

# Teaching Science: Content, Method and More?

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*Science is more than facts, concepts, theories, mathematics and experiments. In the long debate on what science really is, many scientists and philosophers tend to describe science not in terms of its content, but in terms of its approach and method. Thus, definitions of science are often expressed in terms of 'a body of knowledge', 'systematic approach to knowledge', 'critical enquiry into the nature of the world' and so on. Unfortunately, the problems and exercises are rarely taught as method. Instead, they have become tools to discipline the intellect of the students; more a strategy to evaluate the intelligence and competence of students. If, instead of packaging science as is done in our school textbooks now, the same content were presented through a larger framework of human and social interaction through the disciplines of social science and humanities, we might have students with a deeper understanding of science.*

What is it to teach science? How does the teaching of science differ from the teaching of other subjects? Is the difference only in the content of the subject which is taught or is there something else that is unique to science teaching, such as a process of thinking and a process of integrating? But even if we focus only on the content, are there explicit guidelines for choosing the content? For example, can the content include histories and philosophies of science as an integral part of teaching science? Or, if we consider teaching science as including the teaching of the methods of science or of teaching particular ways of thinking and arguing, then should subjects like logic and the philosophy of reason be included in science textbooks?

What should be taught and how it should be taught are also related to the larger aims of science education (SE). Why are we teaching science as a necessary subject for all school students? The belief that science teaching (ST) is necessary right from primary school is based on the view that science is an exemplar of knowledge in today's society and that a student in the contemporary world should know something about science. There is also a related belief that if education is to make students productive citizens of human society, then they should learn science since our contemporary society is a

scientific and technological society. Thus, the underlying belief seems to be that unless the students learn science, they may not be productive citizens in the long run. But given that there are a large number of people who do not work in science or use science in their profession, the aim of science education for *all* students cannot be to make all of them be a part of a larger scientific profession.

Not every student who studies science is, or should be, expected to make a career in science. This is exactly like the motivation for teaching subjects like literature or history. Not every student who studies literature is expected to become a writer. So in one sense, teaching science for every student is like teaching literature as part of the school curricula. It makes the students aware of these important human activities. It makes them scientifically literate without necessarily making them professionals in the domains of science. However, if this is the aim of science teaching then that will influence what and how something is taught. After all, in a class of say 50 students, perhaps more than half will not continue with science as a subject for higher studies. In such a scenario, what kind of science content should be taught? Should it be focussed on the students who will go on to study science and thus give them more content and more rigorous approach to the subject, or should the content be averaged out over all the students? This is the primary challenge in science teaching today since students who study science subjects seem to study it primarily for future careers in science and technology. Since we do not factor this differential future of our students, we have created generations of students who are traumatised by science and mathematics education and come out of school not wanting to do anything with these subjects.

The difficulty which students face in science and mathematics education is exaggerated by the method of teaching these subjects. They are most often taught as a set of specialised skills like problem solving with numbers and operations, or with problems relating to natural phenomena. Very often, the textbooks introduce some scientific concepts and expect the student to master certain kinds of skills. Rarely do you see teachers actually teach these subjects from a broader perspective, one that draws upon the world experience of the student.

These issues have been part of a long debate in SE. In particular, the discussion on the inclusion of the nature-of-science as part of science teaching responds to the specific problem of what it is to teach science. But even if we acknowledge that the nature-of-science has to be factored into ST, it is still not clear as to what elements of this nature have to be incorporated.

The structure of science textbooks does encode some aspects of the nature of science. For example, the questions and problems to be solved are an integral part of the lessons. A student who learns science learns by solving these problems. An essential part of science has to do with the use of both the experimental and theoretical methods. In general, textbooks would engage – however peripherally – with the experimental method.

So, in a sense, one could then argue that science textbooks not only have a content of science but they also incorporate the nature of science both explicitly and implicitly. However, there are various themes that are usually omitted in this content. For example, the history of concepts may not find a place. So while a concept like acceleration would be introduced in a lesson, the reasons why that concept was first used would not be found in the text book. Nor will there be a discussion of the historical trajectory of that concept: how it is related or indebted to other ideas, how its use changed over time and so on. In the case of certain concepts like mass or force, there will usually be no historical description of these concepts or even how different cultures have understood these concepts.

Should these elements be part of a science textbook? Those who reject the addition of these ‘extraneous’ elements end up primarily projecting a linear and simplified view of science. But, in their defence, they might say that science is defined only by its content as is accepted currently and other historical, philosophical or sociological issues are not relevant for teaching science.

However, this argument is based on the assumption that science education is primarily meant to make scientists out of students, or at the very least to give them technical competence over scientific concepts, theories, tools and related aspects of science. But, as mentioned earlier, only a fraction of the students who study science go on to use these technical aspects and knowledge of science. Thus, are we doing justice to the large number of students who are left out through this approach to science education?

A counter argument to this could be that the hope is to create as many trained science students as possible. If at the end of it, only a fraction continue with science it has more to do with the intellectual competence of the student and should not be seen as a mistake of pedagogy or related aspects of science education. I would argue that this claim is simplistic; and that equating intelligence and intellectual capability with a capacity to do some specific acts related to science is a very limiting view and has harmed the prospects of a large number of students over the years.

In saying this, I am not negating the importance of rigorous training in the complexities of science. Perhaps those who are competent in it and who have the capacity for it can be trained in this manner. But the problem of uniform science teaching in schools is that it imposes certain specific kinds of skills in science and mathematics as the baseline parameter for education and when some students don’t perform to this level, their educational career suffers. After all, education must be more than mere science and mathematics education.

### **Missing from Science Textbooks**

So, to motivate this discussion further, let me look at some specific absences in science textbooks and argue why their inclusion will help make science education far more

effective, not just in producing good science students but also in not excluding many students because of the lack of particular skills.

We can begin by looking at the material that is accepted as being part of science. What are the subjects that are taught as science and who decides on it? For example, lessons on cosmology often do not mention the narratives of many different cultural views and imaginations of the universe. Even in texts which give a brief introduction to the origins of science, one usually finds mention of some Greek thinkers to the exclusion of contributions from other cultures, including India. For example, it is very common for students to get exposed to Pythagoras theorem with absolutely no mention of this result being derived by other means in Indian mathematical texts.

When we look at biology, for example, there is almost no mention of the way human body was understood in ancient times in different cultures. The description of the human body is given as if it was always understood to be so, and the mention of a few select European scientists tend to add to the mystique that a few scientists had this extraordinary capacity to grasp these truths. Such presentations are not only misleading but untruthful. Even Harvey's theory of the body and the model of the heart as a pump, had its origins in earlier work, including that of Chinese theories of the body.

In the case of medical sciences, we can note the absence of different medical traditions like Ayurveda that are still practiced today. These are extremely efficacious systems which are followed by millions, but which are not accepted by scientists as being part of science. Thus, even in the choice of content, there is an implicit decision made about what constitutes science and what doesn't. For many cases, such a choice may be justifiable – for example, astrology – but there are also many other domains where the choice is contentious.

The removal of other contexts in describing science succeeds in presenting science primarily as a set of facts. This gives a wrong picture of science and also of scientific knowledge. How did these facts come into being? Historians of science have charted the history of how scientific knowledge developed and it is important to introduce concepts to children through such narratives instead of the concepts-fell-from-the-tree narrative. This historical approach makes it easy for the students to understand the difficulty of concept creation not as a personal moment of inspiration but as a historical, collaborative and contentious process. By giving them this narrative, we make the students think about how these concepts came into being and thereby engage critically with the meaning of these concepts.

There is voluminous historical material on various theories and experiments of science. There are also rich accounts of the multicultural origins of science. If all this can be somehow factored into the teaching of the content of science, the learning of science not only becomes more engaging but the social character of science will also be clearly exhibited. In the larger context of ethics, it is necessary that students understand

that knowledge production in a society is a social process and that there are ethical dimensions to it.

Science is more than facts, concepts, theories, mathematics and experiments. In the long debate on what science really is, many scientists and philosophers tend to describe science not in terms of its content, but in terms of its approach and method. Thus, definitions of science are often expressed in terms of ‘a body of knowledge’, ‘systematic approach to knowledge’, ‘critical enquiry into the nature of the world’ and so on. Some of the ways by which this method distils into the textbook are through exercises and problems. These exercises are designed to make the student think about a problem and find the means to solve it using the tools of mathematics, diagrams and so on. In a sense, this component of a lesson is primarily a way to teach scientific method, its processes of evaluation, of using evidence, of bringing theory and experiment together, and to process all these elements in a unified manner.

Unfortunately, the problems and exercises are rarely taught as method. Instead, they have become tools to discipline the intellect of the students. They become more a strategy to evaluate the intelligence and competence of students. Since the correct answer is so much emphasised in these problem sets, the students tend to think of science as a collection of facts instead of seeing these problems as an illustration of a particular way of thinking about problems.

Many times, even the science teachers are not aware of the relevance of exercises and problems in defining science. The reason for this is that science teachers are also normally not conversant with the disciplines of history and philosophy of science. In fact, I would argue that this lacuna is far more damaging to science teachers than the students. It is the teachers who must first be exposed to these disciplines since it makes the teachers understand science better and thus be able to teach it more effectively.

Why should philosophy of science matter to science teaching? Philosophy of science has largely been concerned with some fundamental questions about science such as the nature of scientific knowledge, the special character of scientific explanations, the meaning of scientific laws, the role of mathematics in the sciences, the structure of scientific theory, the character of experiments and observation, and the relation between theory and observation. Philosophy of science is a rich source of reflections on the nature of science and all that goes into the name of science. It also takes seriously the question of the existence of objects that science postulates, such as atoms, electrons, molecules, DNA at one end, and galaxies and blackholes at the other end. It gives us a way of making sense of the complex narratives of science.

One would think, as indeed scientists in Europe in the early 20th century did, that knowledge of philosophy of science would be very useful for doing science. We can extend this observation to science teaching, since through philosophy of science, the student can be taught the nature of science and of scientific method. Again, I believe

that it must be the teacher who must first be exposed to this, since their teaching of science will radically change after this exposure. They will be able to understand why certain concepts are developed in science, and they will be able to engage with problems not merely as a tool for evaluation but also as a tool for teaching scientific thinking. They can teach mathematics in different ways once they understand how and why mathematics came to play such an important role in the sciences. They will be able to teach students the meaning of unobservable entities which science often invokes. If through philosophy of science they get exposed to the basic methods of logic, then they can actually tell students how and why science is logical. Without knowing this, calling science logical is only a rhetorical claim. Through philosophy of science, they can communicate these ideas of logic and its relation to science to the students.

Those who say that philosophy of science is not relevant in science teaching miss the point that specific histories and philosophies of science are already present in the text the moment certain material is chosen, a specific set of problems are given as exercises, and an order is given to the text. So, I think that the question is not whether history and philosophy of science are essential for science education but more a question of what kinds and how much of these subjects should the teacher know and how much the student should.

Similarly, there is a rich amount of material available from the sociology of science. This subject describes the social character of the practice of science and scientists. It also shows how social and cultural factors influence the type of knowledge that is produced and legitimised. In other words, it shows us how scientific knowledge is not a mere product of private intellectual capabilities, but is more a product of social, economic, political and cultural factors. Why is this information useful for science education?

First of all, if science teachers are aware of these influences, they can demystify difficult scientific concepts and situate them within ordinary human activities. They can make science far more human, which it really is and which has been glossed over by textbooks for the specific reason of making science seem like a domain of knowledge outside human influence. They can also understand how the vagaries of human thought and action create these powerful scientific theories. There are two other important lessons that both teachers and students can learn about science when they enter science through the portals of history, philosophy and sociology of science.

First is the importance of the scientific imagination. Historically, imagination has often been viewed with suspicion since it has been closely associated with fiction, unreal worlds and so on. Imagination was also contrasted with reason, which came to be associated with science. However, without imagination there is little science that is possible. Science is not formal logic only because it draws upon specific modes of imagination. This capacity for imagination not only creates new ideas and theories but also helps to validate them.

There are numerous examples of the role of scientific imagination in the practice of science. Holton isolates thematic imagination along with visual and analogical imagination as being crucial to the creation and legitimisation of scientific ideas. As examples of imagination in science, consider how the atom was first visualised as the solar system even though they are dramatically different systems. I use this example because it is so common in science textbooks. Visual thinking is in fact one of the most important ways of teaching science. For example, look at the kinds of charts and diagrams that are used in science. Atoms and molecules are taught using physical models of balls and rods. Pictures of events are often drawn and schematic diagrams of experiments are integral to science teaching. What the students and teachers may not be aware is that these visual representations are not only pedagogical tools, but are actually ways by which scientific research advances. There is a large amount of work on the area of imagination in science which will in principle be very useful for teachers and students to know.

The second important theme from HPS is the role that mistakes and errors play in the practice of science. Unlike the picture of science that emerges from science textbooks, science is not about truth and deriving correct answers all the time. In fact the production of science is based on a large mass of discarded ideas, theories, calculations, concepts and experiments. This aspect of science is not reflected in textbooks which only ‘factualise’ science, i.e., present it as a domain of facts that seem outside human intervention. Moreover, there are many important theories which are accepted as true today that were actually discovered in error. Many experimental discoveries have often been made through accident. Sometimes these accidents are due to lab workers who make a mistake which leads to new discoveries that have led to the Nobel Prize! There are also many examples where mistaken theoretical assumptions or even mistakes in calculation lead to new ideas, which later turn out to be true. While some scientists might place these kinds of examples under the domain of creativity, we should also recognise that these play a major role in the creation of new scientific knowledge. This is true not only of radically new theories, but is also part of everyday science.

Brining these views of imagination and error into the content of science textbooks humanises science as a subject. This, I believe, will make science education far more effective, efficient and also easier to learn. Instead of packaging science as is done in our school textbooks now, if the same content were presented through a larger framework of human and social interaction through the disciplines of HPS, we might be surprised at how many more students will end up doing science and understanding it better!

## Suggested reading

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