WHY SCIENCE MATTERS

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Oftentimes, a collection of 'facts' is mistaken for science and the process that leads to those facts is ignored. Science is a process of discovery and a way of thinking. Our approach to teaching it needs to reflect key aspects of its process and practice.

Until about 20 years ago, we were taught that our solar system had nine planets. But in August 2006, the International Astronomical Union (IAU) demoted Pluto from its position as the ninth planet from the sun to one of five ‘dwarf planets’.[1] Ever since, we are being taught that our solar system has eight (major) planets instead of nine. Such changes have occurred earlier too. Uranus and Neptune were discovered in the 18th and 19th centuries respectively. The presence of Pluto was confirmed in 1930. If we allow ourselves to, it would be interesting to wonder what was taught about the solar system before these discoveries were made.

Facts, like those about the major planets in the solar system, change with new insights, discoveries, and a reanalysis of existing data. If teachers rely solely on the information in science textbooks and use didactic methods of teaching it, students learn to see science mainly as a ‘conglomeration of facts’ rather than as a way of thinking. Such an introduction may help students meet the requirements of contemporary school evaluations, but impacts their perception of its practice and relevance in their real worlds. These impacts can range from a mild apathy towards ‘factual’ science to a general distrust of science and, worse, the denouncement of scientists and scientific practice.

Distrust of science raises its head frequently and on a variety of issues of great societal interest—be it climate change or effective individual and societal responses to the COVID-19 pandemic. These issues are often complex and lend themselves to questions like: is the current crisis of global warming natural or are human activities causing it? How do we know which of these is true and how much of it is true? On the one hand, public debates between scientists can help bring attention to opposing perspectives. Debate on the interpretation of new knowledge is, after all, an intrinsic part of the process of science. On the other hand, those unfamiliar with this process can (and often do) misinterpret such debates as being a sign of 'lack of knowledge among experts'. If we think of science as being only a list of answers (or facts), then open questions can be unsettling.

For students to appreciate the relevance of science, we must teach it in ways that highlight some of these aspects and their possible implications for teaching practice.

The practice of science

The modern usage of the word 'science' refers to a systematic study of the natural world in its many facets. While this may not be evident, science is an active process and pursuit of discovery.

Why do we engage in this pursuit? Because human beings are naturally curious and the process of what we refer to as scientific thinking is innate to humans. This process involves observation and experimentation, both of which are subject to human perception and to the analytical tools available to us at any given point of time.

Perhaps the best example of this process can be seen in the San hunting tribes indigenous to South Africa. Their hunt for an animal starts with an observation (pug marks in the sand, for example), a hypothesis is formulated (direction the animal went), a course of action is decided (the equivalent of research methods) and pursued till conflicting evidence is found (overlapping pug marks), at which point an alternate hypothesis is formed. Even though the San are miles away (literally and metaphorically) from the schooling you and I see in the 'civilized world', their actions follow the same thread as any scientific investigation: observation → hypothesis → experimental methods (to test the hypothesis) → record results → analyse results (whether they support or contradict the hypothesis) → develop alternate hypotheses in case of contradictory results and follow-up accordingly.

How does science progress from individual observations? Remember the parable of six blind men describing an elephant (see **Fig. 1**). Each of these men tries to figure out what the entirety of the elephant is by touching only one part of it. In doing so, one of the men likens the elephant to a fan (its ear), another to a pole (its legs), a third to a rope (its tail), and so on.[2] Quite interestingly, this story is reminiscent of the pursuit of science. Different scientists pursuing a common question follow essentially the same process to discover different parts of the puzzle. Unlike what is frequently presented in textbooks, our understanding of how these different parts fit together to make a whole is hardly ever linear. An example of this can be seen in the progress of our understanding of not-so-obvious phenomena like the construction of the solar system and its workings. This has involved a long-standing tradition of using a growing amount of knowledge to create models that can best explain related phenomena. This process is iterative, has continued over several centuries, and involves people from different cultures.

The history of science is also replete with examples that underscore how our factual knowledge of a phenomenon is subject to the clarity of our perception and the tools available to us at a given point of time. Often, limitations in previous ideas and technologies can result in an incomplete understanding of the phenomenon. In such cases, our understanding can improve with deeper study and better tools (see **Box 1**). In some cases, erroneous interpretations

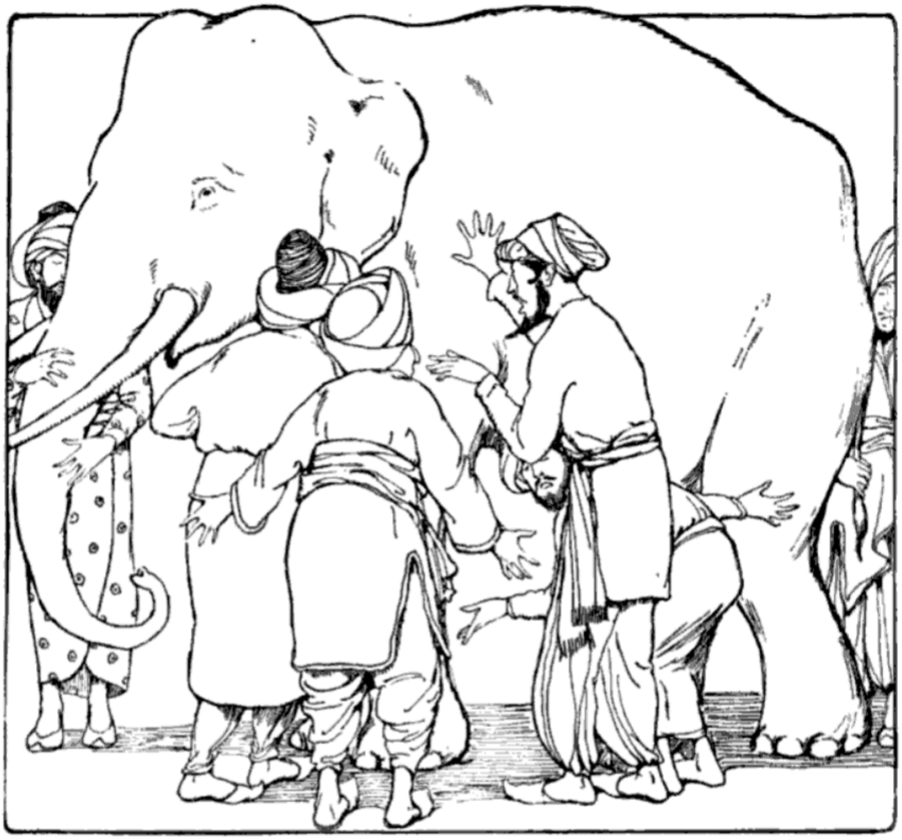

Fig. 1. The six blind men and the elephant.

Credits: From Martha Adelaide Holton & Charles Madison Curry, Holton-Curry readers, Rand McNally & Co. (Chicago), p. 108. Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Blind_men_and_elephant.png. License: Public Domain.

and inferences can lead to a misunderstanding of the phenomenon. Some of these errors can survive for a long time before they are corrected and resolved. These examples point to how 'what we know' at any given point in time is unlikely to be the complete picture. This poses a great opportunity as well as a challenge. The opportunity is for those eager to delve deeper into the secrets of nature. The challenge is for those who struggle to reconcile with the incompleteness of available knowledge in their efforts to comprehend nature's workings.

It is not just the facts of science that change. The practice of science is itself changing. For example, the distinction of what counts as 'basic' and 'advanced' is changing rapidly with time; it always has. Traditional boundaries between physics, chemistry, and biology are getting increasingly blurred. The role of science in society is also considerably different from what it was just a generation ago. Climate change, genetically-modified crops, and gene editing in humans are just a few examples from a long list of issues of societal relevance that scientists grapple with today. The resolution of these complex issues is no longer the onus of a select few. In addition to scientific knowledge (of the issues as well as their potential social impacts), it will involve elements of policy and a scientifically-literate citizenry.

Implications for teaching practice

In teaching science at the school level, our aim, above all else, should be to foster scientific thinking in students. Folklore and anecdotes can make their way into the lives of our students as 'immutable facts' rather than 'testable ideas'. Students ought to question the 'common wisdom' in things like *"cold weather makes you catch a cold"* or *"the human body is designed for a vegetarian lifestyle"* (see **Box 2**). Time spent in the science classroom ought to give them tools to critically analyse and dissect myth from fact in the stories they hear. It is also important for them to be able to dissociate the 'age' of the fact from

Box 1. The paradox that was the beginning of modern neuroscience:

The history of neuroscience offers an excellent example of how improvements in tools lead to an enhancement of knowledge. In 1871, the German anatomist Joseph von Gerlach proposed that the central nervous system was an exception to the cell theory. Rather than being made up of individual cells, it consisted of a single continuous 'network'. This was called the reticular theory. In 1873, the Italian physician Camillo Golgi was studying the structure of the nervous system. He found that the methods of staining available at the time were inadequate in revealing the finer details of brain tissue—they marked all parts of this dense tissue homogeneously. Golgi developed a more effective method of staining nervous tissue. Called silver nitrate staining, this tool revealed what seemed like a single continuous network of highly branched membranes (which are today referred to as dendrites). Golgi saw this as evidence to support the validity of the reticular theory. The Spanish pathologist Santiago Ramon y Cajal made improvements to Golgi's staining method (1901) and developed a gold staining method (1913) to study the finer structure of neural tissue. With an extraordinary eye for detail, Cajal spotted fine gaps between the stained membranes. This led him to propose that tissue in the brain or spinal cord was not a continuous network; like any other tissue in the body, it is made up of distinct cells. After the German anatomist Wilhelm von Waldeyer-Hartz named these cells 'neurons', this theory came to be known as the 'neuron theory'.

Despite their opposed views, the 1906 Nobel Prize in medicine was jointly awarded to Golgi and Cajal for their work on the structure of the nervous system (see **Fig. 2**). Their difference of opinion was resolved for good only in the 1950s, after the discovery of the electron microscope, when it became clear that nervous tissue was made up of individual cells and that these cells were connected through what we call synapses. While this observation conclusively disproved the reticular theory, there was a time when both interpretations of the available data were considered 'facts' by opposing groups. This exemplifies Cajal's famous quote: *"Hypotheses come and go, but data remains"*.

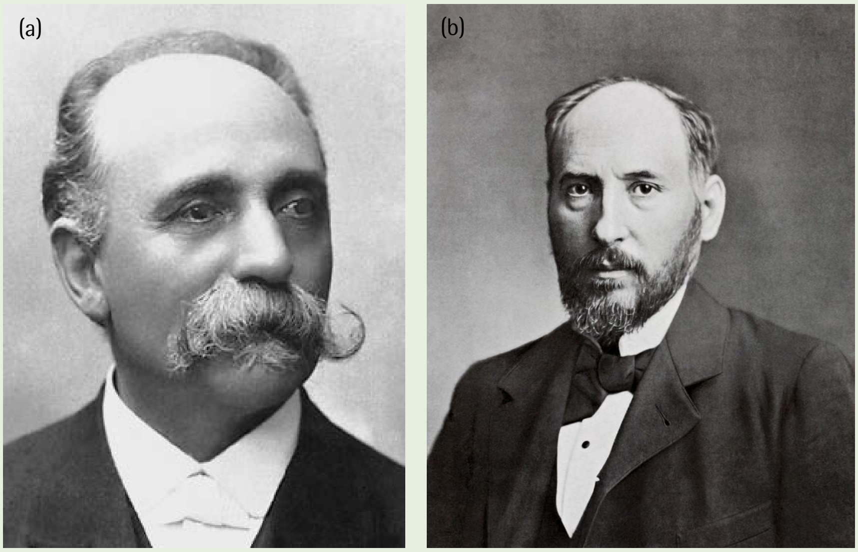

Fig. 2. The joint winners of the 1906 Nobel prize in medicine. (a) Camillo Golgi. **(b)** Santiago Ramon y Cajal.

Credits: **(a)** Materialscientist, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Camillo_Golgi_nobel.jpg. License: CC BY 4.0 DEED. **(b)** First published by Clark University in 1899, restored by Garrondo. Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Santiago_Ram%C3%B3n_y_Cajal_(1852-1934)_portrait_(restored).jpg. License: Pubic Domain.

Box 2: Myth or fact?

Q. Should you take antibiotics when you have a cold?

No. Antibiotics (anti = against; bios = life), also called antibacterials, only work against bacteria. Common colds are caused by many different viruses. Antibiotics cannot destroy viruses.[3]

Q. Does the cold weather make you catch a cold?

Rhinoviruses are known to be the most frequent cause of colds (see the article titled 'Catching the Common Cold' on Page 33 of this issue). These viruses tend to infect the mucus lining the insides of the nose. In the 1960s, scientists observed that these viruses multiply much faster at cooler temperatures. The reasons for this were not known. One possibility was that these viruses were better adapted to lower temperatures. In 2015, a team of Japanese scientists reported that the higher replication rates of rhinoviruses at lower temperatures was more likely to be because our immune system falters at these temperatures. Why does our immune system falter at lower temperatures? This remains an open question.

Box 3. Enabling experiential learning:

In March this year, The Astronomical Journal published a peer-reviewed paper that described the discovery of four new exoplanets. This paper was coauthored by 16-year-old Kartik Pinglé and 18-year-old Jasmine Wright. This highlights the rich potential of experiential opportunities in allowing young people to not only learn science, but also contribute to the growth of scientific knowledge.[4]

One challenge with experiential learning is that it can be a slow process, taking as long as a phenomenon itself. For example, we would need a month to observe and experience the phases of the moon or a year to study the changing of seasons.

Another challenge is that not all phenomena can be experienced as easily and directly as the phases of the moon. Observation of and/or experimentation with some phenomena that children meet in their textbooks may need tools of some sophistication. For example, peering into the tiny world of microorganisms or large cosmic spaces needs optical instruments that are not easily available to everyone. In the absence of low-cost alternatives, like the Foldscope, that allow children direct experience of these worlds, it may seem practical for a teacher to share factual knowledge. However, this need not be a passive process. The current availability of digital technologies allows teachers to present rich multimedia content on these phenomena in class and encourage analysis of this content to help students develop useful perspectives.

its veracity—myths are not necessarily ancient or from the past and facts are not always modern or from the present.

Secondly, it is important to recognise that children learn about natural phenomena organically in the natural course of their lives. In teaching science, we need to provoke curiosity and excitement about the natural world and build on what students observe and experience themselves (see **Box 3**). In contrast, when we use didactic approaches to teach generalized facts, we strip science of the context and nuance that are important to its process and practice. Students exposed to such instruction are unlikely to develop any depth in their understanding of natural phenomena. They may develop a 'belief' in the facts of science, but lack an understanding of how we know these facts and the limits of our existing knowledge. Such beliefs can be counterproductive to the advancement of the true spirit of scientific endeavours. This is also why it is extremely important that, to the extent possible, we provide opportunities for young people to experience natural phenomena directly.

Lastly, it is important for teachers to recognise that textbooks often present the progression of science as a linear process. This is why relying solely on information presented in textbooks can be misleading and devoid of proper context. For example, cell theory is introduced in Grade IX. When students are quizzed on their understanding of this theory, they may be able to recite its tenets, but are unlikely to be aware that it is the culmination of more than 300 years of research (refer 'The Wacky History of Cell Theory' at https://ed.ted.com/lessons/the-wacky-history-of-cell-theory), with contributions from scientists from many different disciplines (like botany, zoology, physics, chemistry, and mathematics). Understanding the iterative process of science in the context of this rich history of human ingenuity brings an important perspective to scientific discoveries. By incorporating stories of **how** discoveries were made, teachers can keep their students connected with the context of the facts presented in their curriculum.[5] Such a strategy offers an added advantage of 'hooking' students' attention since our brains relate to stories much better than they do to disjointed facts!

Parting thoughts

The clarity of our perception depends on the quality of tools at our disposal. As young minds engage with life and learn about how things around them work, it makes sense to have effective tools. The process of science is critical in enabling human perception through continuously improving and evolving tools. This is why we introduce science at the school level—not to get all our students to grow into professional scientists, but to help them develop into scientifically literate citizens of the future. To help them engage more critically with real-life questions like: is genetically modified food safe for us? How much should we worry about contracting infections caused by drug-resistant bacteria? What are the biological and social consequences of our ability to edit the human genome? In doing this, science education can enhance students' perceptions of themselves, their immediate surroundings, their communities and ecosystems, and the planet at large. This is why science matters.

Key takeaways

- If teachers rely solely on the information in textbooks and use didactic methods of teaching it, students learn to see science mainly as a compilation of immutable facts rather than as testable ideas and a way of thinking about natural phenomena.
- Children who see science as a list of facts may develop anything between a mild apathy to a general distrust of science and scientists.
- We are, today, faced with many complex issues, the resolution of which will need to go beyond scientists and elements of policy to a scientifically literate citizenry.
- To develop scientific literacy, the pedagogy of science needs to be guided by the history and practice of this discipline.
- Science teaching at the school-level must foster scientific thinking; offer students direct experience of natural phenomena and discovery; and explore the context and nuance of science.

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Notes:

1. This article was first published in i wonder..., February 2017, pp. 29-31. The original draft can be found here: https://publications.azimpremjiuniversity.edu.in/1283/. The version included in this issue has been reviewed and modified for school teachers. It includes new material.
2. Credits for the image used in the background of the article title: San hunter with bow and arrow, CharlesFred, Flickr. URL: https://www.flickr.com/photos/charlesfred/2129551464. License: CC BY-NC-SA 2.0 DEED.

References:

1. Hogeback J (2016). 'Why is Pluto No Longer a Planet?'. Encyclopedia Britannica. Accessed on Apr 12, 2024. URL: https://www.britannica.com/story/why-is-pluto-no-longer-a-planet.
2. Wikipedia contributors (2016). 'Blind Men and an Elephant'. Wikipedia, The Free Encyclopedia. Accessed on: Nov 4, 2016. URL: https://en.wikipedia.org/w/index.php?title=Blind_men_and_an_elephant&oldid=747758070.
3. Dworkin B (2003). 'Microbiology 101: Why Antibiotics Don't Kill Viruses'. Dr. Barry Dworkin: The Official Website. Accessed on: May 22, 2024. URL: https://drbarrydworkin.com/articles/medicine/infectious-disease-articles/microbiology-101-why-antibiotics-dont-kill-viruses/.
4. Unknown authors (2024). 'High School Students Contribute to Exoplanet Discovery'. SETI Institute. Accessed on: Apr 12, 2024. URL: https://www.seti.org/press-release/highschool-students-contribute-exoplanet-discovery.
5. The Story Behind the Science. Accessed on Nov 4, 2016. URL: https://www.storybehindthescience.org/.

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