Preparation to Read *The Evolution of Physics* by Einstein and Infeld

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1. Educatedness and *The Evolution of Physics*

The word 'educated' may be said to have at least two meanings:

Meaning 1: *Those who have gone through the experience of educational institutions and have degrees and certificates.*

Meaning 2: *Those who have educated minds, regardless of the educational institutions they have been in and regardless of the degrees and certificates they have.*

In terms of meaning 1, someone who has a Master's degree is 'more educated' than someone who has only a Bachelor's degree. In terms of meaning 2, 'educatedness' as a quality of mind, we can say such things as "X has not completed class 10 and does not have a school leaving certificate, but he is truly educated" and "Y has a PhD but has had a deeply flawed education."

Let us imagine that a subset of Bachelor's students and those who already have Bachelor's degrees are keen on becoming educated in terms of the second meaning of education. If I were to select five books to recommend enthusiastically to that subset of learners who may or may not be 'students', *The Evolution of Physics* by Albert Einstein and Leopold Infeld would definitely be one of them. (Free pdf copies of the book are available on the internet.)

Twenty-five years ago, I used to think that anyone who is sixteen or above and had the ability to read and comprehend written materials in English can learn from the book. During the last few years, I have been responding to questions from a few learners who have chosen this book as their reading-learning project. And this year, I have been working closely with three groups of learners who have taken up *The Evolution of Physics* as their reading-learning project. Given that experience, I must say that I no longer subscribe to my earlier view. The book is not easy reading: it calls for guidance from an experienced mentor.

What follows are my current thoughts on what makes learning from *The Evolution of Physics* a challenging activity, and how we can help the learners in their struggle to learn from the book.

I make a distinction between students and studying on the one hand, and learners and learning on the other.

I use the term 'student' to refer to

> those who are enrolled in an institutionalised educational program,

and 'studying' to refer to

> doing whatever students are required to do in order to do well in the tests and exams in those programs.

Those who are not enrolled in such programs or have completed the programs are no longer students. For instance, university professors are no longer students (unless they are registered in some course.). In contrast, learning can take place till (the body or mind of) a person dies. Conversely, real learning need not happen during the programs in educational institutions. In this sense, one who has retired as a full professor can still be learner: I regard myself as fortunate that I am a learner though not a student.

The remarks given below are about learning, and about the obstacles that the process of studying tends to create for meaningful learning.

2. Institutionalised Concepts of Science and the Scientific

Most students (and those who are employed in educational institutions) think of 'science' in terms of subject matter and the institutionalised classification of academic knowledge. From this perspective, physical sciences, biological sciences, and medical sciences are 'sciences' while social sciences are not sciences. And as for the issue of whether or not cognitive sciences and behavioural sciences are sciences, I think the conventional classification doesn't seem to have much to say.

Interestingly, 'geography' in the conventional system is not classified as a science, while 'geosciences' and 'earth sciences' are classified as sciences, regardless of the subject matter or the strategies of inquiry employed in these domains. That means the distinction between science and non-science is just a matter of labelling, not even subject matter.

Suppose we were to change the current classificatory system, and use the term 'science' to denote

a body of knowledge that results from the process of scientific inquiry,

such that we recognise the physical sciences, the sciences of life, the human sciences, society, the behavioural sciences, the cognitive sciences, and so on as sciences. Extending this line of thinking, we may use the term 'mathematics' (occasionally called mathematical science) to denote

a body of knowledge that results from the process of mathematical inquiry.

and the term 'philosophy' to denote

a body of knowledge that results from the process of philosophical inquiry.

As you can see, we are shifting the focus of attention from the domain or subject matters of inquiry to the ***modes*** of inquiry, such that topics like learning, mind, or language, can be studied in terms of mathematical inquiry (in which case the outcome would come under mathematics), scientific inquiry (in which case the outcome would come under science) or philosophical inquiry (in which case the outcome would come under philosophy.)

Let us assume that the above distinction between ways of knowing on the one hand, and the bodies of knowledge resulting from those ways of knowing is an important one. Let us also assume that the classification of knowledge outlined above is desirable. Even so, these by themselves are not sufficient, even if we accept that they are necessary.

Standard textbooks and classroom practices in current institutionalised education in India (and other parts of the world) present these statements to students as infallible objective truths, as dogmas that cannot be doubted or challenged, not subject to sceptical, critical examination.

To illustrate, take the body of knowledge that we call 'physics' or 'astronomy', resulting from the process of scientific inquiry, in terms of theories like classical mechanics, relativity, quantum mechanics, and the heliocentric theory. Now, these bodies of knowledge can be taught as either dogma, something that needs to be accepted without question; or a body of fallible, rationally justified conclusions based on systematic observation. As it happens, most science textbooks and science programs in current mainstream education teach physics and astronomy as collections of statements that offer absolute objective truth, very similar to the kinds of 'religious knowledge' provided to students going through religious instruction. As an example, take the following statements:

> Any two bodies in the universe attract each other with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.
>
> The earth revolves around the sun in an elliptical orbit and rotates on an axis tilted to its plane of revolution.
>
> All existing and extinct forms of life evolved from unicellular life forms of life.

Most standard textbooks and classroom practices in current institutionalised education across the world present these statements to students as infallible objective truths, that cannot be challenged or subjected to sceptical, critical examination. Given that practice, it is not surprising that those who have been through such a system of indoctrination find it hard to understand the concept of scientific inquiry as an uncertain, fallible enterprise guided by the canons of rationality, the position outlined in *The Evolution of Physics*.

That lack of understanding directly functions as an obstacle to understanding what is meant by the 'scientific temper' that the Constitution of India requires of all its citizens, let alone the understanding of the concept of rational temper that covers not only science, but also mathematics and philosophy.

3. Scientific Thinking and Scientific Theory vs. Data Gathering

Scientific inquiry is commonly perceived as the activity of

- (a) gathering data,
- (b) conducting experiments in laboratories
- (c) using instruments and equipment, and
- (d) using statistical or other types of calculations to process the numerically coded data,

to arrive at or defend

- (e) observational generalisations (called hypotheses)

The combination of (a) – (e) is what may be called ***observational science***.

In conventional education, ***theoretical science*** (enshrined as theory periods vs. lab periods), is typically taught as a bunch of 'facts' in standard textbooks and classrooms. As a result, activities designed to develop the capacity to construct and evaluate theories is absent in institutionalised mainstream curricula.

That capacity calls for

- (f) insight, imagination and reasoning to come up with theoretical concepts and propositions,
- (g) capacity for conceptual inquiry to unpack and critically evaluate those concepts and propositions,
- (h) ability to articulate these concepts and propositions with clarity and precision, and

(i) ability to engage in rigorous reasoning, using formal logic where required, to deduce the logical consequences of theories, to justify conclusions, and to justify the theoretical concepts and propositions

At the core of *The Evolution of Physics* is the evolution of theoretical concepts and ideas in physics, using only the outcome of observational science ((a)-(e)), without even mentioning equations, formulae and calculations. For a typical Bachelor's student hoping to major in physics, knowledge of the subject called 'classical mechanics' is equated with an understanding of such things as mass and weight, velocity and speed, vector, and equations for the laws of gravity and motion. The subjects called heat, electricity, magnetism, optics, quantum mechanics, and relativity, and so on are also treated in a similar manner, as information and application. They are unlikely to include questions like "Is time real?", or concepts like "the unreasonable effectiveness of mathematics in physics", "backwards causation", and so on. It definitely does not involve questioning why physicists tend to think in terms of causation - e.g., gravity causes the falling of an apple in a straight line" - even though the concept of cause does not find a place in any of the equations in physics.

The Evolution of Physics does make references to what is taught as physics in textbooks and classrooms, occasionally saying something to help make those familiar concepts more understandable, but that is not the point of the book. What it does is to outline the ***evolution*** of the ***ideas*** – the ***concepts*** and ***propositions*** – which have shaped the evolution of theories in physics; and the thinking, the insight, and the conceptual clarification that went into the evolution of the theories; which in turn led to the equations and derivations we see in standard physics textbooks.

Einstein knew that there are dozens and dozens of excellent textbooks to teach students how to calculate results and give derivations. He was trying to do what only an Einstein could do, to show learners what lies behind those equations and derivations.

What can we learn from this book? We can learn about some of the ***fundamental questions*** that physicists (and scientists in general) ask, some of the ***strategies*** they employ when looking for answers and ***constructing theories***, how they ***evaluate*** theories and ***choose among*** competing theories, how they ***reason*** and arrive at conclusions, and so on.

Many physics students invest considerable time and effort to understand the exposition and to work through exercises in standard textbooks such as

The Sciences: An Integrated Approach by James Trefil and Robert Hazen,

and

Fundamentals of Physics by Halliday, Reznick, and Walker.

They also attend the classes conducted by competent physics teachers/ professors. For them, the discussion of (f)-(i) without (a)-(e) in *The Evolution of Physics* would indeed be quite perplexing. They may not even recognise it as 'rigorous physics' since they typically equate 'rigour' with mathematical derivations and not with conceptual clarity or rigorous reasoning.

Those who have grown up with religious fundamentalism that holds the Sacred Scriptures of one's own religious community (whether the Bible, the Koran or the Gita) and only those Scriptures have the words of God, might experience some degree of bewilderment when they are introduced to the philosophical debates in ancient South Asian philosophy on such issues as monistic *Brahman* concept and the dualistic *Purusha-Prakriti* concept, *nirguna Brahman* vs. *saguna Brahman*, and whether or not scriptures are legitimate bases for knowledge. They may not even see that these discussions come under 'religious' philosophy. The bewilderment experienced by physics students when reading *The Evolution of Physics* is quite similar.

4. Epistemology and Ontology of Scientific Inquiry and Knowledge

Underlying the capacity to engage in scientific inquiry that involves (f)-(i) above is the understanding of

> the epistemology (the study of the nature of knowledge and ways of knowing) and
>
> the ontology (the nature of the 'reality' that we seek knowledge of)

of scientific inquiry and scientific knowledge.

To arrive at what we take to be 'scientific knowledge', we need to have a clear concept of what we mean by 'knowledge' and the ways of seeking it; but then these are grounded in our preconceptions of what we take to be 'reality' , and in turn, they are modified by the knowledge we acquire through our epistemology.

Consider this: is what we call 'Nature' governed by logically consistent principles of organisation? That is a question about reality, but if the answer we choose is 'yes', then it follows that the knowledge of that reality must be free of logical contradictions. Thus, our preconceptions of reality shape the epistemic principles we employ in our inquiry.

To take another example, is what we call 'Nature' governed by a set of logically connected, integrated and unified principles of organisation? If the answer is yes, the knowledge that we construct also must have those properties. Does everything have a cause? The answer has an immediate consequence to the methodological strategies we adopt in our theory construction.

We won't go any deeper into some of these issues of epistemology and ontology, but what we have already said must give an inkling of the need for at least a rudimentary understanding of epistemology and ontology as preparation of reading *The Evolution of Physics*.

Now, as I said in the beginning, reading *The Evolution of Physics* and understanding what it offers would be of immense value to those who wish to become truly educated. Is it possible to create a reading course such that anyone above sixteen can learn from this book, such that what they learn about the evolution of physics can be generalised to the evolution of science, and, as the next step, to the evolution of academic knowledge?

My answer is 'yes'.