Open Investigations in Science: Posing Problems and Asking Investigative Questions

Christine Chin

Abstract

To carry out an investigation, one must first pose a researchable problem and ask investigative questions. However, this is a difficult task for many students who are more accustomed to having the problem given to them. Furthermore, the questions that students ask are sometimes non-investigable. This paper offers suggestions on how teachers can help students formulate problems and questions that are feasible for investigations. A typology of investigable and non-investigable questions is also given.

A problem well stated is a problem half solved.
(Charles F. Kettering)

Introduction

Given the current emphasis on inquiry, thinking skills, and self-directed learning, open-ended investigations are becoming increasingly important in the science curriculum. In such investigations, students pose the problem to be investigated and design their own procedures to answer the question. Sometimes, more than one design, solution, or answer are also possible. However, this is a new experience for many students in Singapore, who are typically provided with well-defined problems and the aim of the investigation. Students seldom identify a researchable problem or pose the investigative question themselves (Chin, Goh, Chia, Lee & Soh, 1994; Lee, Tan, Goh, Chia & Chin, 2000).

Research by Chin and Kayalvizhi (2002) on local Primary 6 students, also found that the students experienced some difficulty in posing problems for open investigations, and particularly in generating investigable questions (i.e. questions that lend themselves to practical investigations). Accordingly, the purpose of this article is to offer practical suggestions on how teachers can help students to pose problems and questions that are feasible for investigations. A typology of
investigable and non-investigable questions is also proposed, as a guide to teaching
science investigations.

Posing Problems and Asking Questions for Investigations

An investigation is “an experimental study that requires first-hand student partici-
pation and leads towards providing evidence that permits a question, posed at the
outset, to be answered” (Lock, 1990). Problems for investigations can be well-
defined or ill-defined. They can be (a) given problems, where the solvers are given
both the goal and strategies; (b) goal problems, where the solvers are given the goal
but have to decide and develop their own strategies; and (c) own problems, where
solvers generate and decide on both the goal and the strategies themselves (Watts,
1991). For ill-defined problems, the investigation begins with a search for the “prob-
lem space” (Newell & Simon, 1972). This involves the construction of a mental
representation of the problem using existing schemata perceived as relevant by the
problem solver (Appleton, 1995), and includes the scale of the problem and size of
the tasks involved. During the problem identification or problem posing phase,
students formulate questions which drive the subsequent investigative process.

To carry out investigations, researchable questions are required. These could
come from the teacher, science activity books, or even the students themselves. When
students work on investigations stemming from their own questions, they
are generally more enthusiastic. Students’ ideas for their problems and questions
can arise during other pre-planned activities (Keys, 1988). Students can either
change the teacher-directed activity or invent questions from their own imagina-
tions. Original questions can surface spontaneously from group discussions about
experiences with previous science lessons and everyday life. Students’ questions
often arise from a gap or discrepancy in their knowledge or a desire to extend
knowledge in some direction. Such questions may stem from curiosity about the
world around us, and spring from a deep interest or arise from an effort to make
sense of the world (Scardamalia & Bereiter, 1992).

Inspirations for students’ problems can also come from (a) curious events, or
observations that cannot be explained by habitual responses, (b) data gaps, or
failure to find observations that have been predicted by a theory or law, and
(c) chance observations (Wilson, 1974). Other sources of students’ ideas for inves-
tigative projects include passing thoughts, fleeting concerns, phobias, obsessions,
or fascination with media-related characters (Katz & Chard, 1998), as well as
chance events in family life, significant hobbies or interests (Tytler & Swatton,
1992). Some problems can also arise from societal issues, such as conservation of
the natural environment. Whatever the source, the process of problem discovery
often stems from students’ interactions with real-world issues, and the desire to
find out something relevant to their personal lives, as part of their curiosity and
inquisitiveness.
Feasibility of Students' Questions for Investigations

Not all questions asked by students are amenable to practical investigations. Investigable questions refer to those that allow students to generate and collect some original data, analyse and interpret their findings based on these data, and finally make a conclusion that addresses the investigative question posed, on the basis of available first-hand evidence. Questions to which students can find out the answers by simply asking someone, or looking up a book or other secondary sources, and which do not involve manipulating with concrete materials, apparatus, or instruments are considered non-investigable. "Virtual investigations" that involve manipulation using computer simulations, for example, would also be considered investigable.

Symington (1980) found that more than half of the questions children asked did not lend themselves to "hands-on" practical investigation. Roth and Roychoudhury's (1993) study of 14- to 18-year-olds found that the students usually began with very unfocused questions. However, with time, the students grew more adept at coming up with researchable questions. The study by Chin and Kayalvizhi (2002) found that when Singaporean Primary 6 students were required to pose their own questions for investigations, some students faced difficulty in producing questions during the question-posing sessions and were unable to come up with any. When the questions were asked individually before the students were shown examples of investigable questions, only 11.7% of the questions could be answered by performing hands-on investigations. Most of the questions asked were based on general knowledge and covered a wide range of topics, of which 36.7% of the questions were related to topics that were not formally covered under the school science syllabus (viz. aerodynamics, communications technology, evolution, and religion) or where only some aspects were covered (viz. the solar system and universe, and weather).

However, when the students were asked to pose questions in groups after the teacher had shown them examples of investigable questions, there was a significant increase in the percentage of the questions (71.4%) that were amenable to science investigations, but they were related to a narrower range of topics (viz. chemistry, energy, force, heat, light, plants), all of which were covered in the school science syllabus. This suggests that showing students examples of investigable questions can help them to generate such types of questions. Also, for practical reasons of implementation in class, teachers can ask students to brainstorm their questions individually first, and then redefine the questions in groups so that they would be more focused and investigable.

Generating Investigable Problems and Questions

Given the above findings that students have difficulty in posing investigable problems and questions, the following suggestions are given in order to help students formulate a suitable problem or question to investigate.
(i) Teach students the nature of various investigations, and the different types of investigable and non-investigable questions.

(ii) Teach students the concepts and language associated with investigations.

(iii) Guide students to transform their non-investigable questions to investigable ones through teacher questioning and discussion.

(iv) Tap on students’ prior knowledge and personal interests. Help them to link what they already know to what they would like to find out.

(v) Create a conducive environment that encourages problem-posing and question-asking.

Teach Students the Nature of Investigations and Different Types of Questions

Teach students to distinguish between investigable and non-investigable questions, and to recognize how different kinds of questions can lead to answers being sought in different ways. For example, some questions are answered by detailed observation of changes over a period of time, while others may require the fair test model of experimentation, conducting surveys, or making prototypes and models. Table 1 shows a typology of questions, including examples, which could serve as a guide in teaching students the different kinds of problems and questions that can be posed for investigations.

Non-investigable questions include those that demand basic information or complex information, and those that involve philosophical or religious views. Basic information questions request for simple information or basic facts, and the answers can typically be found by referring to books or searching the World Wide Web, or by asking someone (e.g. “What is the mirror made of?”). Complex information questions are more difficult to answer, and require complex information and explanation for a full answer that is sometimes conceptually beyond a child’s understanding. They are often of the explanatory “Why” type that ask for some sort of explanation, or the “How” type that probe an underlying mechanism. Examples include “Why are there rain, thunder, and lightning and what causes them?” and “How do satellites transmit information so quickly?”. Such questions typically cannot be answered by simply performing an investigation, as their answers often involve postulating abstract, conceptual models that explain cause-effect mechanisms, constructing theoretical entities, and theorizing at the microscopic or molecular level rather than the macroscopic level. Philosophical or religious questions are those with no clear-cut answers (Harlen, 1996) or are not answerable by science. An example would be “Are there really ghosts on earth?”. Investigable questions include (a) comparison, (b) cause-and-effect, (c) prediction, (d) design-and-make, (e) exploratory, (f) descriptive, (g) pattern-seeking,
Table 1.
A typology of investigable and non-investigable questions.

<table>
<thead>
<tr>
<th>Type of question</th>
<th>Example of question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-investigable</td>
<td></td>
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<tr>
<td>a) Basic information</td>
<td>What is the mirror made of?</td>
</tr>
<tr>
<td>b) Complex information</td>
<td>Why are there rain, thunder, and lightning, and what causes them? How do satellites transmit information so quickly?</td>
</tr>
<tr>
<td>c) Philosophical/religious</td>
<td>Are there really ghosts on earth?</td>
</tr>
<tr>
<td>Investigable</td>
<td></td>
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<tr>
<td>a) Comparison</td>
<td></td>
</tr>
<tr>
<td>• Make-a-choice</td>
<td>Which type of lipstick is the most long lasting?</td>
</tr>
<tr>
<td>• Classification</td>
<td>Which of these materials will float on water?</td>
</tr>
<tr>
<td>b) Cause-and-effect</td>
<td>How does temperature affect the rate at which enzymes work?</td>
</tr>
<tr>
<td>c) Prediction</td>
<td>What would happen to the rate at which a basketball bounces if I pump more air into it?</td>
</tr>
<tr>
<td>d) Design-and-make</td>
<td>How can I make an automated device that would clean used overhead transparencies as efficiently as possible?</td>
</tr>
<tr>
<td>e) Exploratory</td>
<td>What are some factors that affect the growth of plants?</td>
</tr>
<tr>
<td>f) Descriptive</td>
<td>What changes occur during the life cycle of a butterfly?</td>
</tr>
<tr>
<td>g) Pattern-seeking</td>
<td>What is the relationship between the type of plants and where they are found in the forest?</td>
</tr>
<tr>
<td>h) Problem-solving</td>
<td>How can I identify and distinguish these three unknown clear solutions?</td>
</tr>
<tr>
<td>i) Validation of mental model</td>
<td>How can the transformation of energy be modelled using a series of concrete materials?</td>
</tr>
</tbody>
</table>

(h) problem-solving, and (i) “validation of mental model” questions. Comparison questions comprise the “make-a-choice” type or the classification type. In the make-a-choice type of question, students compare a given characteristic from among a number of items and make a selection (e.g., “Which type of lipstick is the most long lasting?”). Classification questions require students to compare the properties of several substances and group them into categories based on some observable or testable characteristics. An example is “Which of these materials will float on water?”.

Cause-and-effect questions such as “How does temperature affect the rate at which enzymes work?” allow students to make inferences about how one variable affects another variable. The variables being considered are often continuous in
nature, and can take on a range of values. To answer such questions, the common fair test or control-of-variables framework is often used. For questions of this type, students can be taught to generate "if ..... then" statements when formulating their hypotheses.

Prediction questions include those that ask "What would happen if .....?" "How does ..... affect the .....?" and "What would be the effect of .....?". Such questions encourage thinking about the interplay of variables, simple hands-on experimentation of relationships between variables, and the prediction of outcomes as a result of manipulations or changes in variables. An example would be "What would happen to the rate at which a basketball bounces if I pump more air into it?". Prediction questions of the type that ask "What would be the effect of .....?" also pertain to cause-effect relationships and lend themselves to investigations that involve fair testing. However, unlike questions in the cause-and-effect category which seek an underlying relationship between variables, the focus of prediction questions is on the observational outcome of an event (what is seen), rather than the relationship between the variables (how they are related in terms of patterns and trends).

Design-and-make questions are technological in nature and relate to building something for a utilitarian purpose. The goal is to manipulate variables to produce a desired outcome rather than to investigate the underlying factors involved. An example would be "How can I make an automated device that would clean used overhead transparencies as efficiently as possible?"

Exploratory questions involve preliminary exploration about cause-effect relationships. However, unlike cause-and-effect questions which specify which particular variables are of interest, exploratory questions are not quite focused yet. There is some groping around on the part of the questioner, as he or she attempts to delimit the problem space. An example would be "What are some factors that affect the growth of plants?"

Descriptive questions require students to observe some object or event closely and describe it in depth. They are appropriate for investigations that require students to make a series of detailed observations and rich descriptions of objects and phenomena, or changes that occur over some time, either in natural settings or in controlled situations. Examples include the study of the variety of insects inhabiting the school garden, the germination of a seed and its subsequent growth, the life-cycle of an insect or frog, and the study of temperature and other physical changes when heating ice through water to steam.

Pattern-seeking questions are suited to surveys that deal with natural biological phenomena, such as those dealing with ecological systems, the weather, or genetics, where students cannot manipulate or control factors easily. In such cases, the choice of a suitable sample size is important to account for natural variation within samples, if students are to make conclusions about correlations between variables with some confidence. Such questions include "What is the relationship
between the type of plants and where they are found in the forest?”, and would stimulate students to propose causal links.

Problem-solving questions of the “Can you find a way to ....?” type invite students to integrate and apply their knowledge in new and creative ways to solve a problem. For example, “How can I identify and distinguish these three unknown clear solutions?” requires students to devise a method or procedure to solve a given problem. Unlike design-and-make questions which focus on technological problem-solving and the production of an artefact, questions in this problem-solving category seek a feasible method of implementation.

The category “validation of mental model” is an extension of the “investigating models” category of Watson, Goldsworthy and Wood-Robinson (1999) in that students test their mental or conceptual models against some evidence, and this may lead on to one or more of the preceding types of investigations. Such questions stem from students’ quest for understanding something puzzling and their desire to explain why something happens or how something works. To explain such phenomena and test or validate if their mental models are tenable, students carry out an investigation and check for the goodness-of-fit between their postulated models and the evidence obtained. To carry out such an investigation, the mental model postulated should lend itself to some hands-on activity which provides data for students to check for congruence between the evidence and their model. An example would be “How can the transformation of energy be modeled using a series of concrete materials?” To answer this question, students might work on designing an artefact that shows how energy can be transformed from one form to another.

**Teach Students the Concepts and Language Associated with Investigations**

Students can also be taught the concepts associated with investigations such as hypothesis, control, independent, and dependent variables. They then have the linguistic tools to work with as they articulate their ideas. One practical way of helping students to generate investigable questions is based on the idea of “operational questions” (Alfke, 1974). Such questions help students to identify, control, and manipulate variables through (a) eliminating, (b) substituting, and (c) increasing or decreasing the presence of a variable. They are particularly useful for investigations which involve fair-testing. The questions lead to a task which allows the student to work with materials and obtain first-hand evidence.

A question such as “How does a change in temperature affect the amount of salt that dissolves in water?” would be operational. We could eliminate the effect of heat by carrying out the experiment at room temperature, substitute the effect of heating by stirring instead, and increase or decrease the temperature by using a range of temperatures. However, a question such as “Why does salt dissolve in
water?” would be non-operational as it cannot be easily answered by first-hand experimentation and is more abstract, requiring theoretical explanations.

We can also teach students that differences in wording and formulating a question influence whether the question is investigable, the type of investigation to be carried out, and the methods employed in answering the question. For example, “Why does a candle melt when we burn it?” is non-investigable. The question, “Does a smaller candle begin to melt sooner than a bigger one when it is lighted?” requires only a qualitative direct comparison, as testing with a small and a big candle is sufficient to answer the question. However, the question, “How does the size of a burning candle affect how long it lasts?” requires a more quantitative approach and encourages students to explore relationships more fully.

Teachers could give examples of question stems and illustrate how they can be used. Examples include “How does ... [independent variable] ... affect the ... [dependent variable]?” (cause-and-effect), “What would happen to ... if ...” (prediction), “How can I make a device to ...” (design-and-make), and “What is the relationship between ... and ...” (pattern-seeking).

Guide Students Through Teacher Questioning and Discussion

Teachers can also help students to reformulate non-investigable problems and questions by asking questions that direct them to modify their problems. Such questions include “productive” questions (viz. attention-focusing, measuring, comparison, action, and problem-posing questions) which stimulate productive physical or mental activity (Elstgeest, 1985).

Teachers can also acquaint themselves with a range of questioning strategies that can probe students’ thinking, provide scaffolding, and nudge them towards finding a feasible problem to investigate. See Chin (2000) for a more detailed discussion on teacher questioning. Teachers can also use the “variables scan” strategy (Jelly, 1985) to consider ways in which a non-investigable situation or question could be varied, and turned to a productive one that results in practical activity.

Consider the following example as an illustration of how teachers can use productive questions and variables scan to help students transform a non-investigable question to an investigable one.

Student: My question for investigation is “Where do soap bubbles come from?”
Teacher: Well, soap bubbles must come from soap. What else could you find out about soap bubbles? (problem-posing)
Student: I would like to find out “How long can soap bubbles last?”
Teacher: How about comparing different types of soap? (comparison)
Student: Yes, I could experiment with hand soap, bath foam, hair shampoo, and dishwashing liquid.
Teacher: Besides using different kinds of soap, what other variables might affect how long the soap bubbles last? (variables scan)

Student: Maybe the concentration of the soap solution, the purity of the soap solution, etc.... I could also try adding substances such as water, glycerine, salt, sugar.... I think I would like to find out "Which type of soap solution will give bubbles that last the longest?"

Teacher: Well, that's an interesting question to investigate. How would you go about preparing the different types of soap solutions? (action). And how would you measure how long the soap bubbles last? (measurement)

From the above excerpt, we see how teachers can guide students to reformulate an initially non-investigable question, "Where do soap bubbles come from?" to "Which type of soap solution will give bubbles that last the longest?" which is investigable.

**Tap on Students' Prior Knowledge and Personal Interests**

Teachers can start from what students already know and link this to what they would like to find out. Students' prior knowledge and experiences from daily life often provide fertile ground for investigative ideas, especially those set in contexts which are personally meaningful, relevant and interesting to them. These contexts can revolve around family-based happenings, hobbies, media and events, the environment, and contemporary issues of interest.

**Create a Conducive Environment that Encourages Problem-Posing and Question-Asking**

Teachers need to provide a climate of inquiry that fosters question-asking. Biddulph, Symington and Osborne (1986) suggested providing students with suitable stimuli, modeling question-asking, and developing a receptive classroom atmosphere. Teachers can use anomalous happenings and materials that do unexpected things as question stimulators, and students can be put in contact with a wide range of interesting materials and given the opportunity to ask questions (Jelly, 1985). Students can then generate ideas as a result of observations of events or phenomena, manipulation with objects, and wonderment or curiosity about something puzzling and engaging.

Students can set up two columns in their notebooks or learning journals, with the first labeled "observation" and the second labeled "questions", and then record any questions that they have. They can also use a "question board" to display their questions relating to the topic being taught which may then be used as
starting points for scientific investigations. They can also establish specific “free question times” within a lesson, a question “brainstorm” at the start of a topic, the use of a “question box” where students can put in their questions, a “problem corner” in the classroom, and encourage students to supply “questions of the week”. For a more comprehensive discussion on strategies for encouraging student-generated questions, see Chin (2002).

What is a “Good”, Investigable Question?

We can use the following four criteria, based on the acronym DIPU, to help us determine whether a question posed is “good” for an investigation:

D: Is the question doable, feasible?
I: Is it interesting, challenging, stimulating, motivating to students?
P: Is it practical in terms of difficulty, time, and resources?
U: Is the answer unknown to students?

First, the question should be amenable to hands-on, manipulative activities where students can collect and process some original data to answer the question posed. Second, the question must be interesting and challenging, both practically and conceptually. It should also be meaningful and appealing to the students in order to sustain their interest. In addition, it should provide opportunities for critical and creative thinking, and lead to the acquisition of conceptual and procedural knowledge.

Third, for practical reasons of implementation, the question must be developmentally appropriate and not too difficult. The investigation should also be manageable in the time available, and not require the use of expensive or hazardous materials, the use of unavailable sophisticated equipment, or complex analytical techniques. Fourth, the question should lead students to find out something which is previously unknown to them. This is genuine exploration and discovery, and what real scientists do. Furthermore, venturing into the unknown marks the excitement of learning.

Conclusion

Posing a worthwhile problem to investigate and generating good investigative questions is not always easy, neat, or straightforward. It can be a circuitous pursuit, requiring imagination, critical and lateral thinking. However, it is an essential first step in carrying out an open-ended investigation. We have often emphasized the importance of teaching problem-solving skills to our students. However, since the nature, feasibility, and meaningfulness of an investigation are determined by the kind of problem and question formulated, we should also teach our students
how to pose problems and ask questions. As Eugene Ionesco, the playwright, had so aptly put it: "It is not the answer that enlightens but the question".

Christine Chin is an Assistant Professor in the Science and Technology Education Academic Group at the National Institute of Education, Singapore. Her research interests include students' learning approaches in science, problem-based learning, learning strategies and thinking skills.

References


