Need for Change of Paradigm in Science Teaching

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Learning in India depends on rote and reproduction of material from memory. This has adversely affected the quality of students pursuing higher degrees in science. How can instruction in science be changed so as to improve students' ability to think and abstract independently?

Is the number of students taking up science in high schools and colleges decreasing? The answer is no. We are still getting a large number of bright students opting for the sciences and competing for seats in schools and colleges. However, the number that stay on to complete their course in colleges has declined sharply; one could even say drastically. This has affected the quality of students coming in for MSc and PhD courses. Is the system doing justice to the students who do come to learn science? One of the leading information technology companies in India says that students, even with an MSc degree, seem to lack the skills the company needs and thus, they have to be trained afresh. The students seem to lack initiative and are unable to think independently. This could be because the emphasis in science teaching (or any teaching) in India seems to be on memorising and not on understanding.

How does one change this situation and ensure that education and specially, teaching of science is of high quality? One has to consider the problem in a comprehensive or holistic way, keeping the student (or individual) and society, both in mind. We have to think about how we can keep the student interested and even fascinated. We have also to think about what we mean by personal development, knowledge, science and social sciences. Let us first briefly review the present system of education.

Indian Education System

The system of education in modern India can be traced to Lord Macaulay, who advised the governor general William Bentinck in 1835 to support teaching of English language and science and withdraw the support for study in local languages and Arabic and Sanskrit. The idea was probably to give Indians an idea of the superior ways of the west. The complaint is that the training given helped only in preparing Indians for clerical jobs. Since then, several changes have been brought into the Indian education system. After independence in 1947, the whole system has been expanded and deepened. The system, however, has serious drawbacks. The main problem is lack of proper interaction and rapport between student and teacher partially due to the poor quality of teachers. A related problem is the impersonal examination system. To do well in it, memorisation rather than understanding is needed. Further, the system leads to a feeling that what is learnt at school has nothing to do with real life. The obtaining of a degree is the main goal and not expanding and strengthening one's world view and potential.

In spite of this, quite a few persons because of their innate brightness were able to benefit from the system and the country produced very bright scientists, social scientists, literati, lawyers and other professionals. The increase in the number of schools run privately, after independence, has led to the neglect of government schools and a decline in the quality of schools run by the state. This has happened in urban and rural areas. The malaise has now affected all public schools and most private schools. However, everyone in the country now realises the importance of education. There is an overwhelming demand for good education. The quality of education is very poor due to several reasons: lack of enough number of schools; lack of good, well-trained teachers in adequate numbers; and lack of infrastructure in schools. In facing these problems, "first generation learners" are at a greater disadvantage than children of educated and well to do parents. The inadequacy of teaching in schools has resulted in a need for a lot of support and help for the child from parents and family. First generation learners do not get this and are additionally handicapped. For a country trying to raise educational standards for all, this is a serious problem.

Poor quality of teaching is not something that prevails only in India. All over the world, even in developed countries like the US , UK and others, this problem exists. Children, even after eight to 10 years of schooling, are unable to read and write. Mathematical skills are not well developed.

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However, there are a large number of very good schools in developed countries, which do a very good job of helping the privileged student to learn. The teachers interact with the student at personal levels and guide her to expand and develop her world view, including skills, in areas in which she has special interest. These countries are economically advanced and assure reasonable employment to the youth. So there is a certain relaxed and calm ambience in the educational institutions. In contrast, in Indian schools and colleges, one senses a certain amount of desperation. The need to gain employment creates great stress. It makes paper qualifications more important than learning or understanding. For a vast majority, the lack of communication skills (even elementary reading and writing) acts as a big handicap to learning of any kind. Even those who can read and write have difficulty with science, and more importantly, mathematics.

Physics Education Research

Research in physics education all over the world has shifted focus several times in the last 20 years. According to Grayson (2006) in the early 1980s, interest was in alternative conceptions that students held about various physical ideas. (We know now that an object not stopping in the absence of a force, Newton's first law, is a concept quite alien to most students.) The mid-1980s saw an interest in computer-based and computer-aided instruction. (We pay lip service to this idea in India.) In the early 1990s, interest was on curricula that promoted activity-based or inquiry-based learning. In the late 1990s, it focused on student cognition. We now know a great deal about how students conceptualise physics and what makes for effective instruction. What is missing is curricular content: what physics should we teach? Workplace success seems to depend on the employee's mastery of transferable skills and emotional intelligence than on her knowledge base. This leads to the students perceiving the course content as unrelated topics disconnected from the real world and irrelevant to their daily lives. We see that the problems faced have lot of overlap all over the world.

The place of various disciplines in a person's world view is also very important. G R Ellis (2005) ranks various disciplines in a hierarchy of structures, with physics at the bottom and psychology at the top. As the level in hierarchy rises, so does the level of complexity of the objects studied by the discipline. To appreciate the distinction, consider the question posed by Ellis – why is an aircraft flying?. He discusses it at three levels, calling them the bottom-up, same and top-down levels.

> In bottom-up terms, an aircraft flies because air molecules move at different speeds over the top and bottom wing surfaces to create a pressure difference that lifts the plane against gravity. This is the well known Bernoulli's principle. In same-level terms, the airplane flies because the pilot is flying it, after rigorous training and the airline timetable dictates a scheduled flight. In top-down terms airplane flies because it was designed to fly… It was designed using developments in metallurgy, combustion, lubrication, aeronautics, computer aided design. It was created by society's needs for transportation.

At each level there are different kinds of explanations and differing types of causality. An important implication is that each explanation is only partial and the preference of any explanation is a choice based on context. Physics is useful for answering questions of what and how; religion, philosophy and world view are useful for answering the question of why. Physics teachers need not set up a confrontation between physics and the student's world views [Grayson 2006]. Let us next look at personal development of an individual in some depth.

Inner and Outer World

One can view the evolution of an individual, right from birth, as creation and development of a personal world view. The perceptions that are received from birth, first create and then build up a world view. This is a view of the person's environment made up of both people and things. The ability to communicate by gestures, signs and finally, by language enables a person to realise that there are many things common in one's own world view and that of another person. This leads to knowledge of an outer world or outer reality, which is independent of a person and is common to all beings. One also realises that there is an inner world about which it is very difficult, sometimes impossible to communicate to others. For example ecstasy, created by music or any other beautiful experience, is quite difficult to communicate.

The outer world itself consists of two qualitatively different realities. One is the physical or scientific reality, which is independent of human ideas and attitudes. The other is the social reality, which crucially depends on human ideas and concepts. These form the natural sciences and social sciences respectively. As John R Searle (2002) puts it,

> The distinction, rough as it is, between the so called "natural" sciences and the "social" sciences is based on a more fundamental distinction in ontology (essence of things), between those features of the world that exist independently of human attitudes like force, mass, gravitational attraction and photosynthesis on the one hand and on the other, those whose existence depends on human attitudes like money, property, marriage and government. There is a distinction, to put it in very simple terms, between those features of the world that are observer – independent and those that are observer – dependent. Natural sciences like physics, chemistry and biology are about features of nature that exist regardless of what we think and social sciences like economics, political science and sociology are about features of the world that are what they are because we think that is what they are.

Here, the observer-dependence refers to non-dependence on the human attitudes of the observer. This should not be confused with observer-dependence in quantum mechanical measurements where the physical interaction with the observer, or observing apparatus, is intended.

Whether one includes social sciences in the inner or outer world depends on whether one is talking about society and nature or about the individual and society. As one moves from the inner world to social science and then on to natural science, one moves from a region of a large amount of uncertainty to a region of almost complete certainty. This is the hierarchy referred to by Ellis (2005). One goes from inner to outer, as Ellis goes from top to bottom. The laws of natural science are as close to certainty as one can get in the description of our surroundings. The predictions that can be made about outcomes in controlled situations is highest in physics and chemistry. It can be as high as one part in 10^{14}. When we come

to the predictions in economics, political science or history, even an accuracy of one part in 10 (10 per cent) is very difficult to achieve. When we have to communicate feelings of exhilaration and ecstasy most of the time we do not succeed at all. Yet human beings have to take important decisions based on predictions of varying degrees of certainty. These decisions can be at the individual, family, social, national or international level. A world view as close to reality as possible is essential for the benefit of mankind and the world. World views also influence and change reality as it pertains to the inner and outer social world. As pointed out by Ellis (2005), apart from uncertainty, there is an increase in complexity as we go up the hierarchy or from out to in or bottom to top.

The inner world is the seat of spirituality while science resides in the outer world. There is thus no conflict between science and spirituality. Education aims to create a world view in an individual, which would maximise his potentialities. This would also lead to maximum benefit for society, a law of nature or an implicit assumption, depending on one's point of view. The main thrust in education should be from the side of the learner not from the teacher or society. This is the basic idea of child-centred or learner-centred education.

Education and Classroom

In a classroom in a good school, the teacher suggests a topic for discussion, say learning history from local monuments. The students are taken on a trip to some nearby monument. It could be a very well known one, like the Qutub Minar or some lesser known tomb or minar in the neighbourhood. There are many such all over India. The teacher asks a student to describe his or her ideas about the building and the person associated with it. The students have a discussion under the guidance of the teacher and learn history in the process. In most of the humanities and social sciences this can be done. To some extent even environmental science can be learnt this way. This is because there are enough variations in the accounts of each individual to accommodate differing points of view.

Such methods of teaching are used in a very small number of schools in India. In most others, a textbook is read out by the teacher or a student and explained by the teacher and the students take notes. They then memorise these notes and reproduce them in examinations. Often the teacher may not have the confidence to be able to conduct a discussion, control it and draw the right conclusions. The number of students in a class room may also sometimes be very large for an interactive discussion. Of course, even a good teacher can be lazy or lack motivation.

Different Paradigm

When one comes to teaching sciences, especially physics or chemistry this type of interactive teaching is no longer found to be workable. There is so much definiteness in science that it is taught like dogma. Even when there are laboratory classes and the students draw inferences from the experiments, the freedom to differ is rarely available. This makes teaching science a problem area. In practice students end up memorising facts rather than understanding them. To counteract this, physical sciences provide a lot of numerical problems, which deal with applications of an idea or a principle. They are of limited use, as the student often tries to memorise the type of technique needed to solve the problem. An alternative way is to make students work on projects where they have to think and learn independently with minimum guidance from teachers. The use of projects in teaching is extremely helpful, provided they are refreshed every year. When they get stereotyped there is again no independent thinking.

What is probably needed is the teaching of science, not on its own, as a stark and dreary discipline but as a human enterprise. A bit of history and lots of humanity. It will partially be like teaching a social science. More of personal passion than an impersonal account. Much of the mathematical details that are now given in lectures must be left for the student to solve on her own. This is a bit like a tutorial or guided self-study. This is how a PhD student learns. It probably dates back to the 'guru-shishya' relationship but more importantly, this is the practice all over the world now. Most of us know that this requires much more from the teacher in terms of competence and effort. We should reduce the number of students reading for the MSc and PHD (or more importantly, the student to teacher ratio) and create a more intensely and personally supervised programme for the chosen in their undergraduate classes. Less specialisation and more of a general education is probably what is required. The general education at the bachelor level can include a broad introduction to all the sciences-physics, chemistry and biology and a fair amount of calculus and statistics – which seem to be required increasingly by all sciences and by many social sciences too. Of course, a lot of innovations and field testing will be required before such an approach can be implemented.

The focus on child (or learner) centred education emphasised by the new national educational curriculum of 2006 is definitely a step in the right direction. But for it to succeed in science education, there has to be far less specialisation. It is not uncommon in the US for a person to start learning physics at the age of 20 or even beyond and do very well as a physicist or even as an applied mathematician. (This is however not true for a subject like pure mathematics, where creativity blossoms very early and is over by age of 35 years or so.) Dissatisfied with science education, there have been many recent attempts at new methods and innovations [Grayson 2006]. They try to make the learner, the formation of concepts and the strengthening of the earlier knowledge frameworks important in the educational process.

Child-Centred Learning and Constructivism

Child-centred education is sometimes identified with "constructivism", which is a philosophy of education currently under a fair amount of discussion [Kumar and Sarangapani 2004]. The names of Jean Piaget and Vygotsky are associated with its early versions. The child is said to be constructing knowledge in his own way and at his own pace in the process of education. (We call this forming and developing one's world view.)

In the 1970s, a method of teaching called "learning by doing" became popular in the UK . This was much before it became popular in the US in the 1990s Grayson 2006]. It was tried out in India in some schools in the Hoshangabad district

of Madhya Pradesh under the name Hoshangabad Science Teaching Programme. Later an organisation called Eklavya was formed to run it and it continues to be involved in this and in other educational innovations. Many scientists (including I) from Delhi University, Tata Institute of Fundamental Research, Mumbai and many other institutions were involved in this effort. In this programme, a child in class six, aged 11-13 years was made to perform experiments in groups of five to eight students. They were given a low cost experimental kit for this purpose. They were expected to infer laws of physics like the Archimedes' principle, and laws of chemistry and biology from their experimental observations on floating bodies. It was soon realised that considerable external guidance had to be given to the students to enable them to arrive at the correct physical laws. At that stage, the students lacked several requisites as well. Their ability to make abstractions and their knowledge of mathematics including decimals were both poor. They had difficulty in even following the text. This was because of their poor reading and writing abilities in Hindi (not helped by prevalence of several local dialects and differing vocabulary). "Doing" had to be supplemented by "reading, writing and other external inputs" for "learning".

An extreme form of constructivism [Matthews 2000] seems to consider (one could say even define) knowledge as totally self constructed and denies any reality outside oneself. In an extreme form of constructivism, no external input is supposed to be given. Such relativism of the post-modern type may be of interest to philosophers. It will only confuse everyone and complicate matters when applied to educational methods. One has to steer clear of such extreme philosophical controversies. The use of child-centred methods in the sciences is essential but requires thought and careful planning. More importantly, it requires a change in paradigm in the teaching of sciences.

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