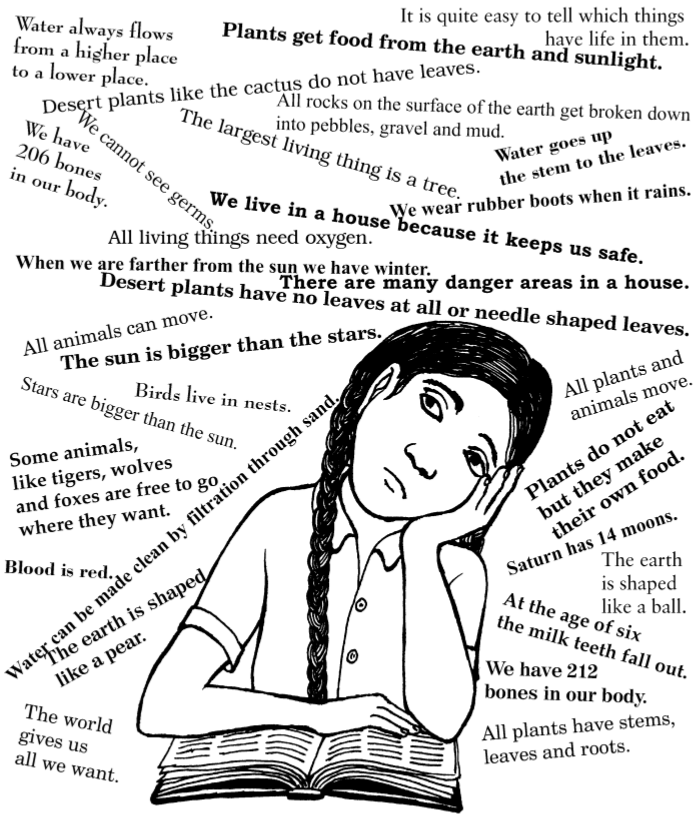
Why do we have problems learning and teaching science?

Karen Haydock
haydock@gmail.com
www.khaydock.com



Many of us who have been struggling to teach have common ideas about why our work is so difficult. The most obvious complaints are work overload, inadequate pay (in most cases), too many duties, too many students in each class, too many classes in each day, not enough time for individual attention, too many corrections, we do not have proper training, and students have poor skills and backgrounds. These are the most important problems we face as teachers, and together with students and parents we must demand that these problems be solved. The solutions are primarily economic. Since the government in any forward-looking country should be responsible for providing free high-quality education to all, and since this is not very expensive even for a poor country[1], there is no justification for this not happening. That this is not happening in India only shows that the government is anti-people. They will not change until and unless we force them to.

In addition to these problems, there are some problems particular to teaching science: the syllabus is too vast; students are not interested; it is too difficult and time-consuming to have students do activities and experiments; there are not enough resources besides the textbook; and science seems to be irrelevant to the students' lives.

However, in addition there is another set of five basic problems - problems which cannot be solved even by alleviating all the economic problems. That does not mean that the economic problems should not be addressed - they certainly must be. But at the same time we should recognise and solve the following problems. I will discuss each one briefly.

Five basic reasons why learning science is difficult

Why do we have trouble answering questions like those shown in the box? Why do we find textbooks full of contradictions and confusing statements, as shown in the above illustration? It is because we are not realising what is the nature of science, and we are not realising what is the nature of our world.

True or False?

1. Plants get big by taking food from the soil through their roots.
2. Burning is a process in which matter is destroyed.
3. The sun rises in the east.
4. Blood is red.
6. Electrical current is used up in lighting a bulb.
7. Heavier bodies fall faster than light ones.
8. Cavemen fought dinosaurs.

(Most people do not realise that all of these are false!)

(1) We think science is a list of 'facts"

This is not correct. Science is not a list of facts to memorise. It is a process - a method of asking questions, hypothesizing, observing, testing, finding evidence, collecting data, analysing, modifying conclusions, communicating, and requestioning. This is not a complete list, and all of these aspects

[1] Excellent infrastructure for education can be provided for a fraction of the amount that a country spends on its military, for example.

need not be present, but this gives an idea of what a generalised scientific method is.

If we want to teach science, we have to teach the scientific method. The way to teach it is to do it.

(2) We rely on faith and authority rather than scientific process

Since we mistakenly think that science is a list of facts, we think that it is possible for some authoritative source to have the correct facts and the correct answers to our questions. Actually, when we rely on authority, we are not necessarily relying on science.

Relying completely and forever on authority for the answers to our questions is non-scientific. Of course we cannot observe everything for ourselves or test out all ideas for ourselves. So we do need to rely on authorities even when we do science. However, according to science, any voice of authority, and any answer can be questioned. If more convincing evidence is found, the answer can be modified or even rejected. But we need not accept an answer just because we have faith in the authority.

(3) We restrict scientific method only to certain areas

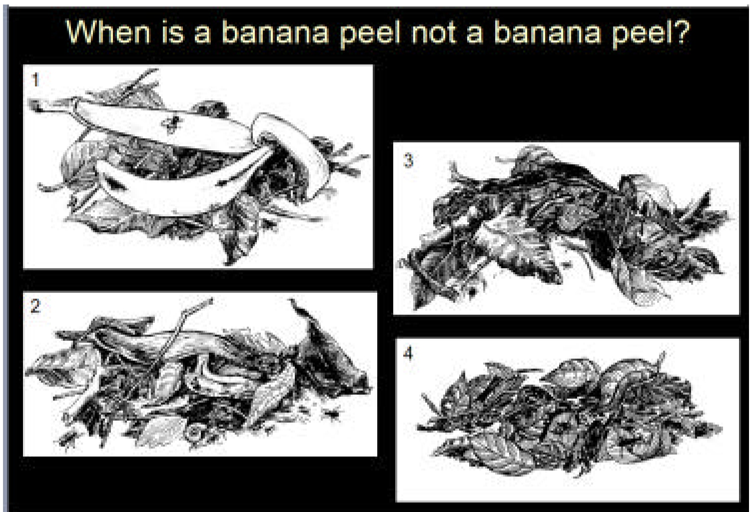
If, using deductive reasoning, we think that there are certain types of questions that cannot be answered by science, we may be needlessly restricting ourselves.

There are many questions which are so difficult to answer that we conclude we may never know even a tentative answer. But how can we conclude that the answer is by definition unknowable?

(4) We use the inappropriate system of logic

We often use a "common-sense" logic which does not make common sense. For example, according to Aristotelian logic: A is A; A is not non-A; and X is either A or non-A, but not both at once. In other words, a rose is a rose. A banana peel is a banana peel. This seems like common sense, and it does often prove useful in day-to-day use. However, we should realise that the real world does not always abide by this kind of logic. In reality, things are not so separate, individual, unchanging, or well defined as this.

Actually it is more appropriate to use a system of logic in which we recognise that A is A and also non-A. In other words, internal contradictions are present in all things. This is shown for example in the sequential drawings of a rotting banana peel. At what point can we say that the banana peel is no longer a banana peel? It is impossible to tell. Actually the banana peel is always a banana peel in the process of becoming a non-banana peel. Using science which is based on this type of logic, we come to understand that the world consists of processes, not things.



A banana peel in the process of becoming a non-banana peel

Furthermore, we come to see that everything changes. There are gradual, quantitative changes, like the slow growth in the size of a grasshopper. However, this slow process leads to a sudden, qualitative change: the death of the grasshopper. It is difficult for us to comprehend such sudden changes in quality.

Another characteristic of the real world is that things (processes) are interconnected and interdependent, not separate or individual, as they seem according to the Aristotelian form of logic. Interdependencies between organisms, for example, cannot even be understood in terms of simple food chains. We see that many interconnected food chains make up a food web. Even then there are problems in trying to define trophic levels. The eagle that eats a snake that eats mice may also eat mice. A mosquito may feed on both the eagle and the mice. An animal may eat both plants and animals that eat plants, making it both a primary and a secondary consumer. An insect which is a primary consumer of a plant may also be eaten by a plant such as a Venus flytrap. Then if we try to add micro-organisms and detritivores, we soon have a very complicated maze of interdependencies. Science is difficult.

Not only that, we also see that in this scientific system of logic, nothing lasts forever. Every new thing gets replaced by a newer thing. We are not used to this way of thinking. It is hard for us to believe that there was a time when there were no people on earth. Maybe this is why we are so quick to believe that cavemen used to fight dnosaurs (actually dinosaurs became extinct 65 million years before the first humans walked on earth). How can we even imagine such long timelines?

(5) We have an unrealistic way of thinking about the world

Thus we see that our ways of thinking about the world make it difficult for us to learn science. Our tendency towards conservatism makes it difficult for us to see change. Our tendency to want to understand the purpose of everything makes it hard for us to understand how things happen without purpose or design, although of course there are reasons. Our tendency to think that our minds are more powerful and more basic than our bodies makes us discount the physical reasons for processes we observe through science.

Perhaps the wonder of the natural world that we investigate through the process of science is in a way too wonderful and too awesome to comprehend.

How can recognition of these problems help us learn and teach science?

If we realise the true nature of science, recognise the problems in our ways of thinking, and try to adopt this new system of logic, this opens up new possibilities for learning and teaching science.

First of all, if science is a method, rather than a list of 'facts', then students should be learning the method rather than the list of 'facts'. This means that the entire science syllabus should be changed.

If science is a list of facts then it makes sense that the science syllabus should be an outline of topics and each topic should contain a list of facts that students should remember. For example, a typical science syllabus, according to this old-fashioned way of thinking is shown in the box on the right.

An Old Syllabus:
1. Atoms and molecules
2. Cells
3. Plants
4. Animals
5. Materials
6. Environment
7. Weather

But if science is actually a method, then the science syllabus should be an outline of methods, procedures, and skills, rather than topics. The topics need not be specified at all in the syllabus. It will not matter exactly which topics are studied, because what matters is that the students are learning the method.

There are three additional reasons why the specification of topics in a science syllabus is not important. First, we cannot possibly specify all the important topics. There are too many of them. Second, if students learn the method of science, they will be interested and able to find out more about any topic when the need arises. Third, students (and teachers) will benefit if topics are not specified, because then they will have the freedom to choose topics according to their particular interests and needs. Science teaching can be guided by the needs of the local community, as well as the more global community. This will also solve the problem of how to allow decentralisation while still assuring that all schools maintain quality and some amount of uniformity.

After all, what difference does it make if a student finishes middle school without being able to define "photosynthesis", or "rafflesia", or "neutron"? Is it really any cause for worry? Anyway, we all know that such definitions will soon be forgotten if they are not useful to the student.

However, we should certainly be worried if a student finishes middle school and thinks that science is just a list of facts, and thinks that every question has one definite, known

A New Syllabus:

1. Ask questions that are important and needed in order to improve our life.
2. Ask important questions that are suitable for our own scientific investigation.
3. Realise that many questions in science do not have one simple answer.
4. Make testable hypotheses to explain observable phenomena.
5. Make sensible predictions, estimations, and educated guesses to answer questions.
6. Design experiments to test hypotheses.
7. Understand and use controls in scientific experiments.
8. Conduct an experiment that changes your mind.
9. Identify possible pitfalls in a design for an experiment.
10. Select appropriate measurement methods for given needs.
11. Make detailed observations and measurements.
12. Design and make equipment to make measurements.
13. Observe and compare things through direct observation, magnification, measurement (including counting, 2 and 3 dimensional measurements, timing, weighing), drawing, and other forms of recording.
14. Analyse data to reach conclusions.
15. Effectively communicate detailed observations, results, and conclusions orally and in writing, using words, graphs, pictures, film, recordings, etc.
16. Actively participate in discussions in which you defend your point of view and try to convince others by giving evidence, examples, and criticism.
17. Effectively communicate scientific reasoning to people from different backgrounds (different ages, levels of education, languages, beliefs, etc).
18. Find specific information in books, on the internet, and from interviews and discussions.
19. Use a guidebook to identify various plants and animals in our environment.
20. Use dictionaries, indexes, tables of contents, encyclopaedias, and the internet efficiently and effectively.
21. Compare and analyse the validity of information gathered. (Also find mistakes in the sources of information.)
22. Identify personal and social biases in information, and become aware of your own point of view and how it may bias your own observations and analysis.
23. Compare and analyse the reasons for variance between repeated measurements and observations.
24. Identify, compare, sort, and classify the materials common objects are made of.
25. Devise and conduct good tests to compare and analyse the properties of different materials.
26. Investigate ways to produce permanent and temporary changes in materials.
27. Evaluate the advantages and disadvantages of different kinds of human activity (e.g. transport, housing, farming, mining, manufacturing) and their effects on the environment.
28. Design a devise for a specified use.
29. Investigate how certain machines and equipment work by taking them apart and putting them back together.
30. Devise models to explain observed phenomena such as day and night, moon phases, condensation and evaporation, skeletal flexibility, digestion, etc.
31. Design, carry out, and analyse surveys to answer relevant questions.
32. Identify local environmental, social, economic, and political problems and evaluate how science and technology may exasperate and/or alleviate the problems.

answer, and has lost the interest and ability to ask questions, experiment, analyse, and make conclusions based on evidence. If this happens we will certainly have failed as science teachers. And in most cases this is what is happening, and we are failing. We need to change our ways of teaching.

An example of what a new syllabus might look like is shown on the left. This syllabus outlines the things that students should do. The topics are not specifically specified.

How might a teacher use such a syllabus? The first step might be for the teacher to guide the students in identifying particular problems in their daily lives that they need to solve. For example in an agricultural community the problem could concern germinating rice and planting it in a nursery bed. The students may start asking questions about what are the different kinds of rice seeds and what percentage of the seeds will germinate under different conditions. This topic might address a number of the first 16 requirements on the syllabus, and it may take one month or more to complete. The teacher might decide that the students need to do a lot of extra work on requirement number 14 - analysing data. The students could be given different kinds of data concerning other questions as well.

Thus, the students will not need a textbook, but they will require a wide variety of other types of books in order to help them do science. This includes dictionaries and encyclopaedias in various languages (perhaps on the internet), guidebooks for identifying plants, animals, and rocks, and other types of reference books.

The students will need books that explain various methods, skills, and protocols they will need to use in their experimental work. Some of the methods they can develop on their own when given the necessary equipment. Some of the equipment they can build themselves in order to satisfy their needs as they arise.

Books and other media with stories, poems, songs, plays, films, crafts, and illustrations are very important so that the students can do relevant cross-curricular work. Books that suggest questions, activities, and experiments to investigate may be useful. Books discussing the history of science and scientists will be useful, especially if they include descriptions of how scientists investigated particular questions.

Teachers need to have sources for handouts and ideas for activities. Obviously the role of teacher training is crucial in this kind of learning.

Assessment

Methods of assessment are not hard to imagine. The main point of some assessment could be just to find out whether each student has done the required minimum number of activities in the syllabus. For example, a teacher may decide that each student needs to design at least 3 different experiments and perform 5 different kinds of measurement within a certain period of time.

Even centralised Board Exams could be easily conducted using this kind of syllabus. An example of an appropriate multiple choice question for such an exam is shown here. The question is not testing whether the students know certain information. They are given all the information they need. It tests whether they understand the method of science.

An exam question:
A group of scientists wanted to find out whether larger mustard seeds produce larger mustard plants. They took two seeds, one large and one small, planted them and weighed the mustard plants they produced. They found that the larger seed produced a plant that weighed 2 grams more than the plant produced by the smaller seed.

This experiment shows:
(a) Larger seeds will produce smaller plants.
(b) Smaller seeds will produce smaller plants.
(c) Smaller seeds will produce plants that weigh less.
(d) Smaller seeds and larger seeds will produce plants that weigh about the same.
(e) No generalization can be made because only 2 seeds were used.