The Importance of Experiments

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A School Experience

One of the school experiences that I recall most vividly is from standard VIII when a trainee teacher from the local Teachers Training College gave a demonstration of a siphon in our class. It was to me totally unexpected that without any pumping action water should flow upwards and then drop down. Later in my house I repeated the experiment with a rubber tube, the water storage tank and a bucket... and it worked.

Although the teacher gave an explanation of the phenomenon, I doubt if it would have registered in my brain so effectively had there been no demonstration in the class. And, of course, my own repetition of it drove home the reality of the effect much more thoroughly.

I think there is a moral here. Science has evolved through experiments and observations as much as it has through theoretical speculations. Indeed, without the former the latter would have been no more than a branch of philosophy. The crux of a scientific experiment is that it is repeatable, is independent of who conducts it and demonstrates some basic fact of nature.

The Role of Experiments in Science

Perhaps no one appreciated the importance of experiments as much as Michael Faraday who himself was a master of the art of experiments. It was no coincidence that the science of electromagnetism took a leap forward when he was on the scene. Realizing the crucial role of experiments, he introduced the system of lecture demonstrations during his tenure at the Royal Institute in London. That tradition is till continuing to this day in that august institution. Distinguished scientists have conducted lecture demonstrations before students and their effect on the audience has been proven to be tremendous.

But long before Faraday, the significance of experiments in science was underscored by Galileo who refuted several of the then current beliefs by actual demonstrations to the contrary. His famous book on the *Dialogue Between Two World Systems* is full of accounts of such experimental demonstrations. Prior to that the tradition had been verbally to argue a point *ad infinitum* without testing reality. What makes an arrow soar through the air after it has been shot from a bow? The air pushes it, argued the Aristotelians who believed that a continuous application of force was needed to make anything move. Galileo asked: Where does the air push? On the back end, answered the Aristotelians. So if the arrow were moving perpendicular to its length, the push should be more. Hence if the arrow were shot on the broadside (i.e., lying parallel to the bowstring), it ought to go farther. Having got his opponents to agree to this statement based on their traditional beliefs, Galileo picked up an arrow and shot it on broadside... it naturally did not get very far. No amount of argument would have gone as far towards disproving the popular belief as this single experimental demonstration.

These historical examples are not limited to proving what was the role of experiments in sciences in the old days: they show that *even in the old days*, experiments were important. That they are so today is without any question. From nuclear fusion to the expansion of the universe, from high temperature superconductivity to Bose-Einstein condensation, the proof of any scientific

amongst schoolchildren. Can we not think of Royal Institution type programmes of lecture demonstrations at a few national laboratories where children from local schools are invited?

At the junior college and undergraduate levels there is need to innovate and modify the experimental programme. Workshops conducted by experts with new experiments demonstrated on site may go a long way towards creating the spirit of innovation amongst the teaching faculty. One such workshop was conducted at the Rajasthan University with UGC support and it may set a new trend. Unless there is a periodic review and evolution of the curriculum for the undergraduate laboratory, staleness inevitably sets in.

The postgraduate programme should have a research component built in: the students should be encouraged to take up experimental projects within the ongoing research programme of the faculty of the department. This way the student will get to share the excitement of working on an experiment whose answer is not known beforehand. And it will not be unusual if the faculty member gets a new insight into his or her research through the questions asked by the student.

The Role of a Journal for Science Teaching

It may not be possible to carry out all these reforms at all places for lack of resource persons and money. This is where a journal devoted to the teaching of science has a unique role to play. *Physics Education*, for example, can include literature on all the above efforts going on in the country and even abroad. Specific new experiments could be described by their innovators. New research projects for the postgraduate laboratory can be outlined. A ''trouble-shooting'' column may advise teachers on their specific problems which may include solutions to typical maintenance problems arising with experimental equipment. Information may be provided on new equipment in the market.

But I believe, that the *PE* should not draw the bottom line at the college level, although it may wish to emphasize it. Ideas relevant to school science education may also be discussed and new classroom demonstrations described. Striking demonstrations of scientific laws in operations will impress the child far more than textbook pages.

I am basing this last remark on my own experience of the ''siphon experiment''.

idea is not complete until it is experimentally or observationally demonstrated.

Experiments in Teaching

Having accepted these facts, it comes as a shock and disappointment to see the relatively superficial role of experiments in our teaching of science at all levels. Let us concentrate on the undergraduate physics programme.

We may ask, how many teaching hours are spent in actual experiments or experimental demonstrations? Are the experiments keeping pace with the changing face of physics? Are the laboratories equipped with apparatus to enable the students to do their own experiments themselves? Does a teacher bother to relate the experiments to theory or are the experiments routinely performed to get the prescribed answers? How clearly does the student appreciate the nature of experimental errors, random as well as systematic?

Alas, in our educational scenario the typical answers to these questions are very disappointing. Far from appreciating the role of scientific experiments in discovering and quantifying the properties of nature, the student is made to perform them as rituals towards passing the examination. The state of the typical undergraduate laboratory may be such as to discourage even the innovative student to do experiments. Nor is he made aware of the fact that an experiment will have inherent errors that will prevent him from getting the answer established over the years with the best professional apparatus. On this last count let me cite an interesting episode.

The Role of Errors in Experiments

I recall that when I was an undergraduate at Cambridge University, an experiment was reported in the press, an experiment confirming the principle of equivalence in general relativity. The experimentalists at the atomic energy establishment at Harwell in the UK had measured the increase in the frequency of a photon as it drops down a height. The photon had been emitted by the decary of a Cobalt-57 nucleus into an Iron-57 nucleus at the top of a tower. As the photon came down it picked up energy (and so had an increase in frequency) due to free fall under gravity. Hence it could not be absorbed by an Iron-57 nucleus at rest at the bottom of the tower in the inverse reaction, unless it was given a Doppler motion to compensate for the frequency change of the photon. The experiment claimed to show that the frequency increase was exactly as prescribed by a gravity theory using the principle of equivalence.

Such an experiment had previously been conceived but had been impossible to execute until the discovery of the Mössbauer Effect which enabled such nuclei to be held in a crystal which would absorb any recoil momentum when a nucleus emitted or absorbed a photon. Thus the 1960 experiment was the first such attempt to measure a very small gravitational effect.

A fellow undergraduate in my class, working in the Cavendish Labs, however, raised a question. Had the temperature difference at the top and bottom of the tower been taken into account to allow for thermal effects in crystals? He worked out that even the difference of a degree or two would produce errors in the measurements that would vitiate the conclusion. His paper was published in *Physical Review Letters*. The experimentalists had indeed not taken the effect into consideration and thus their results fell apart. The experiment was subsequently repeated by another group in the United States with adequate controls on the above error and the veracity of the principle of equivalence was confirmed.

I may reveal the name of the precocious undergraduate: he was Brian Josephson, who a few years later, as a research student for Ph D went on to discover the Josephson Junctions, a discovery that earned him the Nobel Prize.

The Need for Reform

Various corrective measures come to mind when thinking about how to encourage the spirit of experimentation at all levels, from schools to the postgraduate stage. Hands on demonstration models like those found in science centres can go a long way towards creating the spirit of "experiment and explore"