Appendix 11A

Report on Issues in Science Teaching and Learning

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This report is largely based on a couple of books (1. Young People's Images of Science by Rosalind Driver, John Leach, Robin Millar and Phil Scott, Open University Press, 1996; and 2. Selected Papers in Chemical Education Research, edited by Bob Bucat and Peter Fensham; published by The Committee on Teaching of Chemistry of the IUPAC, 1995), a couple of dozen articles from the journal 'Science & Education' and totally random readings. It is concerned with various issues like:

- How is the nature of Science supposed to affect what we (try to) teach or how we (try to) teach Science in schools?
- What are the prior concepts that a child has about the world around it?
- More importantly, how do the prior conceptions that children have about the natural world affect what we try to tell them about 'scientific' world-views?
- What, if any, are the roles of the nature, history and philosophy of Science in informing the Science curriculum?

Why teach Science in school? I guess I'm stating the obvious when I say that the science curriculum has to provide basic scientific literacy to all students (so that everyone has an understanding of science and can be part of the informed decision-making process in a democracy) while also providing the motivation so that some students take up science in higher classes. The usual debates over formulating this curriculum are to decide what facts (propositions, procedures, laws, etc.) in Science are important. That is, people either argue about the 'amount' of facts that are important or, rarely, about the particular set of facts that are important.

But both sets of students above do not gain much from any given set of facts, and studies have shown that children are taking away a very flawed sense of what science is all about. The presentation of science as a series of undisputed facts gives children very little idea of the speculative nature of science; instead it comes across as authoritarian and rigid. Thus, we have fewer and fewer bright students opting for pure sciences and we are also scaring off all the others with the idea that 'science’ is not for them. There is as much a fear of science as of mathematics.

Take the way in which facts are presented or even the manner in which the ‘scientific method’ is portrayed. The tentative nature of scientific knowledge is never acknowledged in textbooks or in the classroom, so when faced with issues like global warming where meagre ‘facts’ can be interpreted / extrapolated in various ways, an ordinary observer is led to conclude that scientists mouth the line indicated by whoever pays them. The other problem involves the public funding of science – if the scientific method is presented as a sure-fire way of finding answers, it arouses irrational expectations from various projects. An intermingling of these two may cause yet another problem – people are not able to evaluate popular claims and beliefs– are they science, opinions of the lunatic fringe or tall tales (for example, take the wide-spread belief here in Madhya Pradesh that the ‘tulsi’ produces oxygen at night). Since science is respectable, we have all sorts of things being labeled as scientific now.

Hence the curriculum would have to factor in these aspects too. This cannot be achieved by tagging on a chapter / unit on the nature of science or the scientific method at the beginning or end of the textbook. Studies have shown that children are more likely to pick up the tacit message from the rest of the chapters that science is a set of ***known*** facts. Even though much (all?) of the science taught at the school level is well-established among practicing scientists, we need to stress not only the provisional nature of this knowledge, but also the process by which this knowledge is established and comes to be widely accepted.

The nature of science also deals with the difference between observations and theories. Most of the experimental work done in school expects children to draw conclusions from observations (or data) as if these follow in a direct and logical way from observations. For example, if the child is told that the glowing of a bulb in a circuit ‘proves’ that electric current is flowing, and not that electric current is a ‘theory’ that explains the lighting up of the bulb, the child is bound to get confused and is not able to appreciate that theory is distinct from data. Further, if empirical generalisations and theoretical models are conveyed in the same way, the child is not likely to understand the role of observations in establishing scientific knowledge.

Various studies have tried to incorporate the history of science in teaching specific concepts in order to take care of the above problems, *i.e.,* the tentative nature of explanations and the process of arriving at a better explanation. For example, Douglas Allchin has used the concept of phlogiston to teach metals and oxidation-reduction reactions in addition to inducing discussions about realism and reliability and the historical development of concepts (Rekindling Phlogiston : From Classroom Case Study to Interdisciplinary Relationships : Science & Education **6** : 473-509, 1997). Phlogiston giving way to oxygen is also the basis of a student guide of the University of Chester (The Discovery of Oxygen – A Case Study in the Chemical Revolution, John Cartwright, 2004). Kevin C. De Berg has suggested an historical approach to the concept of work which clarifies the (force × distance) definition of work (The Development of the Concept of Work : A Case where History Can Inform Pedagogy – Science & Education **6** : 511-527, 1997).

Presently, the history of science has a perfunctory role in textbooks and even this may mislead children, or may be unhelpful in conveying the concept. For example, many children retain the image of Archimedes and his shout of 'eureka!' but hardly remember or understand the science behind the story. And Newton seems to have been linked with gravitation and apples by this kid who wrote, 'Gravity was invented by Newton. It is observed mainly in autumn when many apples fall down.' (I have no idea how authentic this story is, maybe as real as the apple which fell on Newton's head.) It may be helpful to use the historical approach where appropriate and where the experiments can be easily performed by the children.

Coming to the nature of science, Anton E. Lawson (*T. rex*, the Crater of Doom, and the Nature of Scientific Discovery, Science & Education **13** : 155-177, 2004) discusses the issue of differentiating hypotheses from predictions while performing experiments and its implications for engaging students in open enquiries. Other studies show that an understanding of the nature of science supports successful learning of science content. Therefore, open enquiry is an approach that should be taken up.

Also, students who viewed scientific knowledge as reversible (dynamic) rather than fixed (static) were less likely to believe that learning Science depended on memorisation and achieved a more integrated understanding of the topic of study. To quote Jean Piaget (To Understand is to Invent, 1976): 'It is not by knowing the Pythagorean theorem that the free exercise of a person's reason will be assured. Rather, it is assured by having rediscovered that there is such a theorem and how to prove it. The aim of intellectual education is not to know how to repeat or to conserve readymade truths (a truth that is parroted is only a half-truth) but to learn to find the truth by oneself at the risk of losing a lot of time and going through all the roundabout ways that are inherent in real activity.'

Karl Popper's stand is that the 'method of science' does not lie in the way new ideas are conceived but, rather, in the rigorous and systematic way such ideas are tested. Developing this idea in the curriculum should give the children the sense of how theories are not read directly from the observations and the role of imagination in formulating a theory (!). According to Driver, an understanding of the scientific approach to enquiry involves not only an understanding of the empirical enquiry procedures, but also the role of theoretical and conceptual ideas in framing any empirical enquiry and in interpreting its outcomes. This would include an understanding of the limits of application of the scientific approach and of the demarcation between sciences and non-sciences. We would like the children to be consciously aware of why scientific ideas and theories are reasonable, rather than simply learning them.

Coming to the pre-concepts that children bring to the classroom, and quite often carry back with them, various studies have shown how these pre-concepts interfere with the scientific concepts that school tries to teach the children. In Physics, it seems to be well established that both children and adults (and cartoons!) prefer Aristotle to Galileo when it comes to explaining bodies in motion or at rest. In Chemistry, one of the persistent beliefs is that matter is destroyed on burning. In Biology, in spite of being told about photosynthesis, students stick with the notion that plants get their food from the soil through their roots.

In addition to these pre-concepts that affect the learning of scientific concepts, there are garbled versions of some concepts that are seen in many children. In Chemistry, the particulate nature of matter and the difference between macroscopic and sub-microscopic properties seems to be absorbed at a superficial level which quickly disintegrates when probing questions are asked. How we go on from the macroscopic properties and learn about the sub-microscopic world is fascinating, but I guess it is never conveyed to the children. Some examples of this half-baked understanding are: 1) Expansion of a substance on melting occurs because the molecules expand. 2) Particles (atoms / molecules) melt when a substance reaches its melting point. 3) Molecules get hot as the temperature is raised (I wonder if this is before or after the kinetic theory of gases is taught). 4) A plane perpendicular to the ring of a bromobenzene molecule, and passing through the bromine atom, cannot be a plane of symmetry because the "B" and the "r" in the symbol "Br" are different. This last example is a manifestation of the confusion between the sub-microscopic world and the symbolic system for representing it.

There are some studies or approaches which seek to avoid the confusions that arise in the minds of students because we tend to approach the subject from the point of view of an expert. George M. Bodner (Constructivism: A Theory of Knowledge – Journal of Chemical Education, Volume 63, Number 10, October 1986, 873-878) quotes Herron who approaches the definition of molarity from the practical difficulties of measuring the amounts of substances in solutions. Another example of how we tend to present the final finished products in textbooks causing confusion in the child about what came first:

- Why, for example, put lithium's last electron in a new orbital?
- Because Bohr's rules say so.
- But, Bohr was once asked, why did you rule that lithium's last electron must go in a new orbital?
- Because the facts of chemistry demand it, replied Bohr.

(from Henry A. Bent's Uses (and Abuses) of Models in Teaching Chemistry – Journal of Chemical Education, Volume 61, Number 9, September 1984, 774-777.)

This brings us to the use of models in describing the world around us. A model is like the object / phenomenon it is modelling in some aspects, but what is important is that the children understand where the model differs from the original. Nahum Kipnis discusses the strengths and weaknesses of a couple of models in understanding electricity and diffraction in Theories as Models in Teaching Physics – Science & Education **7** : 245-260, 1998.

After all this, there is also the need for children to be able to link together concepts in various areas when dealing with an application of their knowledge in real life. This includes being able to move between various modes of thinking about the world and representing this thinking. One manifestation of the lack of linkages is the difficulty children have in interpreting (sometimes even drawing) graphs. An example is discussed by

L.H.T. West and P.J. Fensham in ‘What is Learning in Chemistry’ (Chemical Education : A View Across the Secondary – Tertiary Interface. Proceedings of the Royal Australian Chemical Institute Chemical Education Division Conference, Gippsland Institute of Advanced Education, 162-169, 1979). Here a student who has read the normal boiling point of bromine and its boiling point at a given pressure from its phase diagram is not able to say why a pressure cooker cooks faster till he is asked very leading questions. This paper goes on to suggest some ways in which inter-linkages in this topic could be attempted.

One of the points that has been made by various people is that the way knowledge is broken down into subjects and topics within subjects followed by evaluation of these same ‘discrete’ bits of knowledge is responsible for the way children learn the facts of science in this piece-meal manner. This indicates that methods of evaluation too need to be considered when framing the curriculum.

Therefore, from all of the above, we have some pedagogic guidelines:

- Use the history of science where appropriate.
- Follow the process of open enquiry (where appropriate).
- Map the pre-conceptions of children and devise ways of tackling them.
- Develop a multiplicity of approaches and see what works.

In conclusion, what are the things we need to do?

- Map the ideas children have of the world.
- Study how these ideas affect what we try to teach them.
- Figure out how best a topic is to be approached after taking into account to the need for getting children to test their pre-conceptions and move beyond them.
- Figure out the framework of the science knowledge that we want to pass on to them and how we would evaluate this.

For example, in chemistry, to understand the nature of chemical changes (*i.e.*, go beyond describing what happens when….), I would suggest that we cover the particulate nature of matter, structure of the atom, bonding (and reactions) and periodic classification in classes IX-X.

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