate questions. This article discusses how self-questioning can be used to enhance process skills thinking.

Process skills, which are used in processing information about objects, events and phenomena, are an integral part of scientific enquiry. To develop these skills in pupils, teachers can involve them in using the skills at first hand during science tasks, and scaffold their thinking through questioning and discussion (Harlen, 1996). At the same time, pupils can also be encouraged to use self-questioning as part of 'self-talk'. Because questions help to direct pupils' attention to things that they may not notice or think about, they can nudge pupils towards more productive thinking (Chin, Brown and Bruce, 2002). The purpose of this article is to discuss the use of self-questioning by pupils in developing their process skills in science.

Self-questioning and the role of verbalisation

Verbalisation is a key process that aids the development of metacognition and self-regulated learning habits (e.g. Manning and Payne, 1996). Vygotsky (1962) viewed private speech as the link in the transition from vocal speech to inner verbal thought. According to Vygotsky's theory of verbal self-regulation, speech becomes verbal thought via three stages: external, private and internal speech. During the 'external stage', the activity of the child is directed by the verbalisations of an external agent, for example, a teacher. During the 'private speech' stage, children internalise the external agent's verbal messages and talk aloud to themselves. This private speech is overt, audible speech-to-self and gradually becomes more reflective as it progresses from an external to an internal activity. In the next, 'internal verbal self-regulation', stage, the self-verbalisations become inaudible, silent and covert. The progression through the stages is referred to as movement from an inter-psychological to an intra-psychological plane of functioning. From a Vygotskian perspective, self-regulation is a linguistically guided process in which regulation-through-commands-of-others shifts developmentally to self-regulation.

One of the linguistic tools that can be used in an internal dialogue with oneself is a question. In what follows, examples are given of how different types of self-generated questions can be used to engage pupils in the different process skills. These questions can be used as 'thought-starters' to scaffold and prime pupils in their thinking. Teachers can encourage pupils to ask these questions themselves and practise using them when they are engaged on tasks.

The process skills discussed include observing, comparing, classifying, measuring and using apparatus, communicating, analysing, raising questions, predicting, explaining, formulating hypotheses, inferring and drawing conclusions, evaluating, investigating, problem-solving and decision-making.

ABSTRACT
Process skills are an important aspect of scientific enquiry. The ability to ask oneself questions can elicit and promote self-regulated, reflective thinking. Thus, self-questioning that is directed towards the use of process skills offers much potential in fostering critical thinking in pupils. This article presents a framework for self-questioning that could develop pupils' process skills.

Observing

Pupils with a keen sense of observation (a) use all senses to obtain information about objects and events, (b) use instruments, where necessary, to make more detailed and precise observations, (c) note changes in objects and events which include the whole process and not just the beginning and the end, (d) distinguish relevant from irrelevant observations, (e) pay attention to the order of events, and (f) note exceptions and the unexpected.

To guide their own thinking in making a focused observation, pupils could ask themselves the following questions:

- What do I notice here (in both gross features and details)?
- What instrument(s) can I use to observe this more closely?
- What changes are there (from the beginning, through the transitions, to the end)?
- Is there an order/sequence in what happens?
- Is there anything unusual or unexpected?
- How can I draw what I see?

For example, in studying the structure of a flower, pupils could request a hand lens and note specific details by asking themselves '*How many sepals/petals/stamens /carpels are there?*', '*How are these structures arranged relative to each other?*', '*What is the shape of the stigma?*', '*What is the position of the stigma relative to the anthers?*', '*Does the flower have a scent?*' and '*How can I describe the petals?*'

Pupils can also use instruments (e.g. a ruler) and go beyond qualitative observations (e.g. '*The leaf is big*') to quantitative observations (e.g. '*The leaf is 20 cm long and 10 cm wide*'). When studying the stages in the metamorphosis of a tadpole to a toad, pupils could pose questions about the sequence of physical changes that occur during its development. This includes what happens to the external gills, whether the hind legs or fore legs appear first, what happens to its tail, and on which days these physical changes occur.

Comparing

This involves being able to identify (a) relevant criteria for comparison, (b) similarities between different objects or events, and (c) differences between similar objects and events. Pupils should also be able to appreciate the significance of the similarities and differences. To facilitate comparative thinking, pupils could ask themselves the following questions:

- What criteria can I use to compare A and B?
- What are the similarities and differences between A and B?
- How are A and B similar?
- How are A and B different with regard to each of these criteria?
- What is the significance of these similarities and differences?

To illustrate, let us compare the *Hibiscus* flower with a *Zea mays* (maize) flower. By posing questions on the features of the different floral parts, pupils will note that, despite sharing several similarities such as the presence of similar component parts, there are differences between these two flowers. For example, the *Hibiscus* flower has large, brightly coloured petals and so is attractive, while the maize flower has small bracts instead and no nectar. Another difference is that the *Hibiscus* flower has fairly rigid filaments with firmly attached anthers, whereas a maize flower has flexible filaments with anthers hanging out of the flower. Also, while the stigma of the *Hibiscus* is small and rigid, that of the maize flower is flexible and long and the style is feathery. This comparison should lead the pupil to deduce that these similarities and differences relate to the way the flowers are pollinated.

Classifying

The ability to classify involves recognising a common characteristic in an assortment of objects or a common feature in a set of events, and then grouping them into two or more meaningful categories. Pupils should also identify the basis of classification and specify their criteria for grouping. To hone their skills of classifying, pupils could ask themselves:

- How can I group these objects/events into two or more groups?
- What are the common characteristics that they share?
- What pattern(s) do I see?
- What are my criteria for grouping?
- What classification scheme can I use?

An example would be the classification of elements. Pupils could be given a list of physical and chemical properties of a variety of elements (e.g. physical states, atomic structure, chemical reactivity). They could then try to group the given elements, giving their rationale. This activity could serve as a prelude to learning about the Periodic Table.

Measuring and using apparatus

Measuring devices that pupils should be able to use include the ruler, measuring cylinder, spring balance, thermometer, stopwatch, pipette, burette, vernier callipers, ammeter and voltmeter. They should also be able to use the Bunsen burner, hand lens and microscope. Pupils who are adept at skills in measuring and using apparatus can select the appropriate instruments to measure a given variable, handle the instrument or apparatus correctly, and measure accurately and precisely. They can also record measurements using the appropriate units, make estimates, recognise the variability and reliability of measurements, repeat and check measurements, as well as take measurements across an adequate range. Being able to select a suitable sample size for biology experiments is also an important skill. When measuring and using apparatus, pupils can ask questions such as:

- What instrument can I use to measure and compare differences in length/volume/mass/temperature/time?
- How would I measure accurately?
- What units of measurement are appropriate?
- What would I need to do to make sure that my readings are reliable?
- Do I need to repeat measurements and take average readings?
- What interval, range and scale would I use?
- What is a suitable sample size (for biology experiments)?

Asking such questions can help pupils to think more deeply about the design of their experiments before they begin hands-on manipulation to collect data. For example, consider the experiment on how changing the height of an inclined plane would affect the distance travelled by a toy car after reaching the bottom of the slope. By asking what would be a suitable choice of values for the range and interval for the height of the inclined plane, pupils might think about what difference it would make to their findings if they chose a range of 1.0 to 5.0 cm with 1.0 cm intervals, as compared to 10.0 to 50.0 cm with 10.0 cm intervals.

Communicating

There are several ways in which pupils can describe and represent an object, event, concept, idea or plan. This includes the oral, written, pictorial or graphic modes. Pupils should be able to use various symbolic representations such as text, diagrams, tables, charts, graphs and keys to communicate their ideas, as well as use scientific vocabulary appropriately.

When communicating their ideas, pupils should consider various ways of presenting the information. They can ask themselves the following questions:

- What is the most suitable way of presenting this information?
- How can I best tell others what I have done and found out?
- How would I represent this information (text, drawing, diagram, table, graph, chart, keys, display or model)?
- How can I present the information in various ways (oral, visual, concrete 3-dimensional models, multimedia)?
- How can I communicate this information using the appropriate scientific vocabulary?

Different types of information lend themselves to different forms of presentation. For example, underlying relationships between variables and the associated patterns are best communicated via a table of numbers and graphs or charts. Likewise, details of anatomical and morphological features of organisms are best represented visually in the form of labelled drawings instead of copious text.

Analysing

Pupils can analyse (a) parts-to-whole relationships, and (b) patterns and trends in data, including relationships between variables. They should be able to see how the different pieces of information are related as a whole.

Parts-to-whole relationships

This involves identifying the component parts of a system and understanding how they are related to each other. Examples include the reproductive system in plants, the circulatory system in humans, the laboratory set-up for distilling a mixture of water and ethanol, and mechanical systems. Questions that can stimulate analytical thinking include:

- What parts make up the whole system?
- What is the function of each part?
- What happens to the system if the part is missing?
- How do the parts work together to make the whole?
- How do these parts affect one another?
- How are these parts related to one another?

In analysing the parts and functions of the human circulatory system, for example, pupils would be guided to think through the roles played by the heart, blood vessels, valves of the veins, red blood cells, white blood cells, and how each part contributes to the efficient functioning of the whole system.

Patterns and trends in data and relationships between variables

To discern patterns and trends in data, pupils need to identify the variables at play and study the relationship between the variables. A variable is a factor that can be changed or manipulated. There are three kinds of variables: the independent (manipulated, changed) variable, the dependent (responding, outcome) variable, and the control (controlled variable) which is kept constant.

To analyse the relationship between variables, pupils need to note the numerical data given in tables, bar charts or graphs. They need to study the labels and column headings of a table or the axes of a graph, the units of dimension, range and interval of values for each variable, sequence of data (increasing or decreasing values), corresponding match between data in table columns or patterns in a graph, and the nature of the relationship (direct, inverse or none) between the sets of data. The aim is to analyse what happens to the dependent variable as the independent variable changes, and then state the relationship between them. To identify patterns and trends and the relationship between variables, pupils can ask themselves:

- What are the variables involved here?
- What is the relationship (direct, inverse or none) between variables A and B (e.g. for tables, charts and graphs)?
- What pattern and trend do I see here (e.g. for tables, charts and graphs)?

For example, in the extension of a spring, the variables involved would be the load or force applied (independent variable) and extension of the spring (dependent variable). When a table or graph of extension of spring versus load is plotted, pupils should note that the extension of the spring is proportional to the applied force, provided the force is not large enough to stretch the spring permanently. Other examples include the relationship between the length of a pendulum and its periodic time, the current passing through a wire and the potential difference between its ends, and how different surface areas affect the rate of reaction between dilute hydrochloric acid and calcium carbonate.

Raising questions

The ability to pose productive questions can advance one's thinking. Pupils can reflect on what they have learnt and pose questions about things that puzzle them, such as:

- What questions do I have about this?
- Is there anything that I am puzzled about?
- What else would I like to know about ...?

Chin (2004) discusses several strategies that teachers can use to stimulate pupil questioning. These include asking pupils to write their questions, providing pupils with suitable stimuli, modelling question-asking, developing a receptive classroom atmosphere that encourages question-asking, and including question-asking in evaluation.

Predicting

A prediction is a statement about what may happen in the future that is based on some hypothesis or previous knowledge. It is based on thoughtful observation, noting patterns, one's mental models, and inferences made about the relationships between specific variables of interest. Pupils may predict a qualitative outcome (based on a given demonstration, imagined scenario, or picture), the next step in a sequence of events, or a quantitative outcome involving interpolation or extrapolation of numerical data from a table or graph. Questions that prompt predictive thinking include:

- What would happen if ...?
- What do I think might happen next?
- If variable A is increased, what do I think will happen to variable B?
- How will changing variable A affect variable B?

For example, before carrying out a laboratory activity on the germination of seeds, pupils could predict what would happen if bean seeds were given water and air, and left at room temperature in a dark cupboard. Those who predict that sunlight is a necessary condition for germination would experience a conceptual conflict and may be stimulated to think about why sunlight is not essential. A diagram of a food web could serve as a pictorial stimulus when pupils are asked to predict what would happen to an ecosystem if a given new organism were introduced into the environment (e.g. releasing the piranha fish into a lake or river which does not have any). An example of predicting numerical data from a table or graph would be an investigation of the effect of changing light intensity on the rate of photosynthesis of a water weed such as *Elodea*. Pupils could ask '*If the light intensity is increased, what will happen to the rate of photosynthesis?*'

Explaining

When pupils generate an explanation, they are attempting to give a reason or refer to a theory to account for why or how something happens the way it does. Questions that they can ask themselves include:

- Why does ...?
- Why do I think this happens?
- What causes this to happen?
- What are some possible reasons for ...?
- How can I explain ...?

As an example, consider a situation where pupils have to explain why a person's heart does not beat at the same rate all the time. In having to think about the possible reasons and causes for this, pupils would consider the conditions under which a person's heart rate would increase and the physiological mechanisms that cause this to happen. They could be prompted to think about the roles played by the circulatory, respiratory, nervous and endocrine systems, and how they function in a coordinated manner to bring about the observed phenomenon.

Formulating hypotheses

A hypothesis is a statement that attempts to explain some observation or happening in terms of a principle or concept. Unlike a wild guess, which is based on uninformed opinion, a hypothesis is a reasoned statement based on prior knowledge and experience. It could also be a prediction about the relationship between variables, such as a prediction about the effect of an independent variable on a dependent variable. A hypothesis is tentative in nature and needs to be tested empirically. If subsequent observations and data support the hypothesis, it is tenable; if not, it is rejected. To construct a hypothesis, we would first identify the variables involved and then state how they might be related. A hypothesis could be stated in one of the following ways:

- If ..., then ...
- If [independent variable] increases/decreases, then [dependent variable] will increase/decrease.
- As [independent variable] increases/decreases, the [dependent variable] will increase/decrease.

Questions that encourage hypothetical thinking include:

- Why do I think ...?
- What do I think will ...?
- What factors might affect how ...?
- What is the independent variable?
- What is the dependent variable?
- What is the relationship between these two variables?

Consider the problem '*What affects how quickly an object will fall through a liquid?*' To formulate a hypothesis, pupils first identify the independent variables that might affect the speed at which an object falls. They may suggest factors such as the volume of the object, shape of the object, mass of the object, density of the object, type of liquid, amount of liquid and temperature of liquid. They then construct a hypothesis showing the relationship between the two variables of interest (i.e. the independent and dependent variables). A possible hypothesis is '*As the surface area of the object increases, the slower it falls through the liquid*'.

Inferring and drawing conclusions

An inference is an interpretation of an observation based on evidence, reasoning and what is known from past experience. Making an inference involves synthesising various findings so that patterns or relationships between factors are discernible. An example is when a pupil infers that '*stomata are found mainly on the underside of a leaf*' when he or she observes more air bubbles coming out from the bottom of a leaf when it is dipped into boiling water. A conclusion is a summary of all the inferences that one makes. To elicit inferential thinking, pupils can ask themselves:

- What can I infer based on this information?
- How would I interpret this information?
- What is the connection between ...?
- What might have caused ...?
- What conclusion(s) can I reach?

Evaluating

Pupils sometimes need to make judgements about (a) the accuracy of data, (b) the quality and feasibility of an idea, (c) whether a hypothesis or an inference is supported by observations, (d) the effectiveness of a method, or (e) the quality of a product. Evaluative thinking can be stimulated by asking oneself the following questions:

Quality of information or data

- Is this information/data accurate?
- Is the information/data reliable?
- Is the information/data/conclusion valid?

Quality of idea or method

- Is the hypothesis/inference supported by observations/data/evidence?
- Is the idea or method feasible/workable?
- Is the method effective?

Quality of product

- What are the pros and cons of this, compared with other alternatives?
- What are the pros and cons of the given options?
- Which is better/the best? Why? Based on what criteria?

An example would be when pupils are asked to evaluate which of two graphic representations, a bar chart or line graph, would be more suitable for presenting their findings on how different materials wrapped around a beaker of hot water affect the rate of cooling of the water. For both representations, the horizontal axis denotes the different types of material (e.g. paper, plastic, rubber, aluminium foil) while the vertical axis denotes the temperature drop in 20 minutes. Pupils who understand the difference between categorical and continuous variables would choose the bar chart in this case.

Investigating

An investigation often involves designing a set-up or situation to gather data to test a hypothesis. Pupils need to define the problem, formulate a hypothesis, identify the variable to be changed (independent variable) and the response to be expected (dependent variable), as well as decide which factors to control or keep constant and how to do this (idea of fair test). They also need to define operationally both the independent and dependent variables, and decide how to measure them.

Pupils also have to devise a method of collecting data such as deciding what materials and equipment to use and ordering the steps to take. In the case of quantitative data, they have to decide on the number, range and interval of values to use for the independent variable, take repeated measurements and compute averages. For biological samples, it may also be necessary to decide on sample size to account for inherent variation among organisms. Pupils also need to think about how to record and present findings, conduct the investigation, interpret the data and reach conclusions.

The following questions provide a scaffold for the self-questioning process when pupils work on investigations:

- What question(s) do I have about ...?
- How would I design an investigation to find out ...?
- What is the aim of the investigation?
- What am I trying to find out?
- What are the variables involved?
  - What is the variable that I have to change (independent variable)?
  - What is the variable that I expect to respond (dependent variable)?
  - What are the controls (factors to keep constant)?
- What do I think will happen?
- What is my hypothesis?
- What materials and apparatus do I need to use?
- What would I measure and how would I do it?
  - What interval and range of values am I going to use for the independent variable?
  - How many measurements do I need to take?
- What did I observe/find out?
- How would I present my findings (text, drawing, table, graph, chart)?
- What pattern(s) do I see?
- What can I say/infer about ...?
- How would I interpret my findings?
- What conclusion(s) would I reach?
- Is my hypothesis supported by the data?
- What improvements would I make?
- Why do I think ...?

As an example, consider the problem of how temperature affects the rate of enzymatic activity of pepsin on egg albumen. A possible hypothesis might be '*The higher the temperature, the faster the rate of enzymatic activity*'. The independent variable here would be operationally defined as the temperature, and the dependent variable would be the time taken for the pepsin–egg albumen suspension to change from cloudy to clear. The same volume and concentration of pepsin and egg albumen are used, the same conditions such as the pH should prevail, and the temperature would vary.

Pupils will have to decide on the values of the independent variable (i.e. temperature) to select and plan how to carry out the investigation. In this investigation, it is important that pupils decide on a suitable range of temperature (e.g. 20–60 °C at 5 °C intervals) that includes values both above and below the optimum temperature. This will allow them to collect the necessary data for a more meaningful interpretation.

Problem-solving

When confronted with a problem, pupils need to (a) analyse the problem situation by identifying parts of the problem and its constraints, (b) think of alternative ideas, (c) evaluate the solutions by judging the quality and feasibility of ideas and selecting the best solution, and (d) try out the solution to see if it works as expected or if it has to be modified. The following questions can be used as a guide for the self-questioning process:

- What is the problem?
- How can I break this problem into smaller parts?
- What are possible solutions to the problem?
- What are some limitations of these solutions?
- What would be the consequences if the solution is adopted?
- What is the best solution to the problem based on the information that I have?

As an example, imagine that one is being confronted with the problem of having to keep a given perishable food (e.g. celery) fresh for as long as possible. One might consider the factors that affect the shelf life of the food (e.g. temperature, pH, humidity, salinity, presence of bacteria) and the chemical processes that are involved in its decay (e.g. role of enzymes), as well as the advantages and disadvantages of various methods of preservation using various criteria (e.g. effect on flavour, effect on health, time needed, cost-effectiveness, convenience).

Decision-making

When deciding what to do about a problematic situation or dilemma, one needs to (a) define the problem, (b) list all options available, (c) anticipate the consequences of each option, if selected, (d) evaluate the options by establishing and prioritising criteria and then judging each option against these criteria, and (e) make a choice, giving reasons. Examples of questions that pupils can ask include:

- What is the problem/dilemma?
- What are the options?
- What are the likely consequences of each option?
- How important are the consequences?
- What are the pros and cons of each option?
- What criteria are relevant and important to help me decide which option to choose?
- Which option is best after taking everything into consideration?

An example would be when pupils have to decide what they would do if they were a politician who had the power to sanction or prohibit research on cloning and stem cells. They would need to think about the options they could choose and the extent of research they might permit. They would also have to identify the criteria associated with making this decision. These might include cost, resources, manpower, need, usefulness, benefits and acceptability. They would also have to think through the likely consequences and weigh the pros and cons of each option in terms of economic, socio-political, bio-ethical, religious and other aspects. Finally, they would make a decision about which option they consider is best.

Table 1 gives a summary framework with sample questions for each process skill.

Conclusion

Self-questioning, used as a metacognitive or reflective tool, can steer pupils' thinking when they are engaged on tasks. Such verbal articulations have the potential to help pupils become more independent and self-regulated learners because they stimulate deeper thinking. With constant practice over time, self-questioning by pupils may become a good mental habit.