Title	Scientific reasoning – Why it is so difficult for students?
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Scientific Reasoning - Why it is so difficult for students?

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Research (Boo, 1994; 1995; 1996) has shown that A-level students have difficulties in reasoning scientifically.

What is 'Scientific Reasoning' ?

In order to understand what we mean by the term 'scientific reasoning', it is necessary to consider what the nature and aims of science are. Einstein (1954) offered the following definitions of science, and the aim of science:

> Science is the attempt to make the chaotic diversity of our sense-experience correspond to a logical uniform system of thought. The aim of science is, on the one hand, a comprehension, as complete as possible, of the connection between the sense experiences in their totality, and on the other hand, the accomplishment of this aim by the use of a minimum number of primary concepts and relations.

Implicit in Einstein's definition is that scientific knowledge is never absolutely true but is a theoretical construct to be constantly refined.

Chalmers (1990) suggested that:

> the aim of science is the establishment of generalisations governing the behaviour of the (physical) world.

Reif and Larkin (1991) offered the following definition:

> The central goal of science is to achieve optimal prediction and explanation by devising special theoretical knowledge which parsimoniously (i.e. on the basis of a minimum number of premises) permits inferences about the largest possible number of observable phenomena.

The important point from all these definitions is the predictive nature of science; i.e., the ability of science to not only adequately explain observable phenomena but also to provide a basis for the prediction of unfamiliar or unobserved events.

From these definitions, it could be inferred that, among other things, scientific reasoning involves both inductive and deductive thinking. It involves inducting concepts, principles, generalisations, theories, models from perceptual experiences with natural phenomena, and then through a process of deductive thinking uses these (few) basic concepts, generalisations, principles, theories or models, to explain and make predictions about a wide range of natural phenomena.

For example, one would reasonably expect an average A-level chemistry student who had been exposed to chemical reactions probably for 5 to 6 years (from secondary 1 to junior college/pre-university level) to have abstracted the chemist's view that all chemical reactions, while superficially different, can be explained or predicted by a single consistent reference model, viz.:

> Chemical change involves interactions between numerous particles which are in constant motion. Such interactions include collisions between particles of reactants; breaking of existing bonds and making of new bonds within/between particles. Bond breaking is a process which requires energy input while bond making is a process which is accompanied by the liberation of energy. The magnitude of the overall energy change is governed by the difference in strengths of the bonds formed vis-a-vis bonds broken. Where bonds formed are stronger than bonds broken, the reaction would be overall exothermic - as is the case in all 5 reactions discussed. Where bonds formed are weaker than bonds broken, the reaction would be overall endothermic. The driving force of the change is the decrease of heat energy in the chemical system resulting in an overall more stable state or the increase in the total entropy of the universe.

Only about 10% of the subjects interviewed by Boo (1994; 1995; 1996) were able to reason consistently according to this (or, indeed, any other) reference model.

In general it was found that students tended to use everyday/layman language rather than scientific concepts and principles in their reasoning overall energy change and driving force of chemical change.

At A-level, having studied at least 10 years of science and 3-4 years of chemistry, one would expect these students to be able to make predictions of the type of change expected based on concepts, principles or models that they have learnt. Instead, when asked for the bases of their predictions (of the type of change expected or of the overall energy change), the vast majority were: 'based on what I can recall' or 'based on what my teacher (or textbook) said' or 'based on what I learnt in school' (or words to those effect). These responses showed that there were little understanding of the role of concepts, principles and models in prediction.

Why do students find it difficult to reason scientifically?

There are at least three possible reasons why students find it difficult to reason scientifically. These are:

1. They lack understanding of the nature and goals of science.

If students view science as a body of facts rather than predominantly a process of constructing predictive conceptual models, then it is likely that they might not have attained and internalised the scientific concepts, which in turn would mean that they would not be able to use these concepts consistently in explaining and making predictions about a wide range of chemical phenomena.

2. They learn labels for concepts without learning the full conceptual meaning.

Many studies have shown that students have a tendency "to reduce theoretical knowledge and principles to a 'factual' level and 'apply' this in a rote fashion" (Garnett, Garnett and Hackling, 1995, p. 89). If students have learnt by rote and have not abstracted or constructed the scientific concepts, principles and

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models for themselves, then it would be difficult for them to apply these across a variety of superficially different phenomena.

3. They have confused the goals and hence ways of thinking of science with goals and ways of thinking of the everyday life.

This third reason is discussed by Reif and Larkin (1991) and is probably related to the preceding two reasons. As a consequence of not understanding the nature and goals of science, and/or of not having learned the concepts meaningfully or deeply, and because the influence of everyday life is stronger than that of school science, students tend to confuse the goals and ways of thinking of science with those of the everyday life. In everyday life, knowledge and rules of conduct tend to be compartmentalised i.e. various kinds of knowledge can be used as appropriate in different contexts without requiring great generality. Not understanding the nature of science and scientific knowledge means that students tend to compartmentalise their knowledge of different type of chemical reactions rather than recognise the generic model underlying all chemical reactions.

In fact another compounding factor which is suggested by Reif and Larkin (1991) is that school science often does not adequately foster the scientific goal of understanding. Instead, many science courses taught in schools tend "to encourage and reward the memorisation of knowledge rather than the ability to make diverse inferences leading to scientific understanding."

Implications for teaching

Today, much science teaching in the classroom is carried out in the 'top-down' manner reflected in the student responses just mentioned. The teacher will introduce a topic, present and explain the concept and its meaning and then follow up with practical work to reinforce the material covered.

As suggested by Gilbert (1991) science education should proceed from a definition of science as "a process of constructing predictive conceptual models". Students therefore need to be explicitly informed of the nature and goals of science and how these differ from those of non-sciences as well as from the everyday life. If they are not explicitly made aware of the nature and scope of science perhaps it is not surprising that their conception of science has been a rather narrow one.

This process of constructing predictive conceptual models has a number of well ordered steps:

1 Observation of a range of natural phenomena.
2 Grouping and categorisation of data collected from observations.
3 Construction of a conceptual model to explain the relationships between data within a category.
4 Design of controlled experiments to test the correctness of the model against the possible values of data within the category.
5 Acceptance of the model as the best explanation currently available of the relationships between data within the category.
6 Use of the model to predict as yet unobserved outcomes, ie to extend the boundaries of the category.
7 In the event that (a) the model is shown to be an inadequate representation during controlled experiments, or (b) new observations are at variance with the prediction, then the process is repeated from either stage 2 or

stage 3.

8 In the search for maximum explanation with the minimum number of primary concepts, science will test the boundaries between categories with the aim of one category subsuming another.

If science teaching is carried out in a 'bottom-up' manner, i.e. through using a wide variety of concrete and perceptual experiences to guide students to abstract and construct concepts, principles and models for themselves, then it in fact, maps the course of development of many scientific concepts, theories and models. In other words, it is this researcher's belief that science teaching carried out in a 'bottom-up' manner and which takes into account the historical development of science could result in more meaningful and effective learning of concepts and principles, and hence, scientific reasoning.

As observed by Lunetta and Cheng (1987), students can learn that they are developing conceptual models to better understand the world around them and that they can come to understand that as they get more information then their conceptual models must grow and evolve and change. Following concept formation, students should be given examples illustrating the wide application of these concepts, rules, principles and then they given situations where they could learn to apply the concepts, principles to make inferences about unfamiliar phenomena.

Another reason for students' use of everyday thinking and everyday language in the context of solving science tasks or questions could be that science (school science) is often taught (and hence perceived by students) as dull and uninteresting. This is in contrast to their everyday life which encompasses things which are interesting and full of strong emotions. Thus another approach to alleviating the problem of wrong use of everyday thinking in a scientific context is to inject interest and emotions in school science. Yet another prong of attack is to ensure that the everyday life is brought into school science by emphasising the applications of particular science concepts, principles in the everyday life.

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