Teaching Science Badly – and Well

by
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A normal, intelligent and curious child – particularly if he or she is Pakistani – must think science to be the most wretched of subjects at school. A few lucky exceptions aside, this is the fate of most. Very few children will actually encounter science in a manner that they enjoy and deserve.

This is sad. Science is taught in schools for a good enough reason – we owe the modern world to it. The prosperity or poverty of nations, and of individuals, has become contingent upon their ability to understand and control science. Take its products away, and we would be back in the dark days of our ancestors when a child at birth was more likely to die than live.

But there is another excellent reason to study science. Far from being a cold and soulless collection of facts, it is delicately beautiful with principles that are amazingly simple and precise. Yet, they are also incredibly powerful and universal. Exactly the same laws explain why stars shine, the blue of the sky, the beating of the human heart, and the flight of birds. Science grips the imagination and fascinates endlessly. It has certainly engaged me for most of my life and I, like most scientists, will never tire of it.

If it is so wonderful, why then do only a few students in Pakistan want to become scientists? The problem is the prevalence of false notions of science. This, in turn, leads to teaching that ranges from bad to terrible, and thus to students who despise what they must study and memorize.

In contrast, a recent survey in India revealed that a majority of school students see science as the most glamorous and interesting career to pursue. Many go on to becoming the world's top scientists. This is a key factor in the emergence of India as a major world power, in scientific as well as economic terms.

A science-phobic younger generation in Pakistan is bad news. This must change else we shall be stuck with low technological prowess, small potentials for future economic growth, and perpetual dependency. These are inescapable penalties for any country without a large scientifically trained workforce. It would be a terrible mistake to dismiss the term "knowledge economy" as a mere cliché.

But what is it exactly that we do so wrong? And, what needs to be put right? To answer these questions needs a clear understanding of what science is. We must also know how it functions, and what it values. Pedagogical style and techniques will follow naturally once we properly clarify and define.

My definition: science is a body of knowledge, together with a very definite way of accumulating and validating that knowledge. Note the phrase "a very definite way". This

indicates that science must be distinguished from art, humanities, religion, etc. Their definitions of acceptable knowledge, and the paths leading to it, are totally different. Science has no place for subjective experiences and, instead, to distinguish between true and false it relies exclusively on logic, reason, and experiment. Hypothesis, theory, fact, observation, and experiment are at the roots of what is known as the "scientific method".

All this sounds a bit abstract, so back to plain talk: science demands proof using things that we can measure. There cannot be airy-fairy discussions of things. Science refuses to offer an opinion on things that are unobservable, or whose existence is impossible to verify even in principle. What you cannot see may still actually be there, but science is going to be mum about it. It's as simple as that.

Every discipline has values and norms. Science certainly does too. Its central tenet is that one's evidence, logic, and claims will be questioned, and that one's experiments will be subjected to replication. Therefore a high premium is put upon skepticism and there is a deep distaste for dogmatism. Successful scientists, mathematics, and engineers are valued because of the institutionalized skepticism they imbibed during their education.

With all this philosophy now behind us, we can now ask what constitutes good pedagogic content for science, the teaching style, and the mistakes that are commonly made. Most importantly we need to ask: what are good science teachers actually supposed to do in class?

I. First, they should help students to simultaneously acquire scientific knowledge of the world, as well as cultivate scientific habits of mind. These are two completely different things. One is providing data and information about the physical world, the other is creating a mindset needed to properly interpret this data.

Therefore, science education must begin with simple things such as exploring the chemical properties of common substances, plants and animals, and systematic observations of the social behavior of humans and other animals. This requires that teachers show students to dissect, sort, count, collect, catalogue, compute, graph, and make sensible notes. Use of simple equipment like rulers, lenses, thermometers, cameras, etc. is important. Many students are fearful of using laboratory instruments and other tools. This fear is often from the lack of opportunity, but girls also suffer from the mistaken notion that boys are naturally more adept at using tools.

II. Second, good teachers must emphasize learning rather than teaching. The two are different. Learning is a process that progresses from the concrete to the abstract as cognitive abilities slowly improve. But students first need to get acquainted with the things around them such as devices, organisms, materials, shapes, and numbers. They must observe them, collect them, handle them, describe them, become puzzled by them, ask questions about them, argue about them, and then to try to find answers to their questions. Abstractions develop after these experiences, not before.

Good teaching starts with using tangible things. One does not need a Ph.D in cognitive studies to know that young people learn best when they deal with visual, auditory, tactile, and kinesthetic objects. As their experience grows, they learn to understand abstract concepts, manipulate symbols, reason logically, solve theorems, and generalize. These abilities are destroyed, or left woefully undeveloped, by rote memorization.

Parsimony is essential. A good teacher picks the most important concepts and skills and concentrates on the quality of understanding, not on the quantity of information presented. In some expensive private O- and A- level Pakistani schools lots of scientific drilling exercises are given for exam grade improvement. Even when successful, this does not necessarily create mindsets for doing good scientific work at a later stage.

Similarly, overemphasizing vocabulary can be dangerous. Understanding is the main purpose of science teaching but many teachers think that their job is to make students learn big words. This detracts from science as a process and jeopardizes learning, particularly in a linguistically fractured country like ours.

III. Third, good science pedagogy happens when the spirit of healthy questioning is deliberately cultivated in the classroom. The scientific mindset starts developing naturally when students encounter questions that engage their mind rather than memory.

It should therefore be normal practice for teachers to raise such questions as: How do we know? What is important to measure? How to check the correctness of measurements? What is the evidence? How to make sense out of your results? Is there a counter explanation, or perhaps a simpler one? The aim should be to get students into the habit of posing such questions and framing answers.

Dogmatism kills science. Students should therefore experience science as a process for extending understanding, not as unalterable truth. Never should the teacher say X or Y is true just because that's what the textbook says. (I grind my teeth whenever a student in my university class gives me this argument! But this is what these over-grown children have inevitably become.)

Equally importantly, teachers should never portray themselves as absolute authorities whose conclusions are always correct. Of course, there has to be a delicate balance here. As a teacher, I do know more than my students and I should not hide that. Was this untrue, my salary should rightfully be stopped. But the point is that I am occasionally wrong, and do make a mistake in class now and then. This can be turned to excellent advantage, as I have often discovered.

How? In traditional societies like ours, the student is told that his teacher "*tumharay baap ki tarah hai*", an autocratic and tyrannical figure whose word is the law. This attitude is simply incompatible with the relative student-teacher equality that science teaching requires. Therefore I use the occasion provided by my mistake – if it genuinely is one – to prove that my authority is not absolute. It gives confidence to the student who points out my mistake and strengthens the spirit of scientific inquiry in my class.

It is wrong to say that science requires no faith. It does, albeit of a certain kind. Personally, I have never seen the 60 moons of Jupiter but am willing to accept their existence on faith because I know that, at least in principle, someone else can do it. In general, science teachers must help students achieve a delicate kind of balance between this kind of faith and skepticism. Teachers must also be able to explain coherently what caused the overturn of accepted scientific beliefs, and what to make out of disagreements among scientists. It is extremely important to keep an open mind and challenge when necessary.

Such open-mindedness is good not just for science pedagogy, but also for changing the stultifying cultural conditions of our society. The inability to deal with, or comprehend, scientific and technological matters has steadily lead to its dangerous "loser" mentality and a lurch towards extra-scientific, magical, and hodge-podge solutions.

Examples abound. Through programs produced and popularized by scientific illiterates, a virulently anti-scientific Pakistani television culture has emerged. It bashes science without knowing what it is about. Flipping through the channels, you can see TV programs trashing evolution, discussing strange fiery creatures in the sky, ascribing earthquakes and calamities to divine retribution, and containing laughable mish-mashes of science and religion.

Bad science teaching in our schools and wide-spread scientific illiteracy has made the siren song of unreason ever more sonorous and attractive. In older times the idiocy of the "aamils", pirs, and mullahs and assorted soothsayers was accepted by just the ignorant and illiterate. But today college graduates, as well as the rich and powerful, now calmly accept this as high wisdom.

Good science education alone can change this. The demons of superstition can only be chased away by those who have learned science the correct way. But for that we may first need a major cultural and attitudinal change that permits real science to be taught in our schools.

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