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Azim Premji University

i wonder...

Rediscovering School Science

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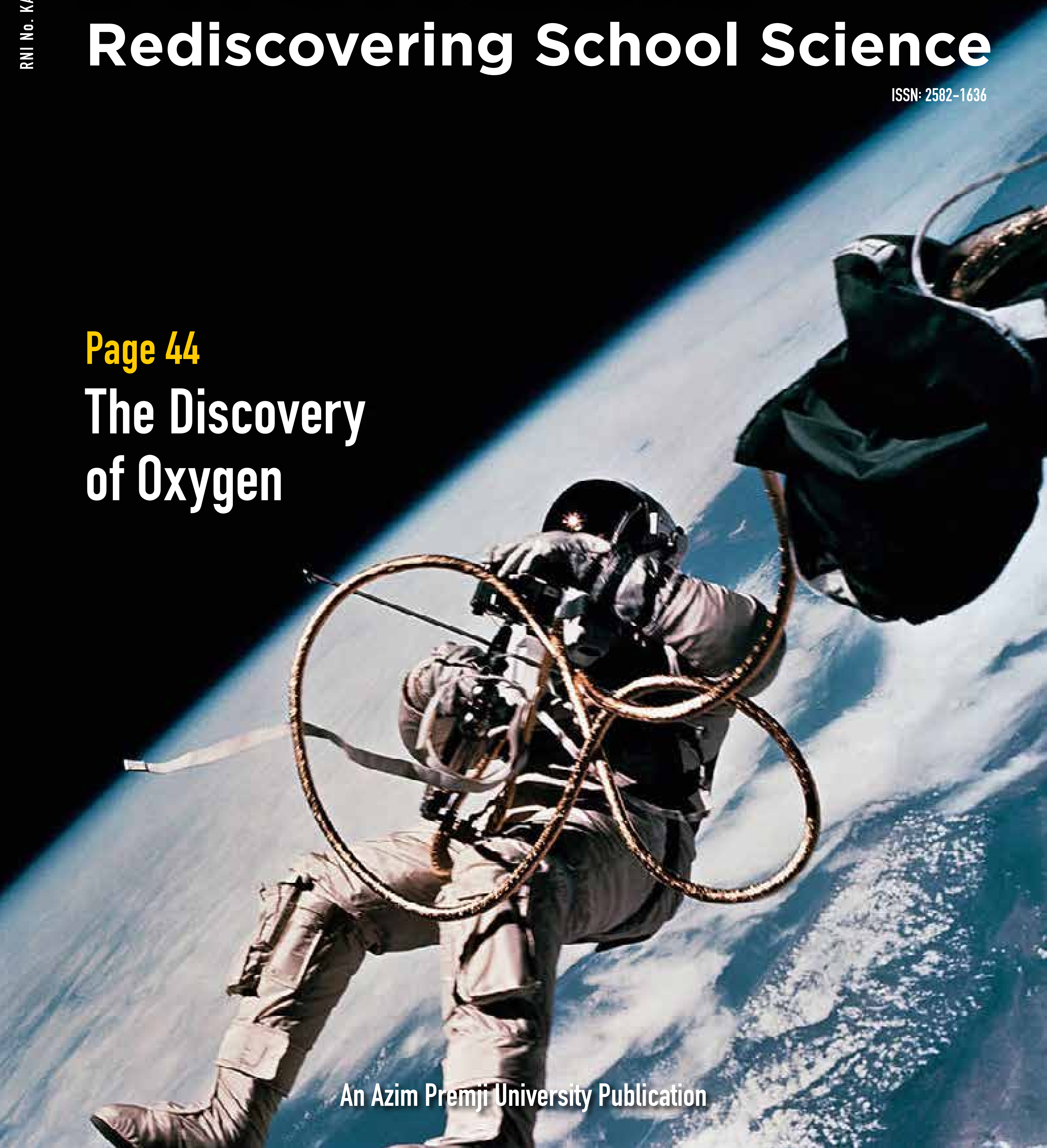

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The Discovery of Oxygen

An Azim Premji University Publication

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About Us

i wonder... is a science magazine for school teachers. Our aim is to feature writings that engage teachers (as well as parents, researchers and other interested adults) in a gentle, and hopefully reflective, dialogue about the many dimensions of teaching and lifelong learning of science in class and outside it. We welcome articles that offer critical perspectives on science and science education, a deeper exploration of the foundational concepts & underlying principles in the school science curriculum, and examples of practice that encourage the learning of science in more meaningful & inquiry-based ways.

i wonder...
REDISCOVERING SCHOOL SCIENCE

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Editorial

How do we teach science? Our most common approach is to focus on introducing children to a core of carefully chosen foundational concepts, theories, models, and ideas that have marked our progress in science. Support this with a description of the experiments that validate this knowledge. Share how these undergird natural explanations for real-world phenomena in and around us. Also highlight how this knowledge helps us make increasingly accurate predictions, develop new technologies, connect different domains, and solve complex problems. The implicit hope is that this is sufficient to enable students to extract an understanding of how we know what we know and why we believe it. Also, that it will equip students with thinking and reasoning skills that they will choose to apply not just to their practice of science, but also to a wide range of practical problems outside it. Many studies suggest that this is rarely the case.

What do children learn from this approach? They encounter our best understanding of the natural world as a dehumanised, decontextualised skeleton of facts. Facts that are often quite distant from what children can perceive of the natural world through their own senses. To children, they may seem more like the effects of magic than the tentative yet reliable results of a rigorous social process of constructing knowledge from careful observation, experimentation, and interpretation. Even when children succeed in memorising many of these facts, they may not know them with the exactness and intimacy that nourishes the ability and courage to make 'free', well-reasoned choices in action and thought. How do they relate to scientists? Seen mainly through the singular lens of their achievements, children may think of scientists as being extraordinary yet one-dimensional characters rather than flawed yet whole humans, like themselves, who often struggle and persevere in the face of personal and societal obstacles. For children who come from underrepresented groups in science, the gulf can be even wider. What about the process of inquiry? Often, children are first introduced to this process through observations and experiments involving instruments and reagents that are expensive and unsafe to play around with. When so, children may welcome the certainty of being told what to do and how to do it. And may see the experience mainly as a test of how closely their own results lend themselves to certain predetermined absolute and certain conclusions. This can interfere with their ability to experience the curiosity, creativity, frustrations, errors, failures, inspiration, and uncertainty of discovery.

Many articles in this issue highlight this challenge and explore interesting possibilities. Uma Sudhir suggests that when teachers connect their own misconceptions about the atomic theory with the instruction they received in school, they are better equipped to examine and choose the resources and approaches that they use to teach it. Arvind Kumar suggests that children develop a more critical understanding of the content of science when allowed to retrace the human choices that have shaped its history or discover it through their own inquiry. Vijay Upadhyay retraces the discovery of oxygen through the many people, ideas, and experiments that led up to it. Steven Carr and Durgadas Kasbekar share how disagreements between scientists strengthen scientific reasoning; and how readily well-reasoned theories from eminent scientists are abandoned when countered by evidence. Varun Sharma reminds us how the remarkable naturalist and fearless conservationist M Krishnan was an average student with a keen curiosity and deep empathy for the natural world. Susheela Srinivas shares how Dorothy Andersen, who made ground-breaking contributions to our understanding of cystic fibrosis, remained undaunted by gender stereotypes in both her professional and personal life. Anand Narayanan suggests that children can infer the implausibility of a 'flat earth', on their own, through simple observations and experiments with inexpensive and easily available materials. Dhanya K shares how a well-designed inquiry-based approach into germination can help transform labs into spaces where children develop a more first-hand and direct knowledge of this process as well as the practice of science. Charles Eisenstein alerts us to the necessity to attend to what we know of local places through our care for them and our own capacity for reasoning rather than being guided solely by our culture's dominant problem-solving approaches. And Deborah Dutta shows how the simple act of growing food can connect classrooms with communities, allowing children to experience a relationship with the natural world that brings their many selves together.

How do **you** engage with this challenge? What possibilities have you explored in your practice? Share your experiences with us at iwonder@apu.edu.in.

Chitra Ravi
Editor

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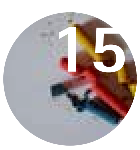

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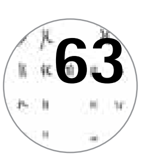
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NATURE'S PASSIONATE AND METICULOUS CHRONICLER

VARUN SHARMA

What does it mean to observe the natural world with the curiosity and enthusiasm of a child? How does one record such observations in meticulous detail, while still conveying a sense of wonder? How does education shape our relationship with the natural world? Why do we value some species over others? Explore these and other questions through the life and writings of M Krishnan.

"The average educated adult knows little or nothing of the teeming plant and animal life of the country, and cares less. Livestock does not interest him, and the world is to him a place which holds only human beings. He can never make friends with a hill or a dog, and if he has no one to talk to, no book to read, and no gadget to turn and unturn, he is quite lost. School education is solidly to blame for all this—children are not taught to know and appreciate nature at first hand, only terms and explanations from books. They think of nature as something necessary for passing examinations, as something unfortunately necessary. And when they are grown, they are unaware that they have missed half the joy of life".—M Krishnan in an essay titled 'Nature Study'.

This excerpt leaves us with a brief but revealing insight into both Krishnan's views on education and into the many shades of his relationship with the natural world—one that was eccentric, passionate as well as empirical (see **Box 1**).

The average student

Madhaviah Krishnan was born on 30th June, 1912 to a modest Tamil Brahmin family in Tirunelveli (see **Fig. 1**). His father, A Madhaviah, was a Tamil writer and reformer. Krishnan was the youngest of eight siblings. Like his siblings, he was brought up with a deep appreciation for literature and the arts. In the early 1920s, the family moved out of a congested part of Madras to a house that his father had built in Mylapore. This move proved decisive. Unlike the concretised jungle Mylapore has become today, it was at the time home to paddy fields, coconut groves, and verdant pastures. Stray wanderings brought Krishnan upon mongooses, palm civets, snakes, tortoises, varieties of birds, and the odd blackbuck.

Box 1. Krishnan's views on education:

In his essay 'Nature Study', Krishnan avidly criticized what he referred to as the 'concentric system' of learning. This pedagogical misadventure, according to Krishnan, found students being guided on "*more and more of the same thing*", even as they passed from one grade to another. He explained this with reference to the cow, as it repeatedly appeared in the textbooks of every successive grade at the time: *"The first year the child learns that the cow has four legs (quadruped), gives us milk, and eats grass (herbivore). The next year, maybe, there is a lesson on milk and another on how the cow is a mammal. And in Form IV the young naturalist learns how the cow chews cud (ruminant), and that its stomach is cut up into compartments"*. According to Krishnan, the same error could be repeated if the curriculum or teacher got fixated on a certain model or theory of understanding the natural world. In either case, the result would be the same—a false sense of confidence. Krishnan's alternative lay in taking children and young learners more and more into the open. Instruction, he felt, ought to reveal the relationships between and within species, both floral and faunal. In choosing or designing books for children, he felt that children would *"readily insert themselves in any text if it was free from morals and illustrated in colour"*. Krishnan also recommended that schools maintain a 'market garden', 'poultry-run', 'goat-pen', 'pigeon-loft', and a 'middle-sized school dog.' He suggested regular field visits to forests that were to be devoid of excessive discipline and led by teachers who were equally willing to learn.

"After all," Krishnan observed in the same essay, *"one never knows beforehand what one might see when setting out, and much of the value of such study lies in its being as per no set plan"*. In this enduring open-mindedness is a basic ethic that Krishnan relied on throughout his career—to desist from the attempt to pin nature down with knowledge. To this end, Krishnan believed in reminding himself as also his wards, that Man (with a capital M) will never be able to master nature. No matter how hard we try, we will never be able to contain it within the ambit of our systems of knowledge. This sentiment is reflected in Krishnan's remark, *"Nature is not simple, logical, and reasoned—thank God it is not"*. Through this piece, Krishnan expanded the concept of nature from a mere object of study to a subject of endless reverie and fascination.

His early education was in Hindu High School. While his academic work was unexceptional, he read widely and his interest in literature and art deepened during this period. In 1927, Krishnan joined Presidency College, Madras, to appear for his intermediate examination. Soon after, he joined its BA programme. During this period, he made acquaintance with the remarkable field botanist, Professor PF Fyson, who was painstakingly compiling the flora of the southern Indian hills. Thanks to Fyson, Krishnan developed an interest in the multifarious interactions between animals and plants. One of Krishnan's early observations concerned the attraction of the koel to the highly poisonous drupes of the yellow oleander, such as the ones that adorned his garden. While the plant was avoided by many other birds and squirrels, Krishnan was among the first to record, with much amazement, how the koel *"sidles up to a fruit and stabs it with its bill, excavating and removing a piece of the mesocarp that it swallows with an upward toss of the head"*.

Fig. 1. M Krishnan.

Credits: Asha Harikrishnan.
URL: https://www.mkrishnan.com/. License: Used with the permission of the rights owner.

Krishnan's academic credentials were average. Since he had obtained a third class in both his BA and MA, his job prospects were dim. On his family's urging, he applied for and obtained a law degree in 1936, but there is no record of his having practised as a lawyer. After a brief apprenticeship course in a court, he worked as an artist in Associated Printers and in the Madras School of Art. In 1937, Krishnan started working as a freelance writer, publishing nature-related notes in newspapers. In 1942, a recommendation helped Krishnan secure employment with the Maharaja of Sandur. He stayed in Sandur, a region now falling in Bellary (Karnataka), for eight years. During this period, Krishnan worked as a schoolteacher, judge, publicity officer, and political secretary to the Maharaja. These jobs were anything but exciting to him. However, the vast hinterlands incited fresh wanderings and the Sandur stint yielded several other gems of writing. In one such piece, Krishnan marvelled at how the Bellary countryside attracted thousands of rosy starlings *(Pastor roseus)* in September and October. It would be reasonable to expect these birds to be drawn to areas that were rich in crops and fruit; instead, they flocked in pockets that were devoid of both. What could be the reason for this unusual pattern? Krishnan ended his essay with this question.

The remarkable naturalist and writer

In 1949, Sandur lost its princely status in independent India; and Krishnan returned to his father's house in Madras. It was at this stage that he emerged as a freelance writer, naturalist, and photographer. Starting in 1950, Krishnan came to maintain a fortnightly column titled 'Country Notebook', in the pages of 'The Statesman' of Calcutta, which he sustained for 46 long years. He also

Box 2. The focus of Krishnan's nature writings:

Importantly, Krishnan was not singularly interested in the physical presence of animal species in their true diversity. He was equally keen to assess their emotional state (see **Fig. 2**). On the one hand, he was moved by any unwarranted pain caused to animals by human hands. On the other hand, he did not fail to observe and record moments of humour, fear, and love within the animal kingdom. He referred to the latter as *"emotive kinships"*. Such kinships, according to him, could not be captured statistically, but only through a fostered intimacy with the animals that one was studying. Thus, he related with great delight the interminable friendship between Rati and Sundari, two elephants in a forest department's camp, whom even the managers felt wise to keep together, *"not out of any sentimental motives but because, otherwise, the work suffers"*. He also observed how a *"sideways glare"* amounted to an act of intraspecific communication between chitals. In mapping the variable expressions and moods of birds, as manifested in their chirps and songs, he affirmed that even though they were *"moved by powerful instincts, [they] are highly emotional and complex beings"*. Each of these pieces is illustrative of the empathy with which Krishnan immersed himself in the world of animals.

Fig. 2. A doe of the tiny, and now rare, mouse deer. Even with smaller species, Krishnan opined that *"to treat live, sentient subjects as a mass of conditioned reflexes and instinctive responses is utterly futile"*.

Credits: M Krishnan. Taken from M Krishnan (1965). 'Letter from M Krishnan'. Cheetal: 7 (2): 10-11. Published by the Wild Life Preservation Society of India (https://wpsidoon.org/).

It is equally remarkable that Krishnan did not need to go as far as a forest, zoo, or national park to experience such empathy. Even a fat old lizard in his house would suffice. One such specimen found him pondering over how the lizard's tail compensated for its relative *"voicelessness"* by serving as an *"organ of emotional expression"*. He received birds in his garden, as also toads, with rapture. Bandicoots also provoked curiosity. At other times, when rain lashed Mylapore, he would step out to see how the birds, squirrels, and monkeys were enduring it. Even today, it would be hard to find an environmentalist who writes as passionately about both wild animals and their urban counterparts as Krishnan did.

In hindsight, one may see some danger of anthropomorphism (or the tendency to attribute human qualities to non-human animals) in Krishnan's writings. Nonetheless, it was through these writings that Krishnan established a high standard, if not ethic, for interspecies companionship between humans and animals of all kinds—big and small, near and far, charismatic and *"pariah"*.

continued writing for other newspapers, like 'The Hindu', 'The Illustrated Weekly of India', and 'The Indian Express'. While Krishnan wrote on a variety of subjects including art, fiction, cricket, and literary history, his most remarkable pieces were on natural history (see **Box 2**).

By this time, the average college student under Fyson had developed into a seasoned naturalist. One of the things that set Krishnan apart is that he chose to focus on the landscape and wildlife of peninsular India. Another distinguishing feature was that he had evolved his own methods of study. For example, he had special gear manufactured to observe the natural world. This included items like a cap and a veil that he wore to avoid being detected by animals. In his own words he had, *"over the years... acquired the ability to stay still and to move, if I must say, in slow motion"*. Another unique aspect was his style. Krishnan's writing was rich in detail that came from his own observations and fieldwork. Each piece was often accompanied by his own pen-and-ink drawings or excellent photographs. It is impossible to overlook the child-like amazement in Krishnan's reflections or even his flair for language. But, more than anything, what was distinctive about Krishnan's pieces was his spirit of inquiry. As the pieces on the koel and rosy starling show, Krishnan was inclined to rake up questions and pursue a suspenseful trail, even if there were no final answers (see **Box 3**). This may have had something to do with the fact that he enjoyed reading detective novels in his spare time, and unsolved mysteries did not seem to harass him. Interestingly,

Box 3. Krishnan's questions:

Here are some other examples of the kind of questions Krishnan would pose to his readers:

- Are there factors beyond love and territory that inspire birds to sing?
- Do monkeys hug out of affection?
- Does the gaur, which can smell the coming of the rain, possess a strong ground scent?
- Does the elephant occasionally devour water hyacinths to obtain its supply of iodine?

Do you have some questions of this kind that you could add to this list?

in asking these questions, Krishnan did not feel compelled to provide all the answers. Rather, it seemed to be a part of his strategy to lead the reader down an alley of interesting facts, only to abandon them to a growing curiosity that was their own by now.

The courageous conservationist

In 1959, thanks to a scholarship, Krishnan gained the opportunity to tour the length and breadth of the country. This period coincided with the early phase of nation-building that witnessed the rampant construction of big dams, mining projects, railway lines, roads, plantations, and the extension of agriculture. Unlike many, Krishnan was not enamoured. He boldly questioned the patriotic spirit driving these projects, given that it grossly failed to respect the sovereignty of wildlife over its territories (see **Fig. 3**).

The bulk of his concerns came to revolve around the elephant. Wildlife suffered in general; birds, cats, and other smaller animals managed to avoid contact with advancing civilization to degrees that were not possible for the elephant. By virtue of being a big, wide-ranging, and long-lived animal that is deeply attached to its habitats and corridors, the elephant was bound to come into increasing conflict with humans (see **Box 4**).

Even as Krishnan's understanding of elephant behaviour matured, India launched Project Tiger in 1973. This remains a much-celebrated, centrally sponsored scheme for the conservation of the Indian tiger. Krishnan, who was a founding member of the steering committee of this project, did not deny that reserving land for the tiger and its prey base would offer a level of reprieve for the elephants. However, it left him with a niggling worry at the other end of the scale: *"When even the decline of the tiger, which has captured human imagination in India for some 200 years, was noticed only at the last stage, it is only logical*

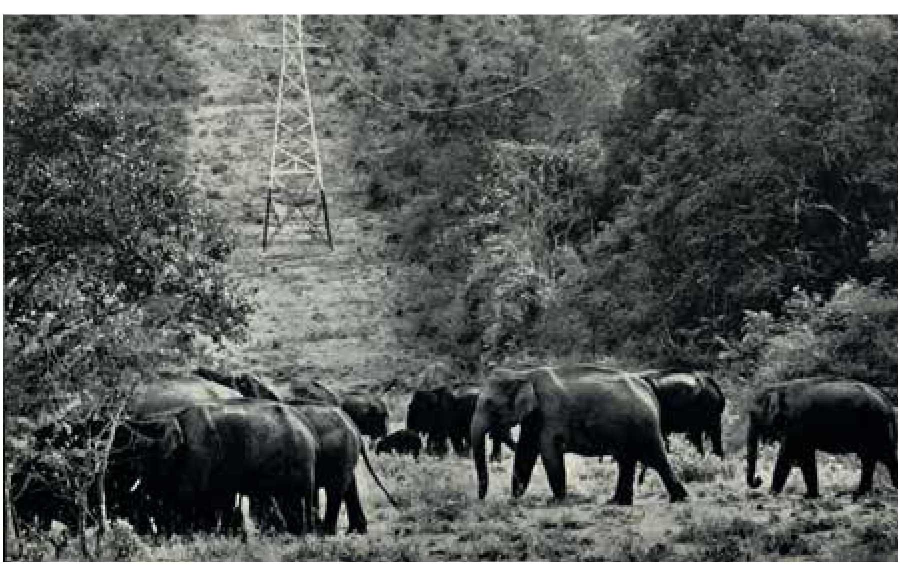

Fig. 3. A photo titled, 'Electricity comes to elephant country'. Krishnan had a simple maxim for wildlife conservation, *"Leave well alone".*

Credits: M Krishnan. Taken from M Krishnan (1965). 'Letter from M Krishnan'. Cheetal: 7 (2): 10-11. Published by the Wild Life Preservation Society of India (https://wpsidoon.org/).

Box 4. In defence of elephants:

Unfortunately, many of Krishnan's contemporaries were not above the spirit of their times. A close clique of naturalists, foresters, and administrators came to contentiously argue that elephants were destructive to forests. They suggested that it was in the character of elephants to multiply fast, populate tracts, and uproot the trees and saplings that fell along their migratory routes. Krishnan meticulously laid bare the nonsense of such ideas. Some went as far as to condone the strategic culling of elephants to make space for development. Krishnan countered this by showing how such measures made things worse. Elephants that survived gunshots, only to be left with open, festering, and maggot-ridden wounds, became doubly hostile to human society. Krishnan's pleas often fell on deaf ears.

In the early 1970s, as part of a report submitted on behalf of the International Union of Conservation (IUCN), the scientist RH Waller rehearsed several disparaging remarks about elephants, especially with respect to the region of Wayanad (Kerala). Given IUCN's prominence, these findings were left unchallenged by others. But Krishnan pounced on them. In 1968, Krishnan had been awarded the Jawaharlal Nehru Fellowship to support a broad-based ecological survey of mammals in Peninsular India, including parts of Wayanad. The findings of this study were published in 1971 by the Bombay Natural History Society (BNHS) as a valuable book called 'India's Wildlife'. More significantly, Krishnan's fieldwork for this fellowship helped show that the destruction attributed to elephants was the *"simple and inevitable consequence of deep, diverse, and sustained human penetrations".*

Box 5. As in forests, so in cities:

Interestingly, as Krishnan grew in stature, his concerns did not remain restricted to forests. The immediacy of his concerns took a form of activism that included urban ecologies, domestic animals, and *"pariah"* species. So, for example, he fretted about the disappearance of indigenous varieties of livestock, such as the Amrit Mahal bullocks due to the use of tractors. He remained consumed by the cruelty weathered by animals in the city that was his home. It pained him to see how beasts of burden, particularly donkeys, were brutally overworked and grossly under-cared for. Likewise, he shot down the proposal of the National Committee for Bird Preservation to eliminate crows in municipality areas for 'encouraging charming and inoffensive birds such as orioles and flycatchers.' He countered this proposal with one to increase the green cover in cities, suggesting that this was sufficient to do the trick. No mass murder of crows was necessary. Similarly, he defended the Indian *"pariah"* dog from those who wished to rid the streets of them in an essay where he shared the opinion that: *"There is no better house-dog. It is so clever and willing; you can teach it practically anything".*

that the decline of less glamorous animals, like the lion-tailed macaque, the sloth bear, the hyena, the wolf, and the dinky little Indian fox has gone largely unnoticed". In time, Krishnan added species such as water monitors and wild dogs to this list and simultaneously flagged possibilities relating to the 'local extinction' of the blackbuck and the leopard. In doing so, Krishnan may have foreseen the possibility of what is today referred to as 'silent extinction'. This is a process whereby our priority for 'charismatic' flagship species can blindside us to the claims of smaller and less-spectacular ones that could be equally salient to healthy ecosystems (see **Box 5**).

Box 6. Some important resources for school libraries:

These three books include some of Krishnan's writings:

- Shanti and Ashish Chandola's (2014) book: 'Of Birds and Birdsong' with a foreword by the renowned ornithologist Zafar Futehally, published by Aleph, New Delhi;
- Ramachandra Guha's (2007) anthology of Krishnan's writings: 'Nature's Spokesman: M Krishnan and Indian Wildlife', published by Penguin Books, New Delhi; and
- Krishnan's own two-volume set, 'India's wildlife in 1959-1970', published by BNHS, Mumbai.

Some of Krishnan's articles that appeared in the Journal of the BNHS (or JBNHS) can be obtained by writing to the current editor:

- Krishnan (1952). 'Koels eating the poisonous fruit of the Yellow Oleander.' JBNHS, 50 (4): pg. 943-945;
- Krishnan (1955). 'The Rosy Pastor in the Bellary Area.' JBNHS, 53 (1): pg.128;
- Krishnan (1974). 'RH Waller's observations on wildlife in India: a partial rejoinder.' JBNHS, 71 (3): pg. 594-598;
- Krishnan (1978). 'Disconnected observations on a species of *Scolapendra.'* JBNHS, 75 (1), pg. 239-240; and,
- Krishnan (1978). 'Emotive kinships amongst animals.' JBNHS, 75 (3), pg. 613-618.

Some of Krishnan's articles that appeared in 'The Statesman' in the early 1950s have been freshly digitised. These can be accessed here: https://www.mkrishnan.com/uploads/1/1/2/5/112547211/1950-54_cn.pdf.

Box 7. Some questions to ponder over:

Q. Krishnan chooses to illustrate concentric systems of learning through the manner in which cows are treated in the school curriculum. Do you know of any other such examples? Describe one.

Q. Think of an animal in your immediate surrounding that interests you. Write a note describing any of its peculiarities in as much detail as possible.

Q. Think of a contemporary naturalist who has extended their sensitivity to both wild and domestic animals. Compose a short biography of them.

Q. Can you list five endangered species that are not seen as being as spectacular or charismatic as tigers and elephants? Try making a collage to highlight these species.

Q. How are current development projects impacting the elephant? Investigate this in an elephant habitat nearest to you.

Parting thoughts

In recognition of his work on wildlife conservation, Krishnan was awarded the Padma Shri in 1970. In 1995, Krishnan was nominated to the Global 500 Roll of Honour of the United Nations Environment Programme (UNEP) for, in his words, *"close on half a century's continuous effort in trying to inform and stimulate an interest in the public in India's stupendous heritage of wild flora and fauna being steadily depleted".* He leaves behind a legacy that can be retraced from the existing literature both by and on him (see **Box 6**).

The life and work of this student of nature offer many examples of the role of relentless curiosity and deep sensitivity in chronicling and conserving the natural world (see **Box 7**). As Krishnan reminds us, *"Only the great heritage of nature that we have owes nothing to our contrivance, intellect, or imagination, and is beyond our creative genius, though we still have the power to destroy it".*

Key takeaways

- M Krishnan's life and work offer many examples of the role of relentless curiosity and deep sensitivity in chronicling and conserving the natural world.
- As a young student, his educational record at school and college was unexceptional. However, he read widely and developed a deep interest in wildlife and art.
- The opportunity to study under the field botanist Professor PF Fyson helped this average student develop into a seasoned naturalist with an eye for the multifarious interactions between plants and animals.
- After holding a variety of unexciting jobs, Krishnan chose to earn his living as a freelance writer, naturalist, and photographer.
- Through his writings, Krishnan established a high standard, if not ethic, for interspecies companionship between humans and animals of all kinds—big and small, near and far, charismatic and *"pariah"*.
- As a conservationist, Krishnan was courageous in questioning the patriotic spirit driving development projects in independent India for its failure in respecting the sovereignty of wildlife over its territories.
- Krishnan questioned the role that school education played in introducing children to the joys of the natural world. He offered important philosophical and practical cues to engage the curiosity and care of children for the teeming plant and animal life in the country.

Notes:

1. The word *"pariah"* is believed to originally refer to a member of an indigenous tribe from South India who played drums (referred to as *parai*) at events like weddings and funerals. It soon evolved into a casteist slur. While it was widely used in the times in which Krishnan lived and wrote, our awareness of its derogatory connotations has grown since then. When used with reference to non-human animals, it can have a wide range of meanings, including 'native', 'free-ranging', 'outsider', 'commonplace, ordinary, or mundane', 'drab or unattractive', 'scavenger', 'outcast' or some combination of these. This word has been retained in this article not only because Krishnan's interest in these species defied common perceptions associated with the more derogatory uses of this word, but also because his observations and writings have played an important role in challenging and changing many of these perceptions.
2. Source of the image used in the background of the article title: Indian elephants in a stream. Credits: PickPik. URL: https://www.pickpik.com/elephants-family-group-river-wildlife-nature-mammal-5110. License: Royalty Free.

For further reading:

1. Bittu Sehgal (2017). 'M Krishnan: In Remembrance and Gratitude'. Nature in Focus. URL: https://www.natureinfocus.in/environment/in-remembrance-and-gratitude.
2. Kumaran Sathasivam. 'The national treasure that was M Krishnan'. Madras Musings. (Archive) Vol. XXII No. 14, November 1-15, 2012. URL: https://madrasmusings.com/Vol%2022%20No%2014/the-national-treasure-that-was-m-krishnan.html.

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DISCOVERY OF OXYGEN: HALL OF FAME

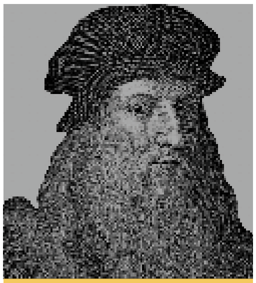
Here are 10 scientists who had a key role to play in the discovery of oxygen. Below each of them is a plaque that needs to carry their names. Do you know their names?


(a)


(b)


(c)


(d)


(e)


(f)


(g)


(h)


(i)


(j)

Stuck? If you would like some clues, turn to page 35 of this issue.

Note: Source of the image used in the background of the article title: Jigsaw pieces. Credits: Wounds_and_Cracks, Pixabay. URL: https://pixabay.com/photos/puzzle-piece-tile-jig-jigsaw-game-3306859/. License: CC0.

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AN UNSUNG HERO

SUSHEELA SRINIVAS

Cystic fibrosis was for long considered a fatal childhood disease. One woman's contributions, as a physician and researcher, to the study of this disorder has helped improve the quality and life expectancy of patients suffering from it in significant ways. Who is this unsung hero? What do we know of her life and work?

"Today is the most best day ever in my life. They found a jean for cistikfibrosis". Written on 25th August, 1989, this was the diary entry of an 8-year-old child, who was lucky to survive a rare genetic disorder called Cystic Fibrosis (CF). This disorder had, until the mid-1990s, claimed the lives of many children in their infancy. Their bodies would produce very thick, sticky mucus that would build up in and obstruct the tubes, ducts, and passageways in many organs, particularly the lungs and pancreas. Affected children would show symptoms like very salty skin, breathing difficulties, and digestive problems. Those suffering from a severe form of the disorder would become malnourished (despite a good appetite), weak, and susceptible to lung infections and pneumonia.

This rare congenital condition had for long baffled doctors. The medical community had attributed the deaths to coeliac disease, a chronic digestive and immune disorder, and would treat it like that. However, a pathbreaking discovery in 1938 by the pathologist Dorothy Hansine Andersen changed that (see **Fig. 1**).

The medical sleuth

In 1935, Andersen was working as a pathologist at the Babies Hospital, Columbia Presbyterian Medical Center, New York. Part of her work involved the dissection of organs and examination of body fluids to investigate the cause of death in patients.

Fig. 1. Dorothy Hansine Andersen. A physician, paediatrician, and pathologist, Andersen was the first to identify and describe CF.

URL: https://healthmatters.nyp.org/it-happened-here-dr-dorothy-h-Andersen/. License: Copyrighted and published with permission from Columbia University Medical Center, New York.

Andersen was often overwhelmed by the number of infant deaths that occurred due to lung infections and malnourishment. Then, one day, in 1938, while performing an autopsy on one such three-year-old, she observed that the airways of the child's damaged lungs were blocked by unusually thick mucus. Further probing revealed similarly thick mucus blocking the tubes leading out of the child's pancreas. She also observed that the child's pancreas was damaged and *"completely covered by a sandy, tough fibrous cyst"*. Andersen surmised that the thicker mucus had blocked the release of the corrosive enzymes that the pancreas produces for digestion. These enzymes had, therefore, acted on the pancreas itself. Further, she correlated the blocked distribution of pancreatic enzymes with increased salinity in the epithelial cells that line airways and pancreatic tubes. In healthy people, these cells secrete mucus to lubricate the airways and tubes. In those with CF, the epithelial cells produced and secreted the thicker, stickier mucus that had clogged the airways of the child and made the lungs more susceptible to infection. Andersen recognised this anomaly as a new disorder. She named it 'Cystic fibrosis of the pancreas' and shared a detailed description of it in a 50-page journal paper. In 1939, she was awarded the E. Mead Johnson Award, given by the Society for Paediatric Research, for her work on this disease.

Andersen did not think of herself only as a pathologist; she also worked directly with CF patients, mostly young children. This was something that many pathologists of the time, and especially women, did not do. In 1942, she collaborated with the researcher and clinician Paul di Sant'Agnese to devise a test to measure the amount of chloride in sweat (those with CF have higher levels of chloride in their sweat). This 'sweat test' continues to be the gold standard for diagnosing CF. Andersen and Sant'Agnese also went on to study and champion the use of penicillin as a treatment option for CF symptoms (see **Fig. 2**). In 1958, Andersen published a paper suggesting that CF was caused by a recessive mutant gene (implying that a child gets the disorder only if **both** parents carry the defective gene **and** pass it on to the child).

A trailblazer

Born in 1901 in Asheville, North Carolina, Andersen was an unassuming and enigmatic person who lived a private life. Very few records remain of her professional and personal life; even portraits of her are rare (see **Box 1**). Her biographers describe Andersen as a soft-spoken but 'ruggedly individualistic' person who did not conform to the societal norms of the day. She remained single by choice. Unlike most women of her time, Andersen was often unkempt in attire and was frequently seen with a cigarette dangling from her fingers and with ash on her clothes. She enjoyed an active lifestyle that included hiking, canoeing, and carpentry.

Professionally, Andersen stood out. In the 1900s, opportunities for women to study and work were limited. In fact, a very small number of medical

Fig. 2. Andersen with her collaborator Paul di Sant'Agnese (standing to her left). The two devised a diagnostic test for CF and championed the use of penicillin to treat CF symptoms.

URL: https://healthmatters.nyp.org/it-happened-here-dr-dorothy-h-andersen/. License: Copyrighted and published with permission from Columbia University Medical Center, New York.

Box 1. Timeline of key events:

May 15, 1901: Born.

1914–20: Loses both parents.

1922: Graduates with a Bachelor of Arts in Zoology and Chemistry from Mount Holyoke College, Massachusetts.

1922-1926: Graduates with a medical degree from Johns Hopkins University School of Medicine, Baltimore.

1930-35: Accepts position of Instructor at the Columbia University College of Physicians and Surgeons. Completes a doctorate in Endocrinology.

1935: Accepts position of Assistant Pathologist at Babies Hospital at the Columbia-Presbyterian Medical Center, New York.

1938: Describes CF.

1942: Collaborates with Paul di Sant'Agnese to develop a diagnostic 'sweat test' for CF.

1945: Accepts position of Assistant Paediatrician at Babies Hospital at the Columbia-Presbyterian Medical Center, New York.

1949: Shows that CF is likely to be caused by an autosomal recessive gene.

1952: Appointed Chief of Pathology at Columbia-Presbyterian Hospital, New York.

1958: Full-time professor at Columbia College of Physicians and Surgeons, New York.

1962: Diagnosed with lung cancer. Undergoes surgery.

1963: Breathes her last on 3rd March.

professionals were women. Andersen was a rare genius who earned two degrees—one in medicine and the other in endocrinology. She obtained a medical degree from Johns Hopkins University School of Medicine in 1926 and taught anatomy for a year at the University of Rochester in Rochester, New York. After this, she applied for the surgical residency programme at Strong Memorial Hospital at Rochester, New York. She was denied this post. According to many historians, the denial was solely due to her gender. Undeterred, Andersen joined the department of pathology at the Columbia University College of Physicians and Surgeons as an instructor. Between 1930-35, she focused on medical research, studying endocrine glands and female reproduction with a grit and tenacity that earned the respect of her peers. It also earned her a doctorate in endocrinology. In 1935, she accepted the position of assistant pathologist at Babies Hospital at the Columbia-Presbyterian Medical Center, New York. It was here that she discovered and described the pattern of disease in CF. It was also here that she developed an interest in congenital heart malformations and started a collection of the hearts of infants who had died of inborn cardiac defects. In 1958, she was made Chief of Pathology at Columbia-Presbyterian Hospital and a full professor of pathology at the Columbia University College of Physicians and Surgeons.

Box 2. Tune in to the podcast on Lost Women of Science, Season 1:

Lost Women in Science is a non-profit organization that describes its mission as an initiative to unearth and narrate the *"hidden histories of women scientists who made ground-breaking achievements in their fields"*. Its inaugural season called 'The Pathologist in the Basement' is dedicated to Dorothy Andersen. This season has four original episodes (called 'The Question Mark', 'The Matilda Effect', 'The Case of the Missing Portrait', and 'Breakfast in the Snow') and one bonus episode (called 'The Resignation'). For more exciting details on Andersen's research, listen to this podcast here: https://www.lostwomenofscience.org/season-1. Also, do not miss the rare voice recording of Andersen's speech on CF, curated by her biographer Dr Scott Baird, that is available in episode 4 of the podcast.

Andersen was an astute pathologist and a meticulous researcher. She kept detailed records of her CF patients and devised disease management strategies for them. As a member of the medical education committee of the Cystic Fibrosis Foundation, Andersen visited medical colleges across the US, where she gave lectures to spread awareness of this disorder (see **Box 2**). Her knowledge of anatomy and cardiology was so extensive that she was invited as a consultant to the Armed Forces Institute of Pathology during World War II. She went on to use her research to develop a training program for surgeons pioneering in open-heart surgery. This was not all. Andersen also investigated and described a rare glycogen storage disease (called GSD type IV or Andersen disease) that was caused by a defective liver enzyme. Showing an autosomal recessive inheritance pattern, the symptoms of this disease first appeared during the first few months after the birth of a child and usually resulted in death within the first few years.

Andersen's habitual smoking took a toll on her health. In 1963, at the age of 62 years, she succumbed to lung cancer. For her pioneering work in CF, she was inducted into the National Women's Hall of Fame in 2002.

Key takeaways

- At a time when women had limited opportunities to study and work, Dorothy Hansine Andersen earned two degrees, qualifying to become both a physician and an endocrinologist.
- Starting out as a teaching assistant, Andersen went on to work as a paediatrician, pathologist, researcher, cardiologist, and an active member of the medical education committee.
- She was the first to identify and describe a rare congenital disorder that had claimed the lives of many children in their infancy. It was also she who named this disorder 'cystic fibrosis'.
- Andersen collaborated with Paul di Sant'Agnese to develop a 'sweat test' to diagnose CF and to advocate the use of penicillin in treating it.
- Her work helped turn a near-fatal disease in children into a manageable condition with improved quality of life and life expectancy.

Note: Source of the image used in the background of the article title: Stethoscope. Credits: Roger Brown, Pexels. URL: https://www.pexels.com/photo/stethoscope-on-white-surface-5149754/. License: CC0.

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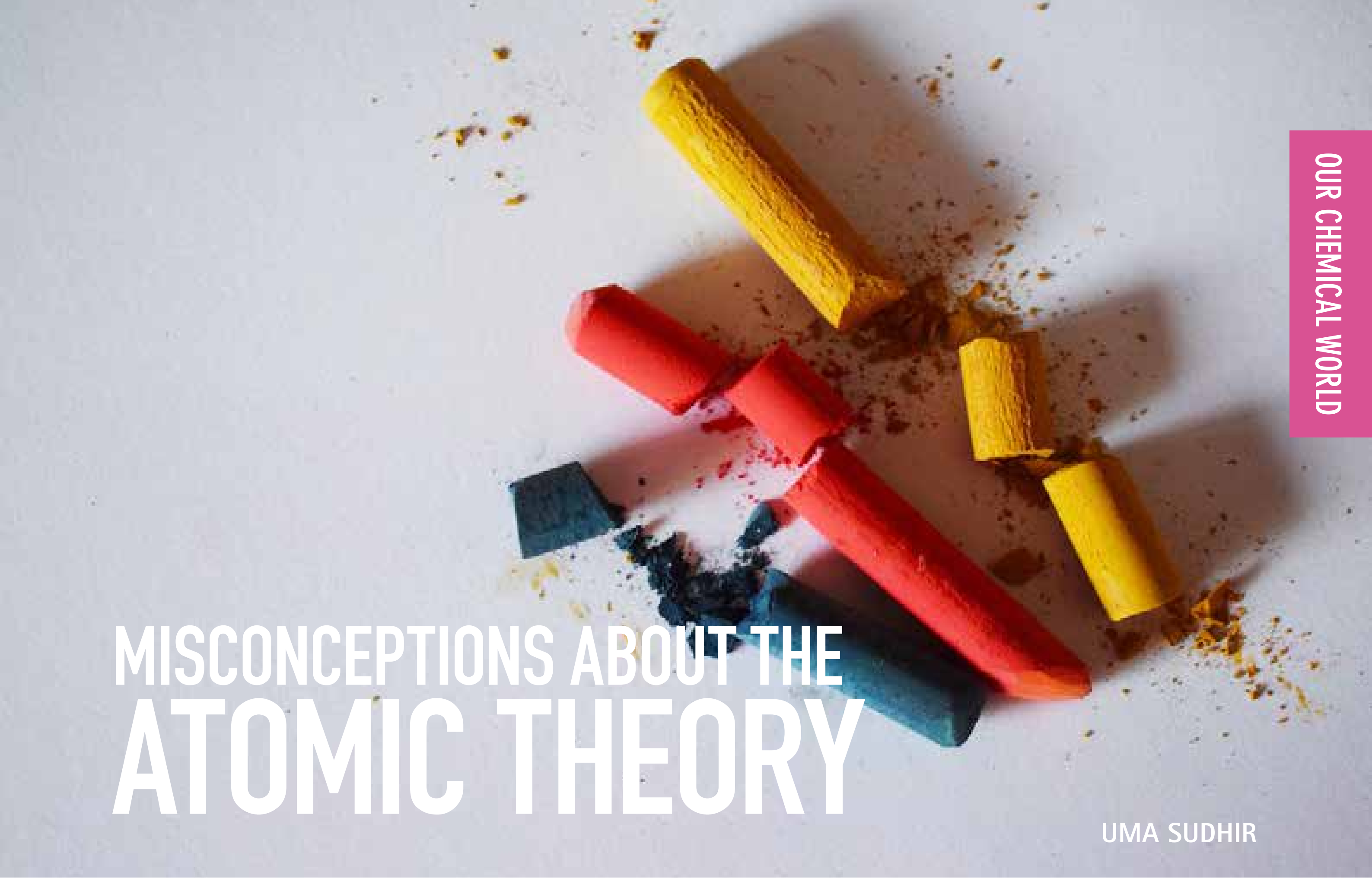

MISCONCEPTIONS ABOUT THE ATOMIC THEORY

UMA SUDHIR

While the atomic theory is a fundamental concept in chemistry, the way it is presented in the school textbook can leave students with a superficial understanding and many misconceptions. Do teachers recognise the limitations and challenges of the explanations and illustrations in the textbook?

The atomic theory, while abstract, is at the heart of modern chemistry. Studies show that many middle and high school students may be adept at parroting information on this theory from their textbooks but hold many misconceptions. Often, they are unable to appreciate the nuances of this theory or understand how it relates to other concepts or scientific disciplines. One reason for these challenges is related to the way this theory is presented in school textbooks. Explanations and illustrations in the textbook are often confusing or carry errors. Also, textbooks do not highlight the relevance of this theory to other disciplines and its linkages with other concepts (such as heat and temperature). If taught in a superficial manner, students are unable to apply this idea to explain observed phenomena or engage with problems related to them.

One of the aims of a workshop organized in June 2007 at Eklavya, Indore, was to introduce 22 Grade VIII-X teachers to challenges in the explanations and illustrations related to this theory in the school textbook. The teachers were given a test with three questions, which they answered in approximately twenty minutes. An analysis of their answers to these questions revealed some important insights.

Properties of metals

The first question was: Copper and mercury are both metals. Copper is a solid at room temperature, while mercury is a liquid (see **Fig. 1**). Also, copper is a better conductor of heat and electricity than mercury. Which of the following statements is true for copper and mercury?

a. Atoms of copper are more malleable than atoms of mercury.

b. Mercury atoms are liquids while copper atoms are solids.

c. A copper atom is a better conductor of electricity than a mercury atom.

d. None of the above. Then, how would you account for the differences observed between the two metals?

Of the 18 teachers who answered the question, many selected one or more of the three incorrect options (a, b, and c). Only eight of them selected the correct option (d). Of these, three did not offer reasons for their choice. Four had given widely different reasons. Only one answer could be considered accurate: *"As the properties are of elements, i.e., the group of atoms, not of a single particular atom"*. The teachers who chose the incorrect options seemed to believe that the properties observed in bulk groupings of atoms are found in individual atoms too. In other words, they seemed to think of the atom as the smallest particle of an element that exhibits all the physical and chemical properties of that element.

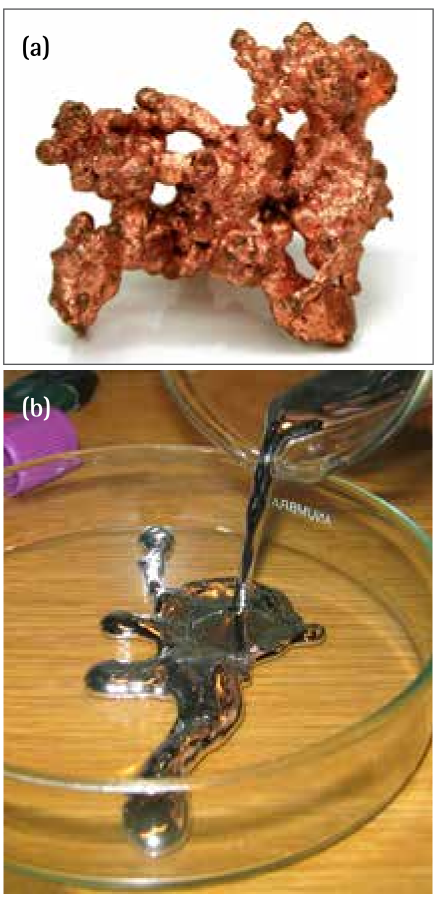

Fig. 1. How are the atoms of copper (a) and mercury (b) different from each other?

(a) Credits: Spinningspark. URL: https://commons.wikimedia.org/wiki/File:NatCopper.jpg. License: CC-BY-SA. (b) Credits: Bionerd. URL: https://commons.wikimedia.org/wiki/File:Pouring_liquid_mercury_bionerd.jpg. License: CC-BY.

What could have led to this misconception? One reason may be related to the most frequent image that teachers use to introduce the concept of atoms to their students. This is of breaking a brick or a piece of chalk into smaller and smaller pieces till one gets a piece that cannot be broken further without losing its 'brickiness' or 'chalkiness'. This vivid image is likely to leave students with the idea that, except for its size, an atom is exactly like the bigger piece it was initially a part of. This idea is so powerful that it seems to overshadow what students and teachers learn at a later stage about metallic bonding and its properties—that this kind of bond not only explains why a metal conducts electricity but also why it is shiny, malleable, etc. Another reason for this misconception may be that, unlike Dalton who formulated the atomic theory, our understanding of atoms is rarely built up theoretically from quantitative laws. Yet another reason may be the compartmentalization of knowledge. This is often strengthened by assessment methods that are not designed to test or probe what children have actually learned about connections between various concepts and the need for coherence between them.

Temperature of a gas

The second question was: What is the temperature of an isolated molecule of hydrogen?

Eleven teachers attempted the question. Four of them stated that the temperature of the hydrogen molecule would be the same as *"room temperature"*. One answer was *"0°C"*, and another was hydrogen's *"critical temperature"*. One of the teachers tried to use the formula: $PV = nRT$, but did not get further than $T = PV/nR$. Another teacher mentioned the *"molecular kinetic theory of gases"*, but did not offer any further explanation. One teacher's answer was: *"The temperature of the individual (isolated) molecule will be the same as the temperature of the whole quantity of gas"*. This reveals one reason for this confused thinking about temperature. Only two of the 22 teachers offered somewhat accurate answers. One of them replied: *"It is not possible to measure the temperature of an isolated molecule"*. The other's answer was: *"Can't predict and measure"*. However, even these answers focused on the problem of measurement.

Many of these teachers were familiar with the kinetic theory of gases. It is likely that they would have been able to solve equations related to this theory with great ease. Yet, none of them seemed to find anything odd about being asked about the temperature of one molecule of hydrogen. They seemed to have ignored the fact that the temperature of a substance (whether it is in solid, liquid, or gaseous state) is a derived quantity that tells us something about the **average** energy (kinetic energy, hence velocity) of molecules in bulk. Their answers seemed to be based on the incorrect belief that temperature is an intrinsic property of individual molecules that is directly measurable (however inaccurately), much like the length of a table.

States of matter

The last question was related to an illustration from the NCERT textbook for Grade IX (see **Fig. 2**). Teachers were asked to study the illustration before answering the following questions:

a. Extract as much information from the given illustration as possible.
b. Compare the change in density of particles during changes in states of matter from solid to liquid and liquid to gas.
c. What do you think exists between the molecules or atoms in the three parts of the diagram?
d. Compare the degree of order in the three states of matter.

The first part (a) was included as an invitation to critically examine as many details of the textbook illustration as

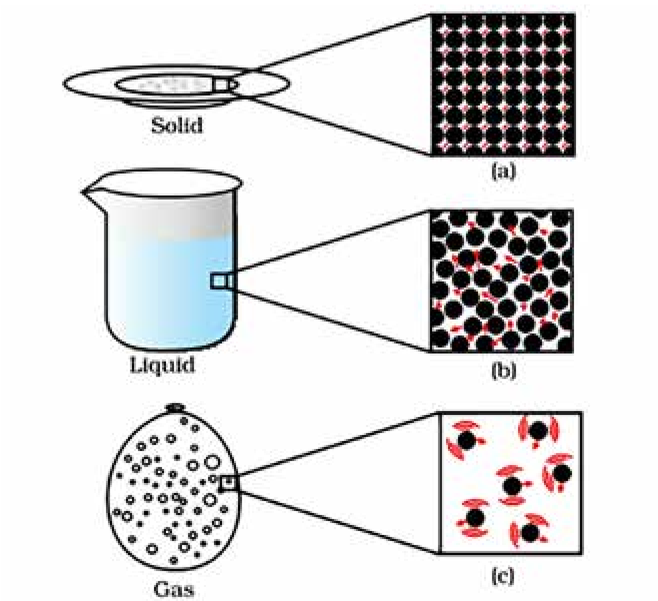

***Fig.1.5:** a, b and c show the magnified schematic pictures of the three states of matter. The motion of the particles can be seen and compared in the three states of matter.*

Fig. 2. Misleading illustrations in textbooks can influence misconceptions about the nature of matter. This is one example of such an illustration. It is included in the first chapter 'Matter in our surroundings' of the NCERT science textbook for Grade IX.

possible. None of the teachers accepted the invitation. Instead, they answered this part with whatever they knew about solids, liquids, and gases.

The second part (b) was included to draw attention to two aspects of the illustration:

- The decrease in particle density when a (crystalline) solid changes to a liquid has been greatly exaggerated in the illustration. Thus, the illustration does not reflect the fact that this kind of change in the state of matter involves more a decrease in the degree of order than an increase in interparticle spaces. One example of this is seen in metals, where a decrease in order explains why the metallic bond survives melting as well as why molten metals are lustrous and can conduct electricity.
- The vast decrease in density when a liquid turns into a gas is not adequately represented in the illustration. To take the simple example of water, one mole of water is 18 mL in the liquid state and 22,400 mL in the gaseous state (if we consider that any gas at STP occupies 22.4 L, although this might not be entirely accurate for water). Thus, this change in state can cause more than a thousandfold increase in volume.

Most teachers answered this part by stating that the density of particles decreases in the order of solid > liquid > gas.

The correct answer to the third part (c) would be that there is 'nothing' between the molecules or atoms (or particles). Answers to this question revealed some confusion and some clarity. Three teachers answered it with *"air"*. Interestingly, research in science education suggests that most children believe that molecules of a gas are separated by air. Could this confusion in students be related to imperfectly taught theory? Seven teachers answered it with *"intermolecular forces"*, six teachers with *"intermolecular spaces"*, and two teachers with a combination of both these answers. Is it possible that these teachers used these terms to avoid having to answer this question with 'nothing'?

The fourth part (d) was included to draw attention to one of the most important differences in the particulate nature of the three states of matter. The arrangement of particles (atoms, molecules, or ions) shows a high degree of order in a solid, less order in a liquid, and a state of high disorder in a gas. Thus, the question invited teachers to examine if the textbook illustration clarified that the particles in a solid can only show vibratory motion while those in a liquid or gas can also show translational motion. However, none of the answers touched upon these aspects. Again, teachers answered this question with textbook statements about order and disorder in solids, liquids, and gases.

These answers seemed to suggest that the teachers may not have looked at the illustration carefully or critically enough, or given sufficient thought to the impact of illustrations on reinforcing incorrect concepts among students. It is also possible that a more direct question on the depiction of quantitative changes in density (like, *"Is the density of particles in the gas depicted in the textbook illustration tenfold, hundredfold, or thousandfold that in the liquid?"*) may have elicited more accurate answers.

Parting thoughts

The aim of this short test was to invite teachers to critically examine how the atomic theory is presented in the school textbook. Do the explanations and illustrations in the textbook really serve their purpose to help children understand and apply foundational concepts like the atomic theory to observations in the real world?

The answers to the test seem to suggest that most of the teachers had not engaged with the information in the textbook deeply enough. Also, surprisingly, many of the teachers had the same kinds of misconceptions that studies have shown to be prevalent among middle and high school students. They may have developed these misconceptions as children and have held onto them even as adults. If so, this would counter the common assumption that a pedagogical and assessment approach focused on ensuring that students can memorize textbook statements is sufficient to help them develop an accurate understanding of these statements on their own.

This small study may help teachers reflect more deeply on how they teach the atomic theory. Also, to ask and answer—how does identifying confusion and errors in textbook explanations and illustrations guide their pedagogical and assessment approach?

Key takeaways

- Studies show that many middle and high school students can describe the atomic theory accurately but hold many misconceptions about it.
- Often, students are also unable to appreciate how this theory is related to other concepts or scientific disciplines.
- Some of these challenges may be due to erroneous or confusing explanations and illustrations in school textbooks. These can go unnoticed by teachers.
- Some teachers may also associate the atomic theory with the same kinds of misconceptions that are prevalent among middle and high school students.
- Identifying such misconceptions and engaging more critically with textbook explanations and illustrations could guide teachers in developing pedagogical and assessment approaches that are more effective in helping children understand and apply this theory more accurately.

Notes:

1. This article was first published in Sandarbh, Issue 60, pg. 35-41. This version is restructured and revised for conciseness. URL: https://www.eklavya.in/magazine-activity/sandarbh-magazines/300-sandarbh-from-issue-51-to-60/sandarbh-issue-60/1211-parmanu-sidhant-or-shikshako-ki-bhrantiyan.
2. Source of the image used in the background of the article title: Breaking chalk. Credits: Viktoria Goda, Pexels. URL: https://www.pexels.com/photo/blue-red-and-yellow-chalk-1107495/. License: CC0.

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VOICES OF INTOLERANCE

I am a good neighbour. In this overcrowded city, hemmed in on all sides with the houses of other men, I am impercipient. Especially do I take no note of the uproars that break out around me from time to time—I presume these are signs of life's onward march here, just as the grating sounds from around the corner are tokens of the progress of trams, and I am incurious. But, on Friday morning, I was awoken by such a varied and sustained din that overcoming my civic sense I rushed to the backyard and looked over the wall.

The hubbub came from a cassia in the compound of my neighbour to the east. A number of crows and rose-ringed parakeets had assembled about the tree, and in its top branches, circling round, settling, and circling again, screeching, screaming, cawing, and demonstrating at something that sat lumped, indistinct, and immobile in the heart of the tree. The something was almost completely hidden by foliage and flowers—it looked large, whatever it was, and apparently it knew there was little calm outside the screen of leaves. I took a quick census of the demonstrators, since the object of their attentions was invisible. The crows (mainly grey-necks) kept flying in and out and were too numerous to be counted, but there were about two dozen of them, and there were seventeen parakeets. A surprising number, for although parakeets visit the neighbourhood, they do not roost here, and I had not thought the locality held so many of them.

For a few minutes I had to rest content with watching the demonstration, for the cause of it all gave no clue of its identity—I guessed it was a large owl that had strayed into the neighbourhood, incautiously. Then unable to suffer the prying eyes and the many-keyed curses of the birds, it broke cover, climbing down surprisingly to earth, a young three-fourths-grown bonnet monkey, with half its tail missing, that raced across my neighbour's compound and streaked up the wall, and from it up the tall coconut tree in the corner of my backyard. Promptly the frenzied crows and parakeets shifted *en masse* to the coconut, and with a plainer view of their quarry demonstrated against it even more agitatedly.

The cause of the demonstration.

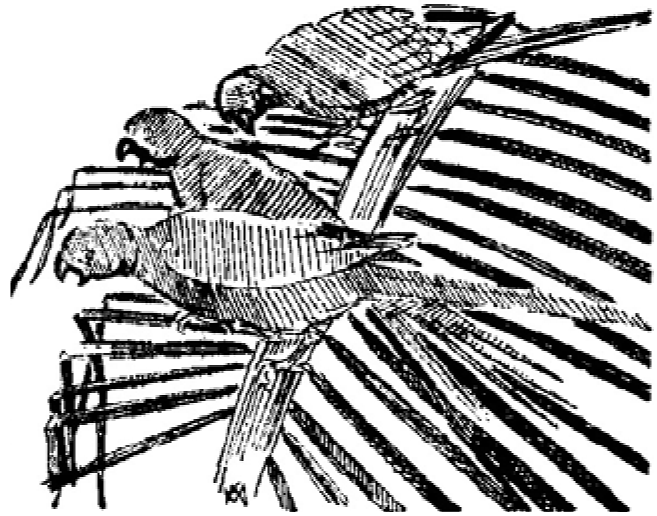
Credits: Bonnet monkey, Pixabay. URL: https://pixabay.com/photos/bonnet-macaque-macaca-radiata-371618/. License: CC0.

There are no monkeys hereabouts—this one must have been a runaway from some gypsy's troupe. From the coconut to the great wood-apple tree in my compound, from there through a row of coconuts to a mango, and finally to the concrete parapets of my western neighbours, the fugitive took its wretched liberty, never descending to earth again, seeking the cover of foliage from the tormentors—and the birds followed every move in its progress in a vociferous mob. Only when that harassed monkey took to the house-tops, abandoning green sanctuary, and disappeared westwards to where there were no trees, did they stop heckling him. Then all at once the chivvying ceased, as suddenly as it had begun some half an hour earlier.

At first all this may seem trifling, and hardly worth the record, but I feel the incident is not without interest to the naturalist. For one thing, this was the first time I had seen parakeets demonstrating at a monkey, or any other creature, for that matter. Dewar, I think, mentions an instance of rose-ringed parakeets panicking at their roost, when a hawk took one of them, but this was something quite different. Though there were many more crows there, the varied voices of the parakeets almost drowned their cawing, and the crows seemed half-hearted in their heckling, by comparison. They just flew in from neighbouring perches to the monkey's tree, and then out again, but each parakeet, before settling, circled the tree on stiff-held wings, with every long-graded tail-feather outspread, heaping shrill curses on the unhappy macaque's head: they sat in rows craning over to peer through the leaves at their quarry till their heads seemed disproportionately big on the taut, thin necks, yelling vituperations, almost toppling off their perches in their excitement.

I cannot imagine why these birds were so affected by the monkey—in the countryside where they lead an arboreal existence together, I have never seen them demonstrating at macaques. Anything out of place excites the birds of a locality, and certainly that monkey was utterly strange in that setting, but this does not seem to explain the obvious anger of the parakeets. The crows were merely a subsidiary force, drawn to the scene of action by the parakeets—they were, as I said, almost casual in their protests.

Another remarkable fact was the complete indifference of other creatures present. I noticed that the numerous squirrels of my compound, and a party of white-headed babblers there just then, utterly ignored the monkey and its tormentors. Palm squirrels and white-headed babblers are notoriously more given to demonstrating against enemies and intruders than parakeets, but they showed no interest whatever.



The main demonstrators.

Credits: M Krishnan. URL: https://www.mkrishnan.com/writings.html. License: Included here with permission from the rights owner—Asha Harikrishnan.

Even more remarkable was the apathy of the human population. A gardener's child threw a small stone vaguely in the direction of the monkey, as it leaped from one coconut tree to another overhead, but this was a purely formal gesture, prompted by some dim, atavistic obligation to throw things at fugitive creatures. After performing this rite, the child took no further notice of the monkey, well within his puerile range. No one else seemed even aware of the commotion in tree and air. One of my neighbours was shaving at a window seat, and got up—I hoped he would step on to his terrace to see what it was all about—but it was only to get a towel before resuming his toilet.

Notes:

1. This article was first published on Sunday, April 21, 1951 under the fortnightly column 'Country Notebook' in 'The Statesman' of Calcutta. It is reproduced here with the permission of Asha Harikrishnan, who holds the copyrights of all of M Krishnan's works. Digitised versions of other writings by M Krishnan can be accessed here: https://www.mkrishnan.com/writings.html.
2. To read more about M Krishnan, check out his Biography titled 'Nature's Passionate and Meticulous Chronicler' by Varun Sharma on page 4 of this issue.
3. Are you wondering who Dewar is? Douglas Dewar (1875-1957) was a British civil servant and an ornithologist who wrote extensively on Indian birds and wildlife. His books include: 'Jungle folk, Indian natural history sketches', 'Animals of no importance', 'Glimpses of Indian birds', and 'The Indian crow, his book'. You can find these and many more in the Biodiversity Heritage Library: https://www.biodiversitylibrary.org/search?searchTerm=Douglas+Dewar&stype=F#/titles.
4. If you are as fascinated as us by the many characters that appear in this short piece, turn to page 43 of this issue.
5. Source of the image used in the background of the article title: Jigsaw pieces. Credits: Wounds_and_Cracks, Pixabay. URL: https://pixabay.com/photos/puzzle-piece-tile-jig-jigsaw-game-3306859/. License: CC0.

Madhaviah Krishnan, better known as M Krishnan, was a pioneering Indian wildlife photographer, naturalist, and writer.

AN INQUIRY-BASED APPROACH TO GERMINATION

DHANYA K

How do we use the science laboratory to introduce students to the process of scientific inquiry? How do we encourage them to design and conduct their own experiments? Can inquiry help students collaborate with and learn from their peers?

What is the purpose of a science laboratory? Children may often associate a lab with test tubes, lenses, lab coats, and maybe even skeletons! And many teachers may see it as a space where experiments are presented to students as a prescribed set of steps to complete. But what if a lab is used to offer students an introduction to inquiry and experimentation? What if students are encouraged to formulate their own hypotheses, design their own experiments, observe the results of such experiments, make predictions and inferences, learn to address unanticipated outcomes, and communicate their findings to their peers?

I used a science lab to facilitate inquiry-based learning among Grade IX students around the concept of seed germination. This form of learning requires students to work like scientists by engaging in: *"the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments"*.[1] It also requires teachers to use an inductive, student-centered, and collaborative approach in class. Thus, the module around seed germination was designed to invite students to collaborate in small groups to:

- Design and conduct experiments to investigate factors that influence seed germination.
- Observe and present the results of their experiments to the rest of the class for peer review.

Introduction to germination

I begin the introductory class with questions about germination, specifically leading up to asking students to list out factors or conditions required for seeds to germinate (see **Box 1**).

This exercise helps draw out what students have learned and understood about germination from earlier grades as well as related real-world experiences. For example, students typically respond by naming conditions like water, sunlight,

Box 1. **Questions for the introductory session:**

Typically, I begin the introductory class with questions such as:

- What is meant by germination?
- How do seeds germinate?
- If a seed is placed on the table (I point to a table), will it grow or germinate?
- What is required for seeds to germinate?
- Can you list out all the factors or conditions that are required for seeds to germinate?

soil, nutrients or manure, temperature, and air or oxygen. This exercise can also help identify misconceptions. For example, students may insist that seeds cannot germinate in the absence of sunlight, soil, or manure. I list each unique factor on the board for the entire class to see while being careful to avoid giving ready-made answers or providing direction to their thoughts. Instead, I allow students to make 'mistakes' (see **Box 2**). This means that I do not leave out any factor that students come up with and encourage students to investigate each factor in subsequent steps. I do, however, allow students to check their textbook or the internet and change their responses as long as they are able to justify the change and the whole class is in agreement with it. I allot about 30 minutes for the introduction.

Initiating collaborative inquiry

For this part of the lesson, I divide the class into small groups (typically 3-4 people). The total number of groups and the size of each group depends on the class strength and the number of necessary conditions for germination listed on the blackboard. I copy out each of the proposed conditions for germination onto separate chits of paper, then mix all the chits up in a bowl or box. Once the students are seated in groups, a member of each group picks up one of these chits. Their group is expected to use experimentation to investigate the role that the factor listed on their chit plays in germination. This ensures that every condition listed on the blackboard, including any 'incorrect' ones (or ones that are known to have no impact on germination), is tested by at least one group in the class.

Once each group settles down at a designated workbench, I share a workflow for them to use for their investigation (see **Fig. 1**). I elaborate on how the members of a group will need to work together to formulate and test a hypothesis regarding the role that the factor they are investigating plays in germination. And that they will do this through an experiment that they will design and conduct together. I emphasize the need for them to design simple experiments involving reagents or instruments that are already available in the school lab. Each group is expected to give me a brief overview of their plan and submit a list of materials that they will need to be able to conduct their experiment.

Due to the novelty of this approach to lab work, students usually meet it with several questions. These include: *"Are we allowed to do any experiment that we decide on as a group?", "Are we allowed to refer to books?", "How much time will we get to do the experiments?".*

Once I have clarified their doubts, the members of each group begin to discuss their hypothesis and the design of an experiment to test it. The lab transforms into a chaotic and noisy space, occasionally interrupted by heated arguments, students prancing up and down the lab to look for resources or to refer to textbooks for ideas. It is a pleasure to walk around the class, listening to students express and debate their thoughts and ideas. Occasionally, the class can get very chaotic or students can get stuck and be unable to proceed. Or a group may start chatting with each other on a topic that is unrelated to their experiment. In these rare instances, I use a worksheet to help students guide and organize their ideas as a group (see **Activity Sheet I**).

By the end of this session, each group draws up their plan and shares it with me. I refrain from 'correcting' their experimental designs, as it would obstruct their learning process. However, I may challenge certain aspects of their plan, such as the necessity of some of the reagents or instruments that a group has asked for. For example, I may ask: *"Why do you need this instrument? Why do you need glass beakers? Why do you need distilled water and not tap water? Why do you think the soil needs to be red and not black? Why do you think the soil should not be clayey?".* Through this discussion, we negotiate for materials and instruments based on their availability in the biology lab. Mostly, students are encouraged to look for substitutes of the chemicals

Box 2. **The importance of mistakes:**

Often, we are taught to be so careful that we do not make any mistakes or hide the ones we make. We need to embody the opposite! We need to cultivate the habit of making mistakes and celebrating them! Why? Because mistakes are a vital part of any learning process and can enable our progress as learners. For example, making a mistake allows us to pause and reflect on how to make our next attempt better with the knowledge and clarity we acquire from a failed attempt. Thus, not only do we learn not to repeat the same mistake, but we also gain deeper insights into ourselves as learners. For these reasons, it is important for teachers to embrace mistakes (students and our own), openly acknowledge them in class, and actively explore learning opportunities that offer the possibility of new kinds of mistakes.[2]

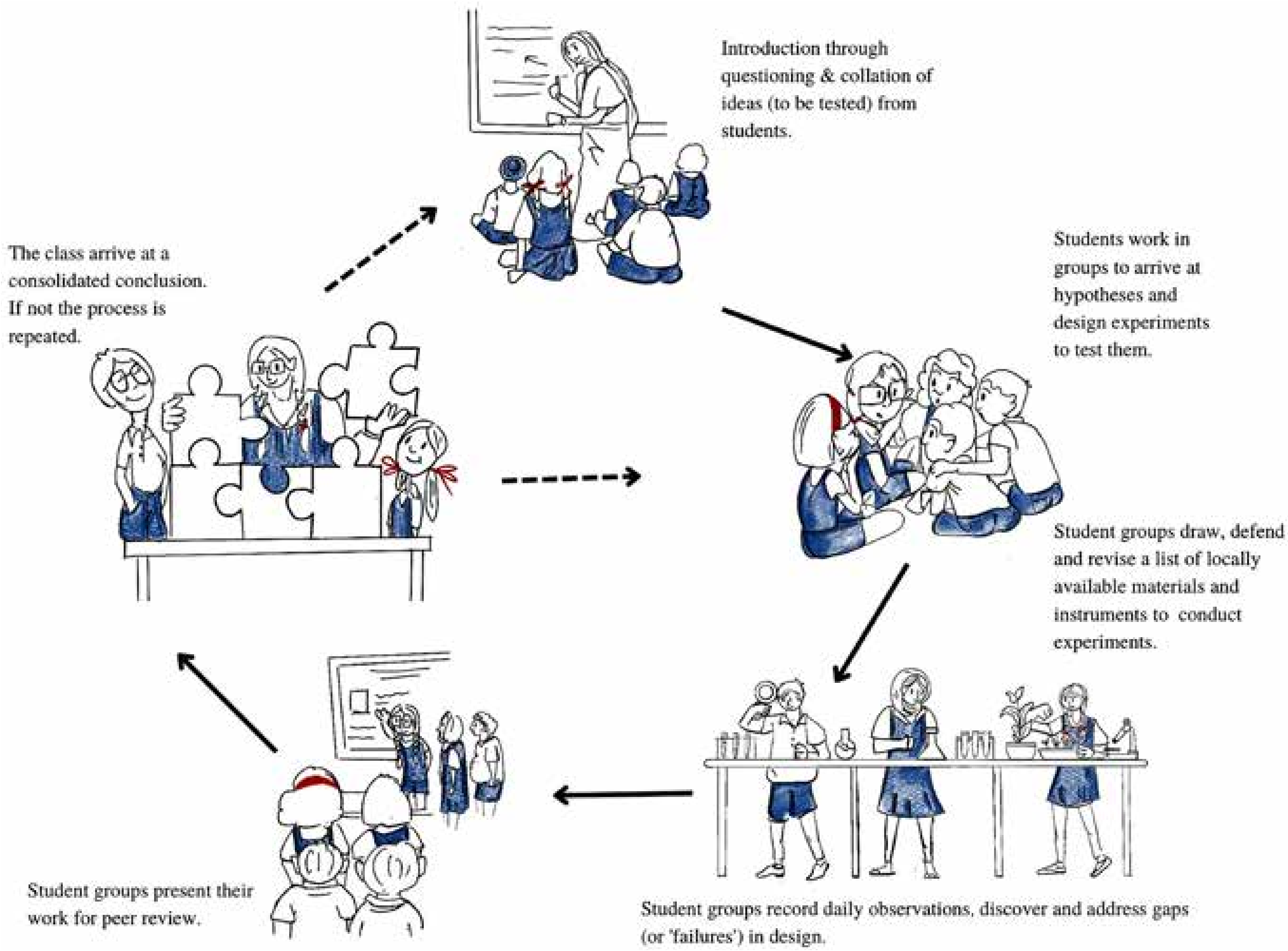


Fig. 1. Lesson workflow.

Credits: Shreya Kedia. License: CC-BY-NC.

or materials they need for their experiment; only rarely, they may need to redesign their experiment. By the end of the class, each group submits their final plan and list of required materials for the experiment. I allot about 40-60 minutes for this stage of the module.

Conducting the experiment and recording observations

I take 1-2 days to set up the the lab for the next class. This involves preparing workbenches for each group according to the final list of materials that they have submitted. This ensures that the lab is fully equipped for students to start their experiments.

Before each group sets up their experiment, I lay out some expectations and guidelines for work and behavior in the lab environment. For example, I touch upon the need for care in handling glassware, precautions in handling reagents and instruments, the importance of consistency in recording their observations, and basic lab etiquette. Over the next few classes, while the students conduct their experiments, the lab assistant and I supervise their work. We ensure an open, learner-centred environment, where we are not instructing, but observing and assisting whenever help is required, such as in using an incubator or water bath for the first time. In this way, the lab transforms into an interesting learning space that allows students to learn from their own mistakes (see **Box 3**).

Each group is encouraged to divide the responsibility to record observations on a daily basis among themselves. While there is emphasis on making these observations as regularly as possible, I am careful to offer minimal instructions and directions for observation. I also avoid using cue questions that direct their attention to observing specific aspects of the setup. This regular yet loosely structured approach to recording observations allows students to include spontaneous observations that emerge from their own experiences with the experiment. For example, some groups observed that not all seeds sprout at the same time. This led them to increase their sample size or repeat the same experiment with different types of seeds. This approach also offers scope to explore ideas and questions that go beyond the experiment at hand. For example, one of my students wondered if gravity plays a role in germination and conducted a separate investigation to test this possibility. Overall, I felt that this approach to experimentation

Box 3. Learning from our own mistakes:

I observed many examples of how students learn from their own mistakes. A group that started their experiment with just one seed learned to increase their sample size when that seed failed to germinate. Another group forgot to include controls in their experiment and learned how this constrained their interpretation of results during peer discussion. Often, groups that were investigating the role of temperature or air on germination neglected to provide water to their seeds. Such groups learned the importance of regular watering when they did not get the results that they expected to see.

Even students who tried to follow the protocol given in their textbooks observed unanticipated results, such as fungal growth on the seeds. This experience helped them pause and reread their textbooks in a more critical manner. Some students were not able to justify the use of a certain material, like cotton, that was specified in the experimental design shared in their textbook. When their need for this material was questioned, these students formulated the hypothesis that cotton may be essential for germination. They went on to test this by designing an experiment where they compared germination in seeds kept in water without cotton with that in seeds kept in water with cotton.

One of my own mistakes during the first iteration was to assume that students would be diligent in making and recording their daily observations. I had scheduled time for them to do this during their recess, but students would often forget. I found that reminding them at regular intervals helped address this. For the next iteration, I created an observation recording sheet and placed a copy of it on each of the work benches (see **Activity Sheet II**). This sheet has helped students to be more consistent in recording their observations. It has also helped me monitor each group's progress on a more regular basis.

allowed students more freedom with their learning (see **Box 4**). I give students about 40-60 minutes for setting up the experiment and about 5-10 minutes daily to record observations.

Class presentations

I allot a final session for each group to present their work to the entire class. Each presentation is expected to be less than 15 minutes in length. Often, students in a group take turns to share different aspects of their work. For example, if one draws a diagram on the blackboard, another explains the experimental setup, and so on. They are also encouraged to share any challenges that they may have faced. The rest of the class is expected to listen actively, point out contradictions, or critique the work in a constructive manner.

In my experience, presentations invariably lead to heated debates as well as laughter. Oftentimes, I observed that students used evidence from their work to argue a point quite successfully. They would do this both to defend a claim made by their own group and to contradict an idea or conclusion presented by another group (see **Box 5**).

Box 4. Learning from an inquiry-based approach to experimentation:

Since this approach to experimentation allows students to learn through their own experience of doing, learning is active and they develop a greater tolerance for mistakes. These factors seem to favour a shift in behaviour. I observed greater motivation and participation from students, even in those who were otherwise non-participative. For example, my students were curious and eager to monitor their experimental setups. They seemed more willing to discuss thoughts and ideas pertaining to their experiments with peers and teachers. In fact, they would often seek me out in school to discuss the progress of their experiment or request help with troubleshooting. They also seemed less hesitant to discuss their mistakes.

Working with peers also seemed to have a positive influence on learning. For example, students who were using apparatuses or instruments such as incubators or water baths for the first time were eager to share their experiences with other students. This led to many peer-teaching-learning moments. It was also interesting to see how students took the initiative to communicate their specific needs to the faculty of other departments, often ransacking other labs or departments for accessories that they could use for their experiments. For example, a black box was borrowed from the physics department to study the role of light, a bottle of pyrogallol was borrowed from the chemistry lab to study the role of oxygen, and timers were borrowed from the sports department.

Box 5. Variation in the format of presentation:

Occasionally, I may invite students to participate in a marketplace activity.[3] Each group is expected to put up a stall to showcase their experiments and display their results. One group member stays with the stall and acts as the 'stallholder'. Other members act like 'customers'—they go out into the 'marketplace' to gather information from other stalls. Each stallholder is expected to present the work and results of the group. They are also expected to answer questions raised by customers from other groups. Customers are expected to make notes on all aspects of the experiments performed by other groups. Towards the end of the activity, the members of each group reassemble at their own stalls. Members who acted like customers take turns to share details of their visits with other group members. Each student is then expected to submit an individual report of what they learnt about germination from all the experiments conducted by their class.

Assessing student learning

Typically, my assessment of student learning from such lab units involves two components. One component is their score on a test with questions related to the experiments (see **Box 6**). The other component involves my descriptive observations of each student's work based on criteria like their general conduct, contribution to peer interactions and presentations, and the lab records they keep. If writing such descriptive term-end reports is a challenge, a well-crafted rubric can be of help.

Box 6. An example of an assessment question:

Aman placed three seeds of *rajma* in two identical glass jars, A and B. Both jars were lined with the same amounts of damp cotton wool. Jar A was wrapped with a piece of black cloth, while Jar B was **not**. Both setups were left in the garden (see **Fig. 2**).

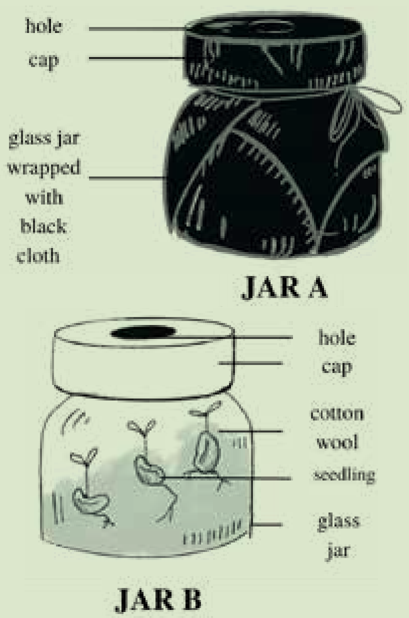


Fig. 2. The experimental setup.

Answer the following:

(a) What was Aman trying to find out in this experiment?

(b) In which of these jars would the seeds germinate? Explain your answer.

(c) What is the function of the hole in the cap of each of the jars?

Box 7. Some guidelines:

These are some broad guidelines that can be of help to teachers who are eager to try an inquiry-based approach in their own classrooms and labs:

- Unlike traditional teaching methods, this approach takes time. So, plan for at least 4-5 classes to conduct an inquiry-based lesson.
- Start this activity by clearly communicating your expectations regarding collaborative group work as well as peer-based review and discussion.
- Larger groups tend to result in unequal participation, with some students taking dominating roles. To avoid this, I recommend creating small groups with not more than 5 students per group.
- Regularly monitor student progress and group interactions.
- Although the overall design is structured, be prepared to build on student's prior knowledge, to stimulate student curiosity with effective questioning, and to challenge them in accordance with their abilities.
- When you first try this approach, classes may seem more chaotic than usual. You may find it challenging to engage in complex and sustained reasoning with students. Be assured that it takes time and practice for the class and you to settle into this different rhythm.
- Be open to creating an environment that encourages students to make mistakes without fear of judgment or failure, and to give them time for reflection.
- Use the terms 'correct' or 'incorrect' for student answers and responses sparingly.
- The focus of this approach is on learning as a process and not on the results of experiments. Hence, assessment of student work needs to be similarly oriented. This expands the scope of assessments beyond a few summative ones to a range of formative ones.

Parting thoughts

A common approach to lab work is to give students recipe-like instructions that direct them to carry out a procedure designed by someone else. In contrast, the National Education Policy (NEP) 2020 emphasizes the need for a more 'experiential, holistic, integrated, inquiry-driven, discovery-oriented, learner-centred, discussion-based, flexible, enjoyable' pedagogy. To move in this direction, our classrooms and labs need to transform into spaces where teachers and students learn together, and where making mistakes is recognized as an integral part of learning. The inquiry-based approach to lab work that is described in this article is aimed at building such a space (see **Box 7**).

I have used this inquiry-based approach to germination with five consecutive academic batches of Grade IX students. I have observed that it helps students to grow comfortable with being confused, making mistakes, and fearlessly exploring questions with their peers. In addition to nurturing curiosity and active participation, it also offers students the opportunity to develop scientific inquiry skills. Seeing this change in how students relate to learning can be encouraging enough for teachers to motivate them to overcome any challenges they may face in trying this approach in their own labs.

Key takeaways

- An inquiry-based approach to engage students in experimentation nurtures their curiosity while also helping them develop important skills in the practice of science.
- Students become more active participants in their own learning when offered a space that encourages them to be less fearful of making mistakes and to learn from mistakes.
- Nurturing a collaborative environment where students experience the creativity and freedom of working with their peers is empowering.
- This approach allows teachers and students to focus more on the process of learning rather than just on its outcomes.

Acknowledgments: I thank my students and my former colleagues for their enthusiasm and consistent support. I would also like to acknowledge Shreya Kedia's contribution to the illustrations accompanying this article. Lastly, I thank the editors and reviewers for their detailed feedback and suggestions to improve an earlier draft of this article.

Notes:

1. To know more about inquiry-based learning: Swan M, Pead D, Doorman M & Mooldijk A (2013). 'Designing and using professional development resources for inquiry-based learning'. ZDM, 45(7), 945–957. https://doi.org/10.1007/s11858-013-0520-8.
2. Additional reading for practitioners: Raghavan N (2019). 'The Reflective Learner: Seeing "Missed Takes" in Mistakes'. Notion Press Media Pvt Ltd.
3. Source of the image used in the background of the article title: An inquiry-based approach. Credits: Shreya Kedia. License: CC-BY-NC.

References:

1. PRIMAS. 'The PRIMAS project: Promoting inquiry-based learning (IBL) in mathematics and science education across Europe.' (2011, March 31). Retrieved on December 22, 2022, from https://primas-project.eu/wp-content/uploads/sites/323/2017/10/PRIMAS_Guide-for-Professional-Development-Providers-IBL_110510.pdf.
2. Dennett DC (2014b). 'Intuition Pumps and Other Tools for Thinking.' WW Norton & Company.
3. Ginnis P (2001). 'The Teacher's Toolkit: Raise Classroom Achievement with Strategies for Every Learner.' Crown House Publishing.

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ACTIVITY SHEET I : FACTORS OR CONDITIONS NEEDED FOR SEED GERMINATION

Date:

Names of group members:

(a) Your group's hypothesis:

Hint: One factor or condition that you think is needed for a seed to germinate?

(b) Justification for your hypothesis:

Hint: Why do you think that the factor or condition you listed is needed for a seed to germinate? Share your reasons.

(c) Procedure to test your hypothesis:

Hint: What experiment would you design to test if the factor or condition you listed in your hypothesis is needed for a seed to germinate?

(d) Materials and equipment required for testing:

Hint: List all the materials and equipment you need to perform the experiment you have designed. State the exact number of items required for each category as well. Check your list carefully. Remember, you will not be allowed to make any changes to this list later unless you can justify the change with a valid reason.

(e) Expected results:

Hint: If your hypothesis is true, what results do you expect to get from your experiment?

(f) Observed results:

Hint: What results did you actually get from your experiment?

(g) Conclusions:

Hint: Does the evidence from the experiment support your hypothesis?

Questions

For before you start the activity:
Q1. What do you know about seed germination?

Q2. What do you want to know about seed germination?

For after you have completed the activity:
Q3. What did you learn about seed germination?

Lab report guidelines:

Introduction: Include background information justifying why you are testing your specific hypothesis. End this with a clear statement of your hypothesis and expectations.

Methods: Include a detailed description of how your experiment was conducted even if it was unsuccessful. It should be so detailed that someone else could read it and recreate your experiment.

Results and data analysis: Clearly describe what your results were (even for experiments that were unsuccessful) and what you did to make sense of the data. This includes writing about how and why you made each graph or table.

Conclusions: Include your interpretation of the results (even from unsuccessful experiments) and key conclusions about your research. If no clear conclusions can be made, mention how you have improved the design of your experiment. This section could also include experiments that could be done in the future based on the knowledge and results you have obtained through this experiment.

Contributed by:
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ACTIVITY SHEET II : OBSERVATION SHEET

Aim:

To test the role of .... in the germination of seeds.

Group members:

Tasks:

Name of group member	Task	Observations	Date	Time	Sign here (after your assigned task is complete)

i wonder... Rediscovering school science

Contributed by:
Dhanya K who has worked as a high school biology teacher. She can be reached at: dhanyak2@gmail.com

Azim Premji University

AN ELEMENTAL CROSSWORD

Textbooks tell us that a chemical element is a form of matter, with a unique combination of physical and chemical properties, that cannot be decomposed into simpler substances by ordinary chemical processes. At present, we know of 118 chemical elements (as recognised by the International Union of Pure and Applied Chemistry). These are arranged in the modern periodic table in order of increasing atomic number. Ninety of these have been observed to occur naturally on Earth, although some are found in extremely small amounts. Two of these elements are the extremely unstable byproducts of reactions in nuclear reactors. The remaining elements have been artificially synthesised by physicists by smashing atoms of different elements together at very high speeds in high-energy accelerators.

Here is a crossword puzzle with 19 of these elements. How many of them can you identify from their clues?

Down clues:

1. This is the first element discovered by Marie and Pierre Curie. Named after Marie Curie's homeland, it may have contributed to the death of their daughter Irène Joliot-Curie. It is suspected to have been used in killing the Palestinian leader Yasser Arafat in 2004. In 2006, a trace amount of an isotope of this element was used to poison a cup of tea served to Alexander Litvinenko, a former Russian spy who had sought asylum in London. Litvinenko died 23 days later.

2. This colourless, odourless, and tasteless gas was accidentally discovered by the Scottish chemist William Ramsay and English chemist Morris Travers, both of whom had also discovered helium, argon, xenon, and neon. They named it after the Greek word for 'hidden'. It shares its name with the home planet of the fictional superhero of a comic book series created by the writer Jerry Siegel and the artist Joe Shuster.

4. The name of this silvery-white metalloid comes from the Latin word for 'earth'. First discovered from Dracula's homeland. You can tell if someone has been exposed to high levels of it by their breath—it will have a pungent garlic-like smell.

6. The French chemist Paul Émile Lecoq de Boisbaudran was only able to isolate this soft metallic element from its oxide after more than 30 attempts at a procedure he had developed for this purpose. He named it after an ancient Greek word that means 'hard to get'. Because it is highly magnetic, this rare element is now in demand for use in electric motors, especially in wind turbines and electric vehicles.

10. This element was first discovered in 1939 by the physicist Marguerite Perey, who was a prodigy of Marie Curie. Named after Perey's homeland, it has an incredibly short half-life of 22 minutes. Scientists predict that it may be a silvery-grey metal. But no one really knows what it looks like because it is so rare that it has never been seen by the naked eye.

11. An oxide of this element was first isolated from a gemstone that gets its name from a Persian word for 'gold colour'. Its dioxide is often used as a substitute for diamond. Because of its strength, very low toxicity, and high resistance to corrosion, it is also used in prosthetics.

12. This silvery-white metal is named after a continent. Small amounts of this metal are now included as an anti-counterfeiting measure in the banknotes of the official currency of about 20 countries in the same continent. Without the robust red colour it produces, all the other colours (whites, blues, and yellows) on your television screen would have to be muted to duller and dingier shades to maintain some balance.

Across clues:

3. The lightest known metal. Can also lighten your mood. Its salts are used to treat mania and depression. They are known to stabilise the wild mood swings associated with bipolar disorder. Research shows that when this treatment is given to sticklebacks parasitised by tapeworms, it helps

restore the natural shyness of the fish. Unlike other diseased fish, ones given this treatment spend less time alone and near the water surface. This reduces the risk of their being eaten by birds. It has a calming effect on worms too, but acts in a way that inhibits their ability to avoid harmful bacteria.

5. This greenish-yellow gas is one of the components of the most common table condiments. It was first isolated in 1774 by the Swedish pharmacist Carl Wilhelm Scheele, who wondered if it was an oxide of a new element. It was identified as a pure element in 1810 by the British chemist Sir Humphrey Davy, who named it after an ancient Greek word for 'pale green'.

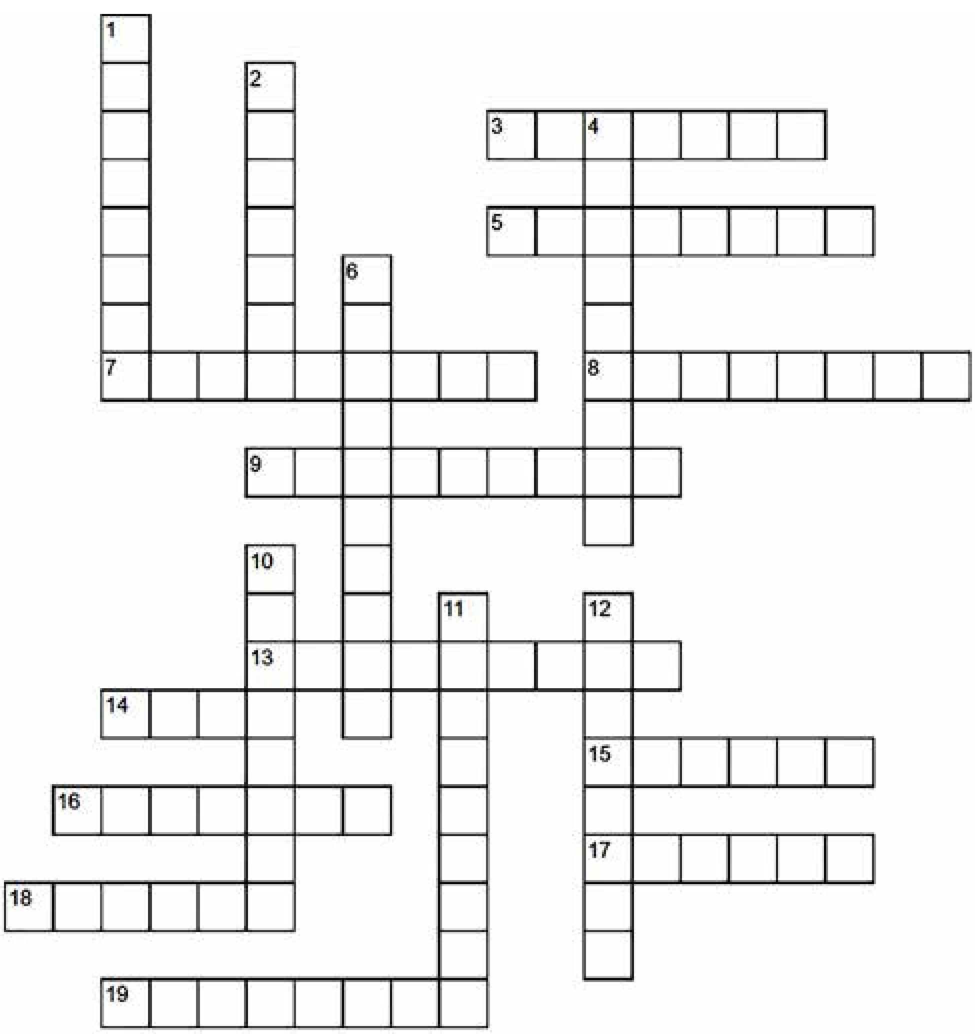
7. Part of chlorophyll, this element is also needed for more than 300 biochemical reactions in our bodies. Good natural sources of this element include fruits, vegetables, nuts, legumes, and whole grains. Supplements of this element are sometimes recommended for medical conditions like premenstrual syndrome and high blood pressure. They can also help reduce tension headaches and migraines.

8. Because this very soft, silvery-white metal reacts violently with water, it needs to be stored in mineral oil. Its name comes from a Latin word meaning 'deepest red'. Can be used in fireworks to give explosions a purple-red colour.

9. This brittle, steel-grey metal combines with trace amounts of the element chromium to form the beautiful green-hued gemstone 'emerald'. It is believed to have pushed all the colonists on the planet 'Junior' in Isaac Asimov's science fiction story 'Sucker Bait' to cough, shiver (from fever), sweat (night sweats), and tire (fatigue) their way into slow deaths.

13. For decades, this silvery-white metal was more highly priced than gold. Lightweight and resistant to corrosion, it is easy to fold, mould, and recycle. Oxygen causes this metal to lose electrons by the same kind of reaction that causes iron to turn to rust. Unlike iron oxide though, the oxide of this metal forms a thin hard film that sticks to the original metal and shields it from further decay.

14. This colourless, odourless, and largely nonreactive gas gets its name from a Greek word that means 'new'. When filled into a clear glass tube and connected to an electrode, it lights up to produce a warm reddish-orange colour. This was first demonstrated in December 1910 in the Paris Motor Show by the French engineer Georges Claude. In 1912, it was used in an advertising sign outside a barber's shop in Paris. Since then, it has been used in signages across the world.



15. This bluish-white metal is one of the densest elements in the world. Its name comes from a Greek word meaning 'smell' or 'odour'. Its oxide has a very strong, acrid, and unpleasant smell at room temperature.

16. Magicians would carry spoons made of this soft, silvery metal for a popular 'melting spoons' trick. The spoons look solid and 'normal' at room temperature. If you were to dip one of them into a cup of hot tea, it would instantly dissolve. If you were to warm one of them by holding them in the palm of your hand for a few minutes, it would melt. If you set the melting spoon down, it would solidify again.

17. This lustrous, soft, silvery metal was first discovered by the German chemist Ferdinand Reich. Because Reich was colour blind, he asked the German chemist Hieronymous T. Richter

to observe the element's spectrum. Richter found that it produced a spectral line that was a brilliant violet in colour and did not match the spectral line of any known element. The two scientists worked together to isolate the element and announce its discovery. They named it after a Latin word meaning 'violet'. However, this collaboration turned sour when Reich learned that Richter had claimed this discovery as his own.

18. You could use this low-density gas for a party trick. Inhale a bit of it from a party balloon and your voice will become squeakier. In fact, you could be mistaken for the Walt Disney character Donald Duck! But be careful to do this in moderation—this gas replaces oxygen in your lungs. Inhaling too much can kill you.

19. The existence and properties of this soft silvery metal were predicted by the Russian chemist Dmitri Mendeleev a decade before it was discovered. Mendeleev called it 'ekaboron'. It is now named after a region in Northern Europe that includes Denmark, Sweden, and Norway. When added in small amounts to aluminium, it forms an alloy that is stronger yet lighter and more flexible. This alloy is used in military and civilian aircrafts as well as in sporting equipment. Interestingly, the US does not announce how much of this element it produces. This remains a well-guarded 'trade secret'.

Want to check your answers? Please turn to page 69 of this issue.

Notes:

1. Source of the image used in the background of the article title: Jigsaw pieces. Credits: Wounds_and_Cracks, Pixabay. URL: https://pixabay.com/photos/puzzle-piece-tile-jig-jigsaw-game-3306859/. License: CC0.
2. The image for the crossword was generated using the free crossword puzzle maker: WhenWe Crosswords. This site can be accessed at the URL: http://www.whenwecrosswords.com/.

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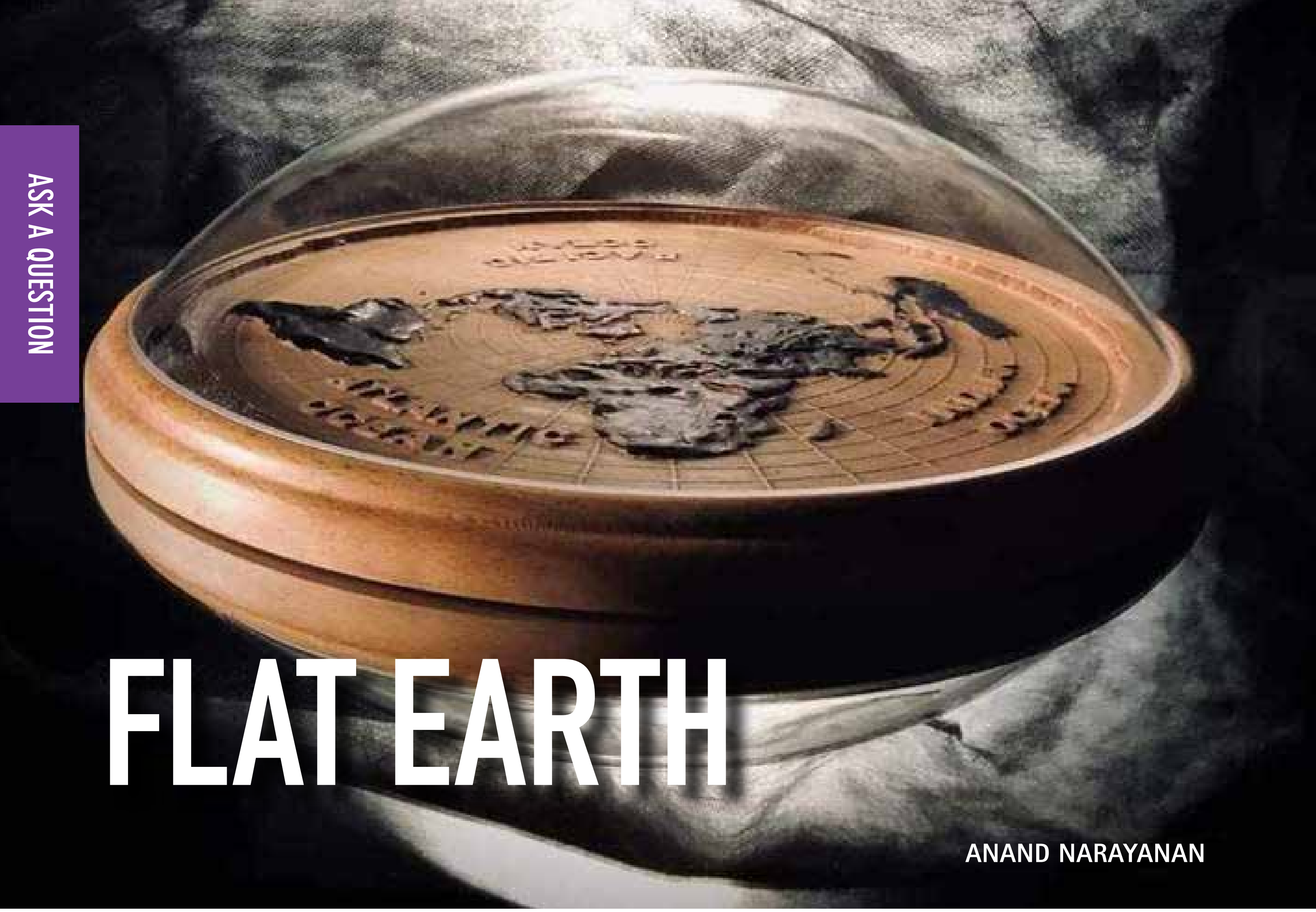


FLAT EARTH

ANAND NARAYANAN

How do we know that our earth is not flat? What kind of evidence do we have? Can children 'know' this through their own observations or through simple inexpensive experiments?

For a long time, the prevailing notion in some cultures was of our earth being a flat disk (see **Box 1**). The farthest one could see along the ground with the unaided eye (the horizon) was its boundary (see **Fig. 1**).

We no longer believe in such a view (see **Box 2**). For most of us, the earth is spherical, a simple fact that we have learnt as children (see **Box 3**). We have also seen numerous photographs taken from different vantage points in space that conclusively establish this fact (see **Fig. 2**). But, for a moment, let us forget the sphere we have seen in these photographs. What experiments or observations would help us conclude that our earth is not flat?

Objects vanishing beyond the horizon

If you are out on a beach or at any place where you have a wide view of water, observe a boat or ship sailing away. If the earth were flat, the boat or the ship would drop out of view abruptly when it reached the horizon. Instead, you will notice that the lower part of the boat disappears first, while the mast or flag will be the last to go out of view (see **Fig. 3a-b**). This happens because the earth is not flat. Its curvature causes parts of the ship closest to the ground to be blocked from our view first.

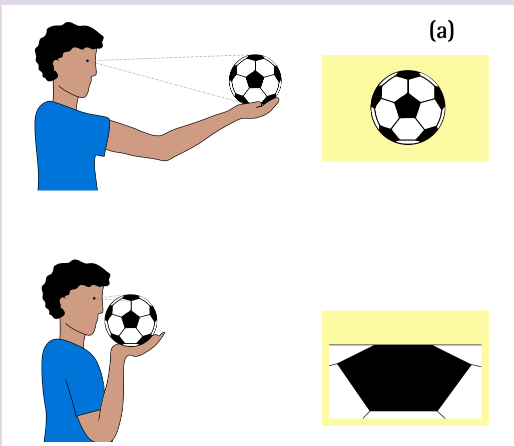
Objects on the horizon

Again, the next time you are out on a beach, compare what you can see of the setting sun when you are standing up with what you can see lying down. If the earth were flat, your view of the sun would be the same from both positions. However, you will notice that you can see more of the setting sun standing up than lying down. It is because the earth is curved like the surface of a sphere that the observer's height determines the

Box 1. Why did our earth appear flat?

Take a ball and keep your eye at the same level as its surface. From this viewing angle, the surface of the ball is likely to appear flat (see **Fig. 1a**). Now, imagine an ant moving on the surface of a fully blown-up balloon. For the ant, it would be difficult to comprehend that the surface on which it is moving about is not flat (see **Fig. 1b**).

This is exactly the case with us on Earth. The difficulty in accepting that the earth is round is that it 'appears' flat to us. But, as these examples show, something that appears flat need not be so. The earth curves everywhere. But the earth is also so big relative to us that the degree of curvature of its surface (the extent to which the earth curves away from a plane) is small and barely noticeable from where we stand. The curvature of the earth becomes apparent to us only from great heights, such as the top of a very tall building or while flying in an airplane.



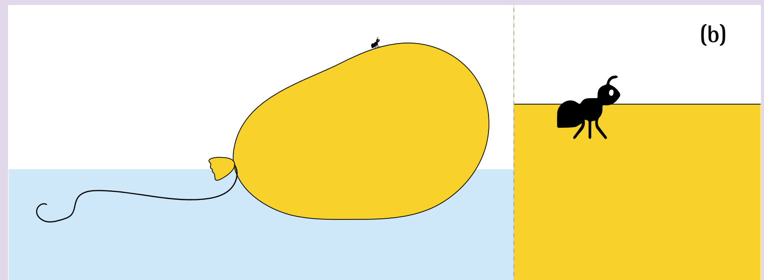


Fig. 1. A spherical object, like a ball or a balloon, may 'appear' flat from a certain viewing angle.

Credits: Anand Narayanan. License: CC-BY-NC.

Box 2. Aryabhata's spherical earth:

Aryabhata, an Indian mathematician-astronomer, described the earth as a sphere in the text *Aryabhatiyam*, written over 1500 years ago. In the *Gitikapada* portion of the text (verse 5), he shares the diameter of the earth in *yojana,* an ancient unit for distance. Combined with Aryabhata's own estimation of the value of the mathematical constant **π**, one can arrive at the circumference of the earth as well. Unfortunately, it has been difficult to compare these estimations with modern estimations largely because there is no consensus among scholars on what a *yojana* is in the units for distance we use today. Nonetheless, it is a fact that even during Aryabhata's time, the earth was known to be a sphere.

Aryabhata was also the first to propose the idea that the earth spins on its own axis and that the 'rising' and 'setting' of the objects that we see in the sky are relative to the earth's rotation. We leave it as an open exercise for the reader to figure out what observations one could do to check if the earth is indeed spinning. It is another one of those conclusions that seem contradictory to our everyday perception of reality and, therefore, not that easy to arrive at!

Box 3. The earth is NOT a perfect sphere:

As it turns out, our earth is not a perfect sphere either. Instead, its shape is that of an oblate spheroid, which means that it is slightly flattened at the poles and bulged at the equator, like a ball squished from two opposite sides. This shape is a result of the earth's rotation, which causes the equatorial regions to experience a centrifugal force that pushes material outward and causes the earth to bulge.

Fig. 2. The first full photo of the earth that showed that it was not flat. Known as 'The Blue Marble' this photo was taken on 7th December 1972, by the American crew of the Apollo 17 spacecraft.

Credits: Harrison Schmitt or Ron Evans. URL: https://en.wikipedia.org/wiki/File:The_Earth_seen_from_Apollo_17.jpg. License: Copyright NASA.

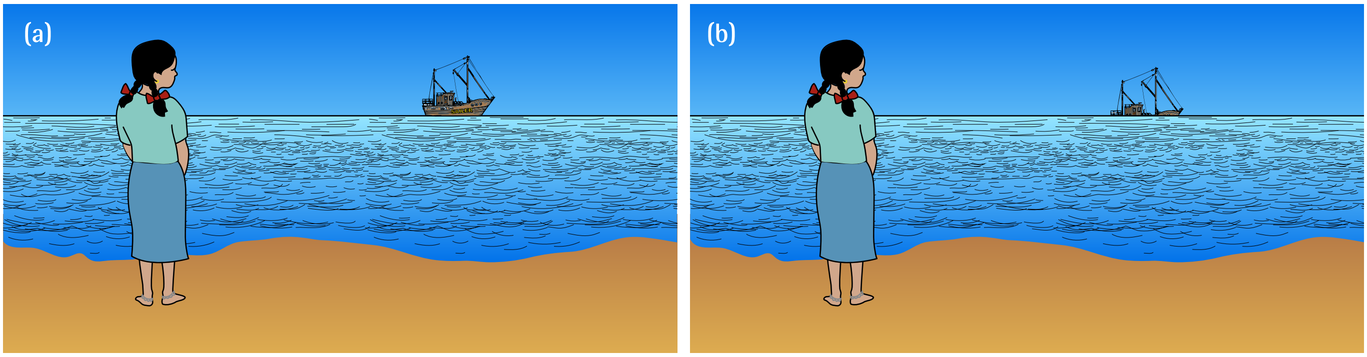


Fig. 3. **Ships sailing away from land disappear gradually from our sight.**

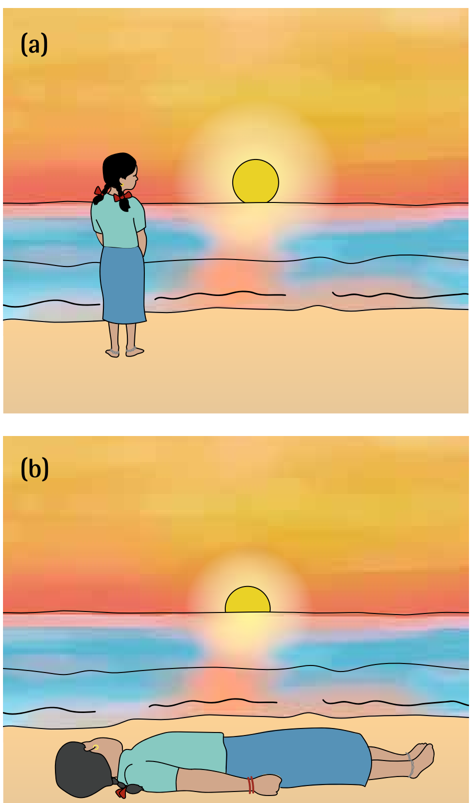


Fig. 4. **We can see more of the setting sun standing up than lying down.**

distance along the surface up to which they can see (see **Fig. 4a–b**).

You can also do this by standing in an open field and observing an object along the horizon, such as a far-distant tree or a building that is partially visible. As you climb to a higher vantage point, such as a nearby tree, you will be able to see more of the same object. You may even be able to see beyond it at other objects that were not visible to you before. Again, if the earth were flat, you would see no difference in the distance of your line of sight whether you were standing at the base or sitting on the branch of a tree. It is because the earth is curved that your line of sight extends further into the horizon the higher you climb. In other words, parts of the earth that were previously hidden by its curvature will now become visible due to the change in your vantage point (see **Fig. 5a–b**).

Length of shadows

Would the flatness or roundness of the earth change the length of our shadows? This can be tested by a simple experiment that can be done indoors. Take a spherical object like a ball or a fruit like an orange. Insert two toothpicks of equal length into it in such a way that they are about an inch apart (see **Fig. 6a**). Keeping the room dark, use a torch to shine a light on the ball and observe the length of the shadows of the toothpicks (see **Fig. 6b**). No matter what angle you choose to shine the light from, the shadows will not be of equal length (see **Fig. 6c**). In this experiment, the light source represents the sun and the ball represents the earth.

If you were to replace the ball with a flat surface, like a piece of thermocol, and repeat the same experiment, you will find the shadows to be of the same length (see **Fig. 7**).

One can repeat the same experiment at the scale of the earth if one were

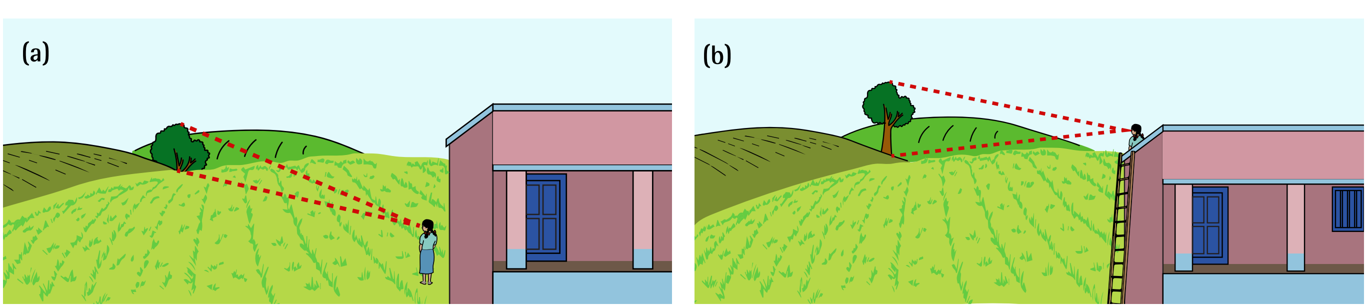
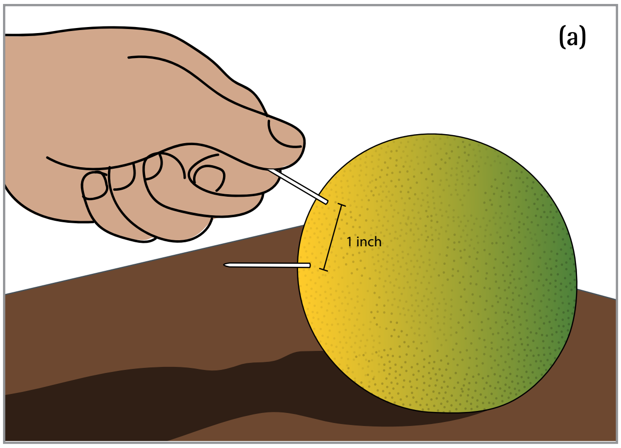
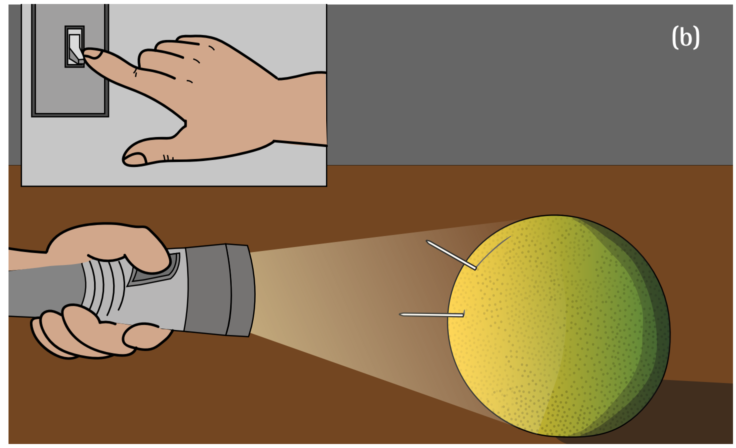


Fig. 5. **The line of our sight extends further into the horizon the higher the position of observation.**

to observe the shadows of two poles of identical heights that are several kilometres apart. The length of the shadows will have to be measured at approximately the same time. Interestingly, such a measurement was carried out by the Greek mathematician Eratosthenes more than 2000 years ago (see **Box 4**).





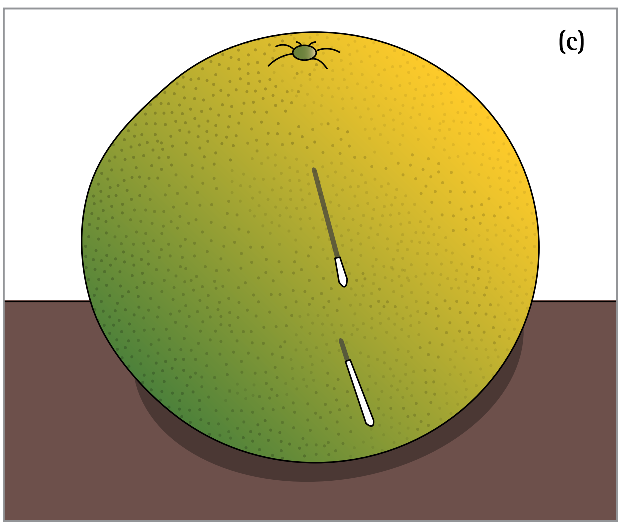


Fig. 6. **When two objects of equal length stand on a curved surface, the shadows they cast are of unequal length.**

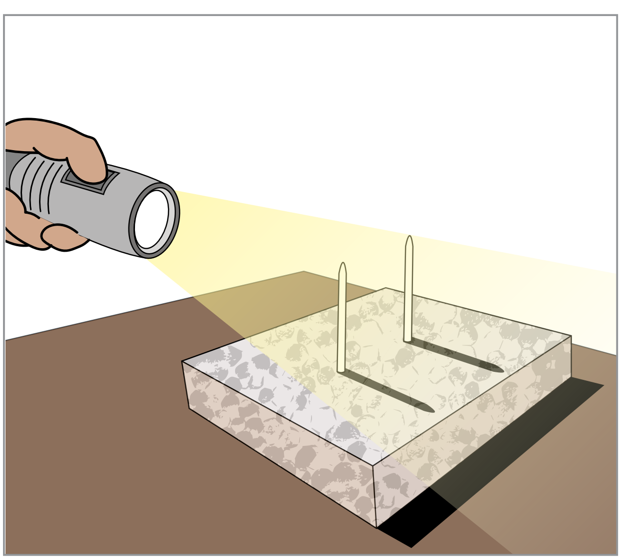


Fig. 7. **When two objects of equal length stand on a flat surface, the shadows they cast are also of equal length.**

Box 4. Eratosthenes' measurement:

Eratosthenes knew that none of the tall objects (like poles) in the ancient city of Syene, Egypt, cast any shadows on the ground at noon on a particular day. He inferred that this was because the sun was directly overhead Syene at this time. In contrast, the tall structures in Alexandria, another famous ancient city further north of Syene, left observable shadows (see **Fig. 8**).

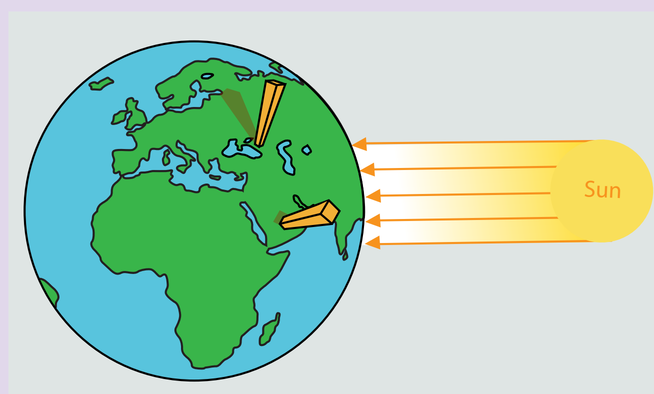


Fig. 8. **Eratosthenes concluded that the earth was not flat based on the difference in the length of shadows at two places at noon on the same day.**

He concluded that the only way this could happen was if the earth were spherical. Because of its curvature, the sun would not be directly overhead at two places at different latitudes. Hence, the length of shadows cast by even identical poles at these locations would be different. Eratosthenes used these measurements to come up with an estimate for the circumference of the earth.[1]

Parting thoughts

Our senses are efficient in providing us with an understanding of the world. However, there are instances where our immediate perception of reality through these senses can be skewed and even plain wrong. This is one of the reasons why it is important for us to rely on the scientific process of making observations, conducting experiments, and arriving at conclusions after carefully considering all possibilities.

Key takeaways

- That the earth is not really flat is not a modern discovery.
- The earth appears flat because the degree of curvature of its surface is so small that it often becomes apparent to us only from great heights.
- We can infer the curvature of the earth through many simple observations, like how objects vanish from the horizon or what we can see of them from different heights.
- Another way we can infer that the earth is curved is through a simple indoor experiment to compare the length of shadows cast by two objects of equal length when affixed to a flat surface versus a curved surface.

Note: Source of the image used in the background of the article title: Flat earth. Credits: Flatearthgifts, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Flat_Earth_model.jpg. License: CC-BY-SA.

For further reading:

1. Brown, Cynthia Stokes. 'Eratosthenes of Cyrene'. Big History Project. Khan Academy. URL: https://www.khanacademy.org/humanities/big-history-project/solar-system-and-earth/knowing-solar-system-earth/a/eratosthenes-of-cyrene.
2. Kate, Amol Anandrao. 'Measuring Earth's Size'. i wonder... pg. 22-26. ISSN 2582-1636. URL: https://publications.azimpremjiuniversity.edu.in/3390/.

Anand Narayanan teaches astrophysics at the Indian Institute of Space Science and Technology (IIST), Thiruvananthapuram. His research is on understanding how baryonic matter is distributed outside of galaxies at large scales. He regularly contributes to astronomy-related educational and public outreach activities. Every so often he likes to travel, exploring the cultural history of South India.

DISCOVERY OF OXYGEN: CLUES

Are you looking for some help in guessing the names of the scientists in the 'Hall of Fame' on page 10? Here are some clues:

(a) Showed that some part of air was necessary for both combustion and respiration.

(b) Wealthy and enormously ambitious, this scientist claimed to have independently discovered oxygen. But this claim was dismissed because he had a reputation for claiming credit for work done by lesser-known scientists. It was also known that both (h) and (j) had shared their findings with him. He did not acknowledge receiving (j)'s letter. Interestingly, it is possible that the letter was received by his wife, who worked as his lab assistant. If so, it has been speculated that having recognised the importance of the letter, his wife had hidden it in the hope that this would allow her husband to claim credit for independently discovering the gas based on his extensive body of work. This scientist dismissed the phlogiston theory as nonsense and suggested that the new gas that (h) and (j) had independently discovered was a unique chemical element. It was also he who came up with the name that the gas is currently known by, although this name was based on an assumption that was later proved to be incorrect.

(c) Proposed that when a burning candle was covered by a glass container, some amount of fire could escape from the glass container in the form of light. This loss of fire created a vacuum in the glass container.

(d) Was a student of (g) and was strongly influenced by his theory. Modified (g)'s theory to suggest that combustible bodies contain a fire-like element called phlogiston, which was released during combustion.

(e) Suggested that a burning candle used up some of the air in a glass container covering it. This used up air created a vacuum in the glass container.

(f) Worked with (i) in developing a pump and conducting experiments on combustion.

(g) Suggested removing air and fire from the list of classical elements and replacing them with three forms of earth, another classical element. Also, suggested that combustible substances contained one of these forms of earth, which he called *terra pinguis*. And that it was this form of earth that was released during combustion.

(h) Independently discovered oxygen soon after (j) but published it two years before him. Is therefore credited with the discovery of oxygen. Like (j), shared his discovery with (b) shortly before it was published. Reported inhaling the gas to experience its effects—a certain lightness in the chest. Believed that this component of air contained little or no phlogiston of its own and could readily absorb the phlogiston released from combustible substances. This property made combustible substances burn brighter in its presence.

(i) Developed an efficient vacuum pump to pump out all the air from a glass container covering a burning coal ember. Showed that the ember would die out in the absence of air and would glow again if some air was allowed into the container.

(j) Was the first to discover oxygen and describe some of its properties. Observed that this component of air supported combustion better than common air. Wrote to (b) sharing his findings, but is believed to be tardy in writing up his work for publication. As a result, this discovery, like a number of his other discoveries, was credited to another scientist. This prompted Isaac Asimov to use the prefix 'hard luck' before this scientist's name. He is also known to have developed a habit of tasting chemicals (even toxic ones, like arsenic) that he worked with.

Still not sure about some of these names? These clues may make more sense after you have read the article 'The Discovery of Oxygen' by Vijay Kumar Upadhyay on page 44 of this issue. If you have finished and would like to check your answers, please turn to page 54 of this issue.

Note: Source of the image used in the background of the article title: Jigsaw pieces. Credits: Wounds_and_Cracks, Pixabay. URL: https://pixabay.com/photos/puzzle-piece-tile-jig-jigsaw-game-3306859/. License: CC0.

Chitra Ravi works at Azim Premji University, Bangalore.

SPILLING THE BEANS

DEBORAH DUTTA

Growing a food garden in school naturally provides a space for students to raise questions about and develop an integrated understanding of the local environment. However, many schools may have limited space for such a project. How do the principles of urban farming, a practice that has emerged from land-scarce megacities, help teachers and students to grow food in their schools?

"The single greatest lesson the garden teaches is that our relationship to the planet need not be zero-sum, and that as long as the sun still shines and people still can plan and plant, think and do, we can, if we bother to try, find ways to provide for ourselves without diminishing the world". —Michael Pollan.

Offering students authentic experiences of engaging with their immediate environment is increasingly being recognized as one of the most important aspects of environmental education. Growing a food garden as a school project naturally provides a space to raise questions and develop an integrated understanding of weather, food, nutrition, the economics of food production, water, and local geography. Harvesting edible plants can help supplement school kitchens as well as keep students invested in the project and derive a sense of achievement from it.

However, many schools may have limited space for such projects. It is in this context that urban farming can offer hope. Urban farming is the practice of growing food within available areas in urban and semiurban areas. It has emerged as an interesting alternative in 'megacities' like Mumbai that suffer from a severe scarcity of land (see **Box 1**). How can teachers and students adapt the principles of urban farming to grow food in available spaces in their own schools?

Space

Your school may not have the luxury of a backyard, but you will be surprised at how much can be grown even within modest structures or sites like the window sills or terrace of your school! You just need to tap into your creative side to design planters that are appropriate to the kind of space that you choose to convert into a garden (see **Table I**). Since the amount of labour and time needed for a food garden naturally increases with the amount of space you choose to work in, it is advisable to start small and keep increasing the number of plants as you and your students feel more confident.

Box 1. Why urban farming?

This practice has become increasingly popular for reasons ranging from food security and urban biodiversity to the need for recreational spaces. This is because urban farming not only eases the pressure on rural land and resources, but also offers a promising way to rebuild our connection to food—through local production and consumption. It allows us to revisit traditional farming knowledge while also exploring creative methods to grow food in smaller spaces. This is not all. Our farms can help enrich local biodiversity. Working on them can help us appreciate the joy and reciprocity of tending to the soil. Farming in a school can also be a way of building a sense of community. Importantly, cities are conventionally seen as a source of numerous environmental issues. We can change that narrative, and it can all start with a handful of soil.

Sunlight

Most plants require about 4-6 hours of sunlight. Balconies and rooftops may have a better chance of receiving ample sunlight. It may also be helpful to grow some common shade-tolerant plants, including herbs such as mint, basil, and celery. Root vegetables such as beet, onions, garlic, and radish also do well in partial shade.

You may need to observe the orientation of the sun to ensure that your plants receive more of the morning sun than the harsher afternoon sun. Any supports you make for climbers need to face the direction that receives the maximum sunlight since these plants tend to grow towards the light (positive phototropism). Since the path of the sun changes with seasons due to the tilt of the earth's axis (the highest arc being followed during the Summer Solstice), it might be necessary to move planters accordingly.

Table I. Pros and cons of potential sites.

Type of structure in the school	Pros	Cons
Window sills	A good place for germination in seed trays; and to grow creepers and green vegetables, if adequate sunlight is available. Easy to manage.	Cannot place bigger pots, as it can cause safety issues. Only a limited number of vegetables and greens can be grown.
Balcony or small terrace	Bigger containers can be used, after checking (with the building architects) for waterproofing and weight-bearing capacity of the floor. Planters can be moved around. Bigger plants can be grown.	Involves more work, depending on how many planters you would like to grow. This may include additional expenditure if waterproofing is not done.
Rooftops	With adequate load-bearing capacity and waterproofing, a large number of plants, including fruiting trees, can be grown. Helps cool the building by reducing the amount of sunlight hitting the roof.	Access to rooftops can be restricted in some school buildings. Need to ensure proper drainage of water. Since high-rises may be windy, additional structures to break the wind may be needed. Some shade may need to be built for plants that are sensitive to sunlight.
Backyard and/or the land all along the perimeter of the school within the compound	Fewer worries about soil and drainage. Trees can be grown without load-bearing considerations. You can also do pit composting, and use the compost easily.	Can be more prone to pests. Access can be restricted. Can be vulnerable to water logging during the monsoons if it is situated in a low-lying area.

Planters

Many different kinds of planters are available in the market (see **Table II**). You and your students can also experiment with using grow bags, jute bags, old metal containers, rubber tires, plain cardboard boxes, or bags made from old clothes as planters (see **Fig. 1**). In general, a good planter should allow for aeration and the drainage of excess water. Care needs to be taken that the planters do not contain any harmful chemicals (such as the coloured pigments from print material) that can leach into the soil. The size of the planters that you need will depend on the plants you intend to grow. Smaller plants, such as herbs, can be grown in planters with a depth of 6-10 inches. Plants such as brinjal, chili, tomato, lady's fingers, and capsicum may require planters with a capacity of 10-20 L.

Fig. 1. Readily available material can be creatively repurposed into planters.

Credits: Deborah Dutta.

Table II. Pros and cons of some common types of planters.

Planter type	Pros	Cons
Clay Pots	Easily available; provide natural aeration and drainage; thick walls prevent soil from heating up.	Need regular watering; heavy to move around; adds to the load on terraces, etc.
Plastic containers	Easily available; lightweight; can be upcycled from discarded waste.	Become brittle and prone to cracking under prolonged exposure to sunlight; tend to heat up; contribute to plastic consumption if buying new containers.
Wooden containers	Aesthetically appealing; larger containers can be designed to allow for multicropping.	Can be difficult to source (fruit sellers can have crates, especially during the mango season). Can leach toxins if the wood is painted, chemically treated, etc. Can be prone to termite infestation.
Raised beds (enclosed area of soil/compost that is higher than the surrounding area). A variety of materials, such as bricks, concrete blocks, wood, and bamboo, can be used to make the beds.	Once constructed, do not require much maintenance; can grow bigger plants together. Easy to control soil conditions and look out for pests.	Can be laborious to construct initially (depending on the building material).
Trellis or supports can be made from various materials, such as coir or nylon ropes or thin strips of wood.	Helps in the growth of creepers and climbers, such as gourds, and plants with weak stems, such as tomatoes and cluster beans.	Can be a little cumbersome to make initially.

Soil

Ideally, the soil for growing plants should be loose, fertile, of neutral pH (~7; neither acidic nor basic), and have good water retention (see **Fig. 2**). Soil fertility can be improved by adding kitchen compost, nutrient-rich soil organic matter (SOM) like Amrit-Mitti, Biochar, green manure, mulch, and natural fertilisers (see **Box 2**).

Seeds

It is advisable to choose seeds that nurture local biodiversity (see **Box 3**). As Hoidal (2015) writes, *"Seeds carry the genetic keys to biodiversity and climate change resilience, and are records of cultural knowledge, reflecting historical breeding practices".* Using organic open-pollinated seeds can help ensure that their mature fruits can be used to save seeds for the next sowing season (see **Box 4**).

Fig. 2. The soil for growing plants should be loose, fertile, have neutral pH, and have good water retention.

Credits: Deborah Dutta. License: CC-BY-NC.

Box 3. Choosing seeds that nurture local biodiversity:

We can help nurture local biodiversity by enhancing plant diversity at different levels:

- Growing different varieties of the same plant species (such as the round, long, purple, and green varieties of brinjals), but not next to each other.
- Growing plants of different species, with mutually beneficial or complementary characteristics, next to each other. This can take the form of growing tall plants with short plants, plants with fibrous roots with those with tap roots, plants with deep roots with those with shallow roots, or climbers with ground plants.

How does this help us? Different flowering plants attract different kinds of pollinators, such as butterflies and bees, and provide them with a habitat! In general, growing a diversity of plants also provides better pest control. This is because different plants can act as hosts for different kinds of insects, which can have mutual predator-prey relationships. Different kinds of insects are more likely to attract a diversity of lizard and bird species (that feed on insects), which can also help control pests.

Box 2. Ways to improve soil fertility:

(a) Kitchen compost: Food scraps are the easiest source of organic matter to enrich the soil (see **Fig. 3**). They can be composted using various methods (hot, cold, anaerobic, and vermicompost). Basically, composting is a process by which organic matter is broken down, under controlled conditions, into simpler constituents through microorganisms or fungi. Composting requires carbon (dry/ brown biomass), nitrogen (greens/ fresh biomass), oxygen (if aerobic), and water. You could use an aerated container with a lid (holes can be punched or drilled into the container or earthen pot), and simply layer food waste and dried leaves in a 1:2 ratio if the food waste is fresh. Sprinkle some red earth after every 2-3 layers. Turn the mixture every 10 days or so. When the container is full, keep it aside for about 15 days to complete the composting process. Compost has a dark, crumbly texture, and smells slightly sweet. While one can and should experiment with methods of composting, it is advisable to follow a tried and tested 'recipe' to begin with, so that the first cycle of success motivates you to try other options. More details and starter kits can be found here: https://dailydump.org/. The steps involved in composting are explained here: http://www.urbanleaves.org/2016/04/savealeaf-solution-2-composting.html.

Fig. 3. Food scraps from the school kitchen can be composted and added to soil to improve its fertility.

Credits: ID 1702759807 © Ann Bulashenko | Shutterstock.com. URL: https://www.shutterstock.com/image-photo/compost-pit-organic-scraps-fertilizing-plants-1702759807

(b) Amrit-Mitti (AM): This is a method of soil-building through composting of dried and green biomass using a microbe-rich mixture of cow dung, cow-urine, and jaggery. The resulting soil is rich in nutrients and organic carbon, lending it a dark, crumbly texture. Since AM weighs less compared to red soil, it is an ideal plant medium for balconies, rooftops, etc. A detailed description of AM and the steps involved in its preparation can be found at the Urban Leaves (a community farming group in Mumbai) website: http://purvita10.wixsite.com/urbanleaves/booklets.

(c) Biochar: When organic matter is burnt slowly under a limited supply of oxygen, it produces highly porous charcoal. When this is added to soil, it helps retain nutrients and water (see **Fig. 4**). If difficult to make due to lack of space, commercially available charcoal in local shops can be used instead.

Fig. 4. Preparing biochar in a pot.

Credits: Sagnik Ghosh. License: CC-BY-NC.

(d) Mulch: Mulching is the process of covering topsoil with a thin layer of organic matter. This prevents soil from compaction due to heat, heavy rain, cold weather, etc. Usually dried, crushed leaves, bagasse (make friends with the neighbouring sugar cane seller!), straw (look out for the mango season since plenty of ready-to-use crates of straw can be salvaged!), etc., can be used (see **Fig. 5**). Cover crops, also known as live mulch, can be used. These include members of the legume family, such as alfalfa, clover, mimosa, beans, and peas.

Fig. 5. Plant mulched with dried bagasse.

Credits: Deborah Dutta. License: CC-BY-NC.

(e) Natural fertilizers: Plants usually need macronutrients, such as nitrogen, potassium, and phosphorous, for their growth. The presence of trace elements like boron, magnesium, zinc, and molybdenum is also important.

Alternatives	What it contributes to the soil
Ground coffee and fresh grass cuttings	Good sources of nitrogen.
Planting legumes in the vicinity	Helps fix nitrogen.
Rock phosphate and crushed bones (of animals) or prawn shells	Good sources of phosphorous. Especially important for fruiting plants.
Egg shells and Epsom salt	Good sources of potassium. Especially needed for proper leaf growth and disease resistance.
Wood ash or the residue left after burning wood	Rich source of phosphorous. But since it is alkaline in nature and can alter the soil pH, care should be taken to avoid overuse as it can cause other problems in the soil and in plant growth.

Box 4. Saving seeds:

Why save seeds? In most cultures, seeds are considered sacred because they symbolise the potential and fertility of life. A single seed can give rise to a million more given the right conditions in the environment. Each of us has the right to save seeds, even though this right is becoming increasingly threatened due to patents by agribusiness companies that sell seeds, thereby making farmers dependent on such companies to continue growing crops. When we save seeds, we strengthen local diversity (of plants that grow best in the conditions specific to our immediate environment) and our ability to freely use and exchange seeds and the knowledge (including traditions and folk wisdom) associated with them with other farmers across generations. This ability is called seed sovereignty. According to Vandana Shiva (2012), seed sovereignty *"includes the farmer's rights to save, breed and exchange seeds, to have access to diverse open-source seeds which can be saved—and which are not patented, genetically modified, owned or controlled by emerging seed giants. It is based on reclaiming seeds and biodiversity as commons and public good".*

How do we save seeds? This can be very plant-specific. However, general guidelines include selecting a healthy plant with minimal stress and disease. The fruit of this plant should be allowed to ripen and mature completely. Seeds from some plants (such as tomato, brinjal, and gourds) are 'wet' and will need to be separated from the pulp. In fact, seeds of tomato and some gourds are best stored after fermentation. Seeds of cruciferous vegetables (like radish, cabbage, cauliflower, and mustard) can be saved by collecting dried pods of the plant. Herbs (such as basil, mint, and spearmint) can be propagated from cuttings. More details on seed saving can be accessed here: http://203.64.245.61/web_docs/manuals/save-your-own-veg-seed.pdf.

(a) Sowing: It is advisable to sow seeds in small containers with loose potting mix. This offers two advantages:

- It allows you to control temperature, moisture, and sunlight during germination. Young saplings may also need to be protected from harsh sunlight.
- It reduces damage to germinating seeds by soil pests.

The potting mix consists of cocopeat (which is composted coconut fibre), sand, and compost. The small containers can be made from perforated plastic bags, Tetra Paks, curd containers, egg shells, and so on. It is also good practice to label the seeds (with, for example, ice cream sticks) so that you can keep track of the germinated plants.

(b) Transplanting: A sapling can be transplanted into a bigger pot once a few leaves have sprouted (remember, the first two leaves are called false leaves; they are part of the seed embryo). Doing this in the evening will allow the plant time to adjust before it is exposed to sunlight. Care should be taken to avoid damaging the roots. Some wood ash can be added to the soil to protect the roots from fungal infection in the time it takes for them to adjust to the new soil medium.

Fig. 6. Students observing their tomato plants to check for ripe fruits.
Credits: Deborah Dutta. License: CC-BY-NC.

(c) Harvesting: Harvesting for consumption should be done when the vegetable or fruit is mature, but not overripe (see **Fig. 6**). For many plants, this stage can be identified visually or by touch. For some plants, you may need to look for other indications of when the vegetable or fruit is ready for harvesting. For example, a radish is ready for harvesting when some part of it can be seen above the soil. Turmeric and ginger have a maturing period of around 10 months (they need very little water in the last month), and are ready to be harvested when the leaves dry up.

Water

Watering plants can be like a zen practice—seemingly easy, yet ridiculously hard to master. Too little can stunt plant growth, and too much can cause root rot, fungal infections, etc. Usually, it is good practice to stick your finger in the soil to check how wet it is. If it feels dry, water the soil. This is best done early morning or evening when the soil is less likely to lose water through evaporation and the plant roots are more likely to be able to absorb water from the soil. You can also explore self-watering systems like drip irrigation. This may be particularly helpful when the school is closed for winter or summer breaks. To save water, you may want to explore rainwater harvesting and recycling of grey water. For example, if your school uses eco-friendly washing materials, such as soap nuts, you can use the wastewater from kitchen sinks, showers, washing machines, etc., for your garden.

Digging deeper

(a) Tilling: Occasional tilling of larger pots may be needed if you feel that the soil seems hard and clumpy. Use a prong or shovel to dig slightly and loosen the soil. Avoid areas near the main stem. Top the tilled area with mulch, sprinkle some wood ash, and water slightly.

(b) Pruning: This refers to the removal of dead, infected, or overgrown plant parts. Pruning can result in better growth and yield. However, this requires some expertise because doing it incorrectly can injure the plant and be counterproductive. It is safer to remove pest-infected parts of a plant to prevent further disease. While handling a healthy plant, however, it is better to consult more experienced farmers. 'Pinching' refers to the removal of immature fruit or buds using your fingers. This is usually done to encourage growth in tomatoes, basil, amaranth, etc.

Pest attacks

In the event of a pest infestation, it may be better to give the plant some time to recover under observation rather than immediately treating it with pesticides (organic or synthetic). This approach to pest attacks is similar to giving a person time to naturally fight a fever rather than prematurely loading them up with high doses of antibiotics.

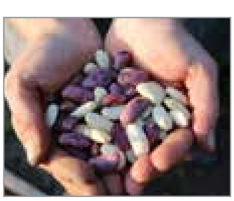
More often than not, the infected plant will recover and show resistance to other such attacks. If pesticides need to be used, it may be better to use natural pesticides sparingly and only after ensuring that other methods (like washing the infected parts and pruning) have not worked. Remember, the indiscriminate use of pesticides can have adverse effects (like the pest developing resistance to the pesticide).

Parting thoughts

In the end, food farming is about relationships. It is an embodied way of understanding the way in which connections between the air, soil, water, sun, plant, and other creatures nourish our life. It can also be a powerful and effective way to adapt to a changing climate. While most environmental actions are imagined on a very small (individual) or a very large (countries, governments) scale, more often than not, community-based approaches can result in long-term, impactful changes in society by creating alternate cultural norms and practices.

Reflecting on the transformative potential of gardening, author Rebecca Solnit writes: *"To garden is to make whole again what has been shattered: The relationship in which you are both producer and consumers, in which you reap the bounty of the earth directly, in which you understand fully how something came into being. It may not be significant in scale, but even if it's a windowsill geranium high above a city street, it can be significant in meaning".* Let plants be the teachers of reciprocity and resilience. There is much to learn from them.

Key takeaways



- Growing a food garden as a school project naturally provides a space to raise questions about and develop an integrated understanding of nutrition, the economics of food production, the weather, water, and local geography.
- Schools that have limited space can draw upon principles of urban farming (a practice that has evolved to meet the need to grow food in land-scarce cities) to engage in such a project.
- Some of the most important factors to consider in growing a food garden are space, sunlight, planters, seeds, and water.
- A surprisingly large amount of food can be grown even within modest structures or sites like the window sills or terrace of your school. It may be helpful to start with a small space, keeping in mind some of the most likely pros and cons that it offers.
- The amount of sunlight, its orientation during the day, and its path during different seasons can vary depending on the space you choose for your food garden. It may be helpful to choose plants appropriate to these variations and move planters around when necessary.

- Planters should allow for aeration and the drainage of excess water. These can be obtained either commercially or repurposed from readily available materials like grow bags, jute bags, old metal containers, rubber tires, plain cardboard boxes, or bags made from old clothes.
- The soil for growing plants should be loose, fertile, of neutral pH, and have good water retention. Its fertility can be improved by adding kitchen compost, nutrient-rich soil organic matter (SOM) like Amrit-Mitti, Biochar, green manure, mulch, and natural fertilisers.
- Using local organic open-pollinated seeds of different varieties of the same plant or different species of plants that complement each other can help nurture local biodiversity. Using plant-specific seed-saving methods can help ensure that mature fruits can be used to save seeds for the next sowing season.
- Determining the correct amount of water for each plant in the food garden may require careful observation of soil moisture. It may be helpful to explore self-watering systems (like drip irrigation) and water-saving systems (like rainwater harvesting, and recycling of grey water).
- Food farming, even at a small scale, can offer an embodied way of understanding the way in which connections between the air, soil, water, sun, plant, and other creatures nourish our life. It can also be a powerful and effective way to adapt to a changing climate.

Note: Source of the image used in the background of the article title: Growing Food. URL: https://pxhere.com/en/photo/1365895. License: Public Domain.

References:

1. Dutta D (2023). Nurturing spaces for wild ideas. Teacher Plus. April. URL: https://www.teacherplus.org/nurturing-spaces-for-wild-ideas/.
2. Dutta D & Hazra A (2023). Cultivating Hope: Food growing possibilities in Indian cities. TESF India, IIHS. URL: https://tesfindia.iihs.co.in/06_there-is-a-bee-in-my-balcony/.
3. Dutta D (2019) Pedagogy of 'dirty' hands: reflections from an urban terrace farm. i wonder.... pp. 72-81. ISSN 2582-1636. URL: https://publications.azimpremjiuniversity.edu.in/2106/.
4. Hoidal N (2015). What's in a seed? The critical role of seed politics in the food sovereignty movement. Sustainable Food Trust. URL: https://sustainablefoodtrust.org/news-views/food-sovereignty-seed/.
5. Ladner P (2011). The urban food revolution: Changing the way we feed cities. New Society Publishers.
6. Tracey D (2011). Urban agriculture: ideas and designs for the new food revolution. New Society Publishers.
7. Alvares C (2009). Organic Farming Source Book. Other India Press. URL: https://www.twn.my/title2/books/organic.farming.sourcebook.htm.

Other resources:

1. Sources for conducting farming projects in schools: The Edible Schoolyard Project. URL: https://edibleschoolyard.org/.
2. Bookstore for reading on various environment-related topics, especially in the Indian context: Earthcare Books. URL: http://earthcarebooks.com/.
3. Network of organic farmers in India: Organic Farming Association of India. URL: http://ofai.org/.

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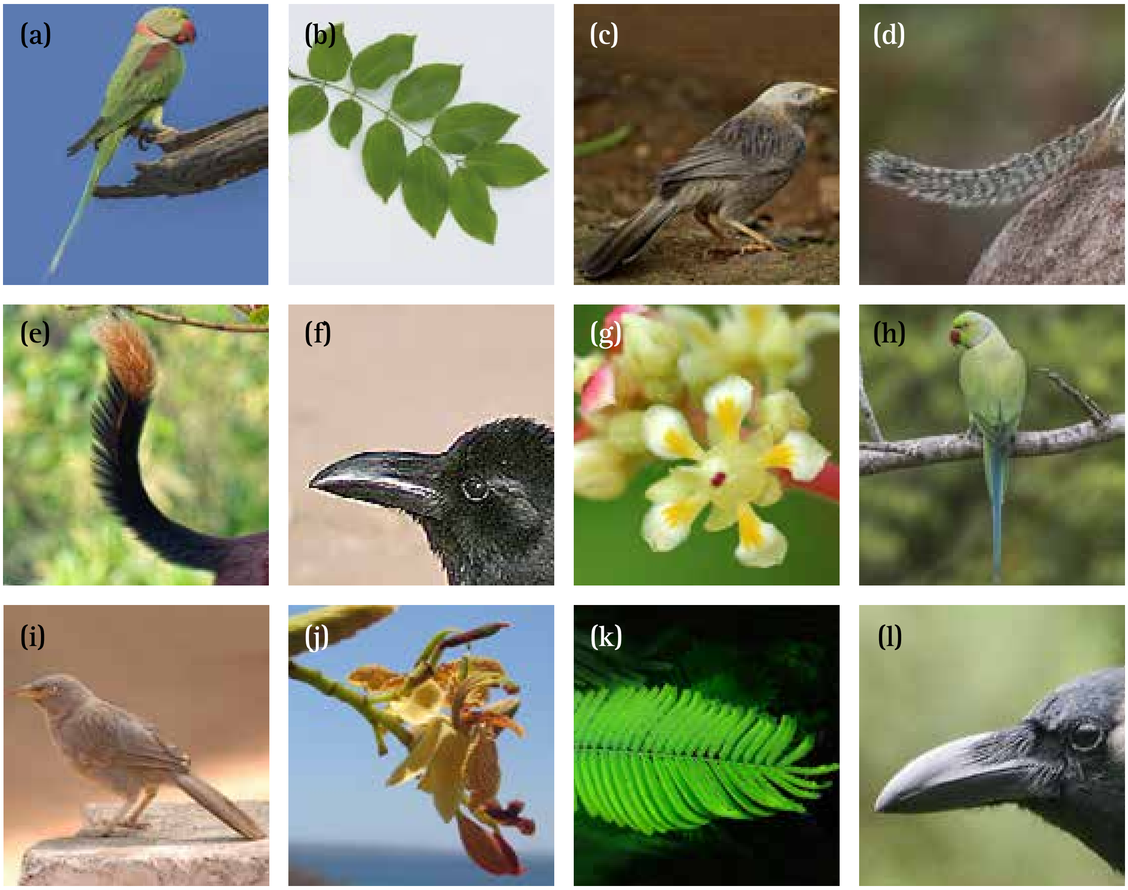
KRISHNAN'S CAST

We meet some of M Krishnan's most interesting neighbours in his piece titled 'Voices of Intolerance'. His writing brought them to life. It is as if they left a bit (or a lot) of themselves in our imagination and on this page. Do you recognise which of these belong to his cast of characters?



Notes:

1. To read M Krishnan's piece titled 'Voices of Intolerance', turn to page 19 of this issue.
2. To read more about M Krishnan, check out his Biography titled 'Nature's Passionate and Meticulous Chronicler' by Varun Sharma on page 4 of this issue.
3. If you have finished and would like to check your answers, please turn to page 48 of this issue.
4. Source of the image used in the background of the article title: Jigsaw pieces. Credits: Wounds_and_Cracks, Pixabay. URL: https://pixabay.com/photos/puzzle-piece-tile-jig-jigsaw-game-3306859/. License: CC0.

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THE DISCOVERY OF OXYGEN

VIJAY KUMAR UPADHYAY

It is essential for life on Earth. It is also the most abundant element in the earth's crust and the second most abundant element in the earth's atmosphere. It is necessary for both combustion and respiration. How was it discovered? When was it first recognized as a chemical element? How did it get its name?

One of the earliest known experiments on the relationship between air and combustion was conducted by a Greek physicist, engineer, and writer called Philo. Born in 280 BC, Philo was a resident of Byzantium (the ancient name for Istanbul). He observed that a few seconds after a burning candle was covered by an upturned vessel (sealed at its base with water), the flame went out and there was a dramatic rise of water in the upturned vessel (see **Fig. 1**). He included a detailed description of this experiment in a treatise called *'Pneumatica'*. Philo inferred that the rise in water level was caused by a partial vacuum in the glass container. Fire was believed to be an element at the time. Philo incorrectly surmised that the vacuum was caused when some amount of 'this' element was lost from the glass container in the form of light.

In the early part of the 16th century, the Italian polymath Leonardo Da Vinci replicated this experiment and concluded that some of the air trapped in the upturned vessel had been used up for combustion by the burning candle.

In 1659, the Irish scientist and inventor Robert Boyle and the British polymath Robert Hooke (who was at the time working as Boyle's assistant) developed an efficient vacuum pump (see **Fig. 2**). When they used this to pump out all the air from a jar inverted over a burning candle, the candle died out. The same happened when the candle was replaced with a glowing ember of coal. However, if they allowed some air into the jar while the ember was still hot, it would start glowing again. Based on these observations, Boyle and Hooke concluded that the presence of air was essential for combustion.

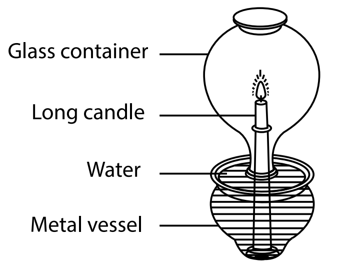

Fig. 1. Philo's experiment on combustion. Philo mounted a long candle (made of animal fat) to the base of a shallow wide-mouthed metal vessel. He poured water into the metal vessel and lit the wick of the candle. As the candle was burning, he inverted a glass container with a narrow mouth and a long neck over it in such a way that its mouth touched the water in the metal vessel.

Credits: Wilhelm Schmidt from Pneumatics of Hero of Alexandria, Wikimedia Commons. License: https://en.wikipedia.org/wiki/File:Philos_experiment_of_the_burning_candle.PNG. License: Public Domain.

Building on their work, the British chemist John Mayow conducted two sets of experiments. In one set, he replicated Philo's setup with a burning candle. In the second set, he replaced the burning candle with a mouse. Mayow found that after some time, the candle went out in the first experiment and the mouse died in the second one. He also found that a portion of the air in both inverted jars had been displaced by water. Mayow referred to this portion of air as *spiritus nitroaereus* (or simply *nitroaereus*) and concluded that this portion was necessary for both combustion and respiration. He described these experiments and observations in his book *Tractatus Quinque Medico-Physici* (or 'Five Medico-Physical Treatises'), published in 1674. In another experiment, Mayow observed that heating antimony increased its weight. From this, he concluded that the *nitroaereus* must have bonded to antimony. He also hypothesised that our lungs separate the *nitroaereus* from air; this is sent into our blood, where it reacts with certain substances to produce the energy that fuels muscle activity. Mayow's ideas as well as detailed descriptions of his experiments were published in 1668 in a book titled 'The Respiration'.

During the 17th and 18th centuries, many scientists attempted to isolate Mayow's *nitroaereus*. This included Robert Hooke, the Danish physician Ole Borch, the Russian scientist Mikhail Lomonosov, and the French chemist Pierre Bayen. However, none of them recognized *nitroaereus* to be a chemical element. This may have been because the phlogiston theory was believed to be the most plausible explanation for combustion and rusting at the time. This theory was first propounded in 1677 by the German alchemist Johann Becher, and modified in 1731 by the German chemist Georg Ernst Stahl. It stated that all combustible substances were made up of two parts—one of these parts (named phlogiston) escaped when the substance was burnt, while the other part, considered the true form of the substance, remained behind as ash (named calx). This implied that combustible substances (like coal and wood) consisted mainly of phlogiston; whereas non-combustible substances (including iron, which is prone to rusting) contained negligible amounts of phlogiston. Strangely enough, according to the phlogiston theory, air was believed to play no role in combustion.

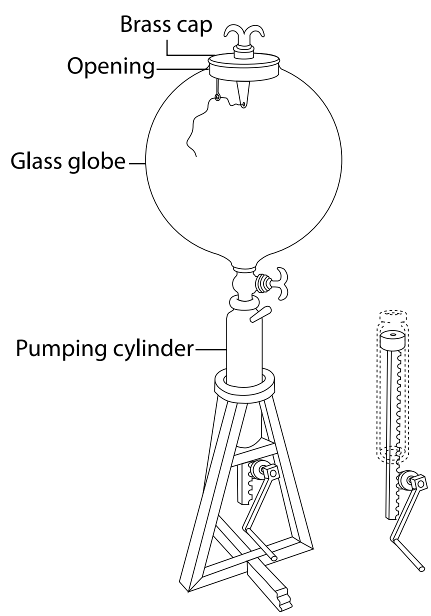

Fig. 2. A replica of the Hook-Boyle air pump. Built by Robert Boyle, with the help of Robert Hooke, this air pump or vacuum chamber had a spherical glass globe and a brass pumping cylinder. Objects could be put into the globe through an opening on top, which could then be sealed with a brass cap. This pump was useful in conducting experiments on combustion and respiration in a closed system.

Credits: Kinkreet, Wikimedia Commons. License: https://commons.wikimedia.org/wiki/File:Repllca_of_the_Hooke-Boyle_Air_Pump.jpg. License: CC-BY-SA.

Mayow's *nitroaereus* was first isolated by the Swedish pharmacist Carl Wilhelm Scheele. Between 1770-1773, Scheele experimented with heating oxides of mercury, silver, and gold. He observed that the gas that was released in these experiments supported both combustion and respiration better than common air (see **Fig. 3**). He used the term *'Feuerluft'* or fire-air to refer to this gas as it was then the only substance that was known to support combustion. Records suggest that Scheele made this historic discovery in June 1771. However, he sent a detailed description of it to his publisher only in 1776. This was published in 1777 in Scheele's only book, *'Chemische Abhandlung von der Luft und dem Feuer'* (or 'Chemical Treatise on Air and Fire').

Meanwhile, Mayow's *nitroaereus* had been isolated by another scientist. On 1st August, 1774, a British preacher called Joseph Priestley observed that a gas was released when he focused a magnifying glass to focus the sun's rays on a lump of reddish mercuric oxide kept in an inverted glass tube sealed with mercury. On studying this gas, Priestley found that it did not dissolve in water. The flame of a candle burned more brightly in the presence of this gas than it did in common air, and a mouse remained alive in it for four times longer than it did in a similar quantity of air. Priestley tried inhaling the gas and recorded experiencing a lightness in his chest that lasted for some time. A firm believer in the phlogiston theory, Priestley surmised that air consisted of two components—'dephlogisticated air' (now known to be oxygen) and 'phlogisticated air' (now known to be nitrogen). According to

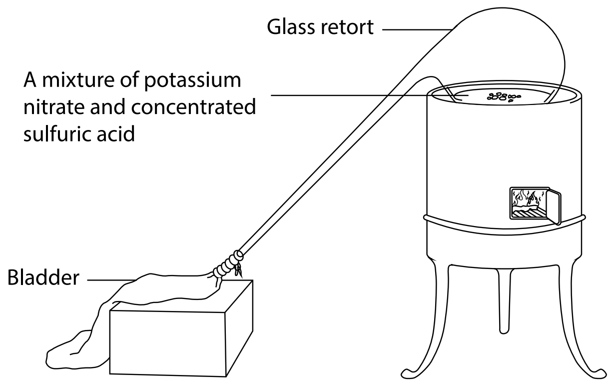

Fig. 3. Scheele's instruments for producing oxygen. In one of his experiments, Scheele placed a mixture of potassium nitrate and concentrated sulfuric acid in the glass distillation apparatus, called a retort. When heated, this mixture released a colourless and odourless gas, which was collected in a bladder tied to the mouth of the retort.

him, dephlogisticated air contained little or no phlogiston of its own and could readily absorb phlogiston from flammable substances. This caused such substances to burn more brightly in the presence of this component. Priestley shared details of this discovery in a research paper titled 'An Account of Further Discoveries in Air'. First published in 1775, this paper was later included in Priestley's book (in six volumes) titled 'Experiments and Observations on Different Kinds of Air'. Since Priestley's findings were the first to be published, the discovery of oxygen is credited to him.

The famous French chemist Antoine Lavoisier also claimed to have independently isolated this component of air. This claim was met with disbelief. Not without reason. Lavoisier had a reputation for taking credit for work by lesser-known scientists. In this case, Scheele had written a letter to Lavoisier on 30th September 1774, describing his discovery. Lavoisier denied receiving any letter from Scheele. Believed to have disappeared, the letter was found in 1890 in the Archives of the French *Académie des Sciences* by the French chemist Edouard Grimaux. Similarly, it was known that Priestley had visited Lavoisier in October 1774. This was just before Priestley had published his own discovery. During this meeting, Priestley had shared his experiments and inferences regarding this newly isolated component of air with Lavoisier.

While the validity of Lavoisier's claim is still disputed, it is indisputable that he was the first to conduct accurate quantitative experiments on oxidation as well as provide a correct and satisfactory explanation for it. This was particularly significant because both Scheele and Priestley had interpreted their findings in light of the erroneous phlogiston theory. Lavoisier dismissed this theory as nonsense and suggested that the component isolated by Scheele and Priestley was a unique chemical element. He shared these ideas along with detailed descriptions of his various experiments on combustion in in 1777, in a book titled *'Sur la combustion en général'* (or 'General Thoughts regarding Combustion'). Like Priestley, he suggested that common air was a mixture of two components. Unlike Priestley, he suggested that each of these components was a chemical element. He referred to the element that was essential to combustion and respiration as 'vital air' (Priestley's dephlogisticated air) and to the other element as 'azote' (Priestley's phlogisticated air). Again, unlike Priestley, Lavoisier correctly assumed that vital air reacted with metals and nonmetals during combustion. He also observed that irrespective of the material that was burnt, the product was always more acidic than the reactant. Based on this observation, Lavoisier incorrectly assumed that vital air was a necessary constituent of all acids. This led him to replace the term 'vital air' with 'oxygen' (derived from two Greek words: *'oxy'* meaning 'sharp' from the taste of acid, and *'genes'* meaning 'that which forms or produces').

Nearly 35 years after the term oxygen was coined, the British chemist Humphry Davy showed that Lavoisier had been mistaken. It was not oxygen, but hydrogen that was a necessary constituent of all acids. However, by this time, the term oxygen was widely accepted and used. This was partly due to the popularity of a book called 'The Botanic Garden', which used this term in a poem in praise of the gas. Published in 1791, this book was authored by the British physician Erasmus Darwin, the grandfather of Charles Darwin. This was also the name that was entered into the English dictionary, despite protests from several British scientists who believed that it was inappropriate that a French scientist was allowed to name a gas that was first discovered by a British scientist (Priestley). As we all know, oxygen remains the name by which we know this gas by even today.

Key takeaways

- Many early experiments showed that air was required to support combustion and respiration.
- Two scientists—Carl Scheele and Joseph Priestley—independently isolated the component of air that supported combustion and respiration.
- Antoine Lavoisier was the first to recognize that this component of air was a chemical element. It was also he who coined the name 'oxygen' to refer to it.

Notes:

1. This article was first published in Srote, May 2014, pg. 10-12. This version includes some modifications. URL: https://www.eklavya.in/magazine-activity/srote-magazine/370-srote-2014/srote-may-2014.
2. Source of the image used in the background of the article title: Solar particles colliding with oxygen gas to produce a Green Aurora Borealis display. Credits: Tobias Bjørkli. URL: https://www.pexels.com/photo/aurora-borealis-at-night-1663376/. License: CC0.

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KRISHNAN'S CAST: CURTAIN CALL

We meet some of M Krishnan's more interesting neighbours in his piece titled 'Voices of Intolerance'.

We see some bits of this cast again in the Snippet titled 'Krishnan's Cast': (b) Cassia leaves; (c) Yellow-billed babbler, which Krishnan refers to as a white-headed babbler; (d) Palm squirrel tail; (g) Mango flower; (h) Rose-ringed parakeet; and (l) The beak and head of a house crow.

Some questions to think about:

Q1. Which of Krishnan's neighbours are also your neighbours? How many were you able to recognise?

Q2. Which of Krishnan's neighbours did you find hard to place? Why?

Q3. You may have noticed that 'Krishnan's Cast' has a red herring to match each of his neighbours. These are (or belong to) other plants and birds that may or may not be part of your neighbourhood but are related to Krishnan's neighbours in some way. Do you recognise any of them? Have you seen any of them in your neighbourhood?

Q4. Krishnan also mentions a large owl, a hawk, and a coconut tree in his story. He thinks about the first two. The third makes an appearance. If you were invited to add one feature of a coconut tree to the puzzle, what feature would you choose and why? And what would you choose as a matching red herring?

Q5. Krishnan invites us to look more closely at the plants and animals in our neighbourhood—not just at their physical features but also at how they behave and their emotional states. Have you noticed a similar demonstration in your neighbourhood? Who had strayed in? Which animals did you see protesting? What cues did they use (for example, what sounds did they make) to communicate the presence of the intruder? Who do you think they were communicating to and why? How different was this from the demonstration that Krishnan observed (for example, in the cast of characters and their roles in the demonstration)? Did you sense any emotions in this display?

Which feature of a coconut tree would you choose?

Credits: Coconut palms, Pixabay. URL: https://pixabay.com/photos/palm-trees-coconut-trees-tropical-3058728/. License: CC0.

Notes:

1. To read M Krishnan's piece titled 'Voices of Intolerance', turn to page 19 of this issue.
2. To revisit the Snippet titled 'Krishnan's Cast', turn to page 43 of this issue.
3. To read more about M Krishnan, check out his Biography titled 'Nature's Passionate and Meticulous Chronicler' by Varun Sharma on page 4 of this issue.
4. Source of the image used in the background of the article title: Jigsaw pieces. Credits: Wounds_and_Cracks, Pixabay. URL: https://pixabay.com/photos/puzzle-piece-tile-jig-jigsaw-game-3306859/. License: CC0.
5. Sources of the images used in the visual puzzle in the Snippet 'Krishnan's Cast':

- Alexandrine parakeet. Credits: Charlesjsharp from Sharp Photography, sharpphotography.co.uk, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Alexandrine_parakeet_(Psittacula_eupatria_eupatria)_male.jpg. License: CC-BY-SA.
- *Cassia fistula leaves.* Credits: bowonpat, freepik. URL: https://www.freepik.com/premium-photo/golden-shower-cassia-fistula-flower-leaves-white-background_25922640.htm.
- Yellow-billed babbler. Credits: Dharani Prakash, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Yellow-billed_Babbler_(Turdoides_affinis)_by_Dharani_Prakash.jpg. License: CC-BY-SA.
- Palm squirrel tail. Credits: Hari K Patibanda. URL: https://www.flickr.com/photos/krishnacolor/51400366812/. License: CC-BY.
- Malabar giant squirrel tail. Credits: Brian Scott. URL: https://www.flickr.com/photos/brianscottgb/49552998332/. License: CC-BY-ND.
- Indian jungle crow beak. Credits: J. M. Garg, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Indian_Jungle_Crow_I3-Bharatpur_IMG_8466.jpg. License: CC-BY-SA.
- Mango flower. Credits: mr_tentacle. URL: https://www.flickr.com/photos/mr_tentacle/212641723/. License: CC-BY-NC-ND.
- Rose-ringed parakeet. Credits: Charlesjsharp from Sharp Photography, sharpphotography.co.uk, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Rose-ringed_parakeet_(Psittacula_krameri_manillensis).jpg. License: CC-BY-SA.
- Jungle babbler. Credits: Fitindia, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Jungle_babbler_2.jpg. License: CC-BY-SA.
- Tamarind flowers. Credits: Ton Rulkens from Mozambique, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Tamarind_flowers.jpg. License: CC-BY-SA.
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- House crow beak. Credits: Timothy A. Gonsalves, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:House_Crow_Sandynullah_Ooty_Aug21_D72_20420.jpg. License: CC-BY-SA.

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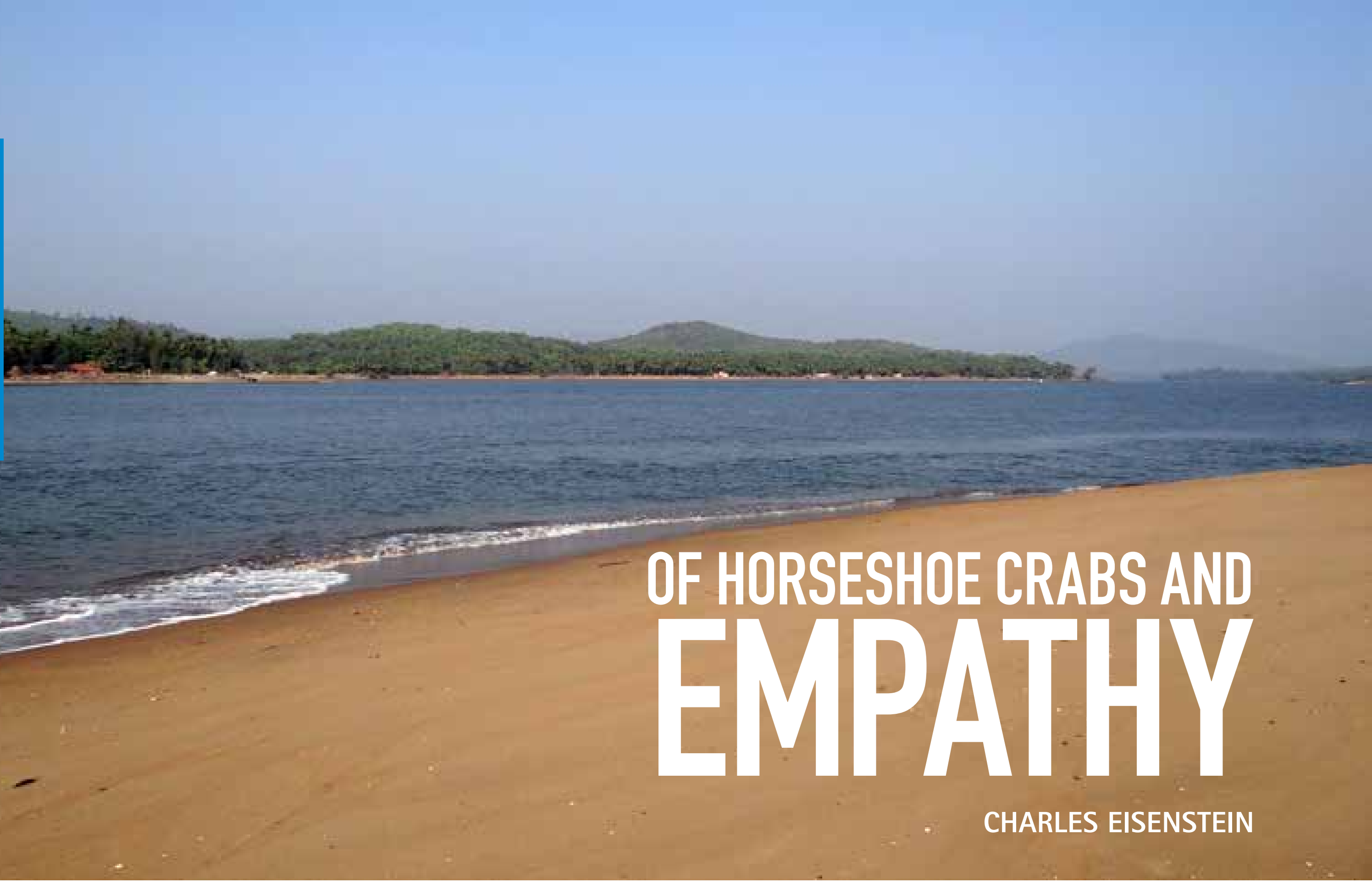


OF HORSESHOE CRABS AND EMPATHY

CHARLES EISENSTEIN

Does the current ecological crisis have one or many causes? How do our common problem-solving approaches address this challenge? What role do empathy and care for local places have in addressing it?

"That estuary used to be full of kelp and eels when we were kids," said Stella. *"It was full of all kinds of wildlife. Crabs, clams, horseshoe crabs—there was a mussel bed right over there—one time I was swimming in that pond and came face to face with an eel".*

Stella was talking about the spot where the Narrow River meets the Narraganset Bay in Rhode Island, US, one of her haunts when she was growing up. It is a pretty spot, and I would not have known it was so depleted of life unless my wife had told me.

Neither of us knows the reason why the eels disappeared. We shared a moment of sadness, and then Stella recalled another memory that somehow seemed to explain it. She and her friend Beverly would sometimes visit that part of the beach in the morning on what they called 'rescue missions'. At night, someone would come and flip over all the horseshoe crabs that had crawled onto the sand, leaving them to die there helplessly. Stella and Beverly would flip them right-side-up again. *"Whoever was doing it, had no reason to whatsoever,"* she said. *"It was a senseless killing".*

This is the kind of story that makes me feel like I have detoured onto the wrong planet.

We did not see any horseshoe crabs on this visit. They are a rare sight here now. I do not know if that is because people killed too many of them or because of the general deterioration of the ecosystem. Or maybe it is because of pesticide runoff, agricultural runoff, land development, pharmaceutical residues, or changing patterns of rainfall caused by development or climate change… Maybe the horseshoe crabs are sensitive to one of these, or maybe the creatures they eat are. Or it could be that the sensitive one is a microorganism that reproduces on a mollusc that lives on kelp that serves some important role in the food chain that feeds the horseshoe crab.

I feel quite sure that whatever the scientific explanation for the die-off of the horseshoe crabs and eels, the real reason is the senseless killing Stella described. I mean not so much the

Fig. 1. What does a horseshoe crab look like?

Credits: James St. John. URL: https://www.flickr.com/photos/jsjgeology/24605087516. License: CC-BY 2.0.

killing part, but the senseless part—the paralysis of our sensing function and the atrophy of our empathy.

The rush to a cause

The crabs and kelp and eels are all gone. The mind searches for the cause—to understand, to blame, and then to fix—but in a complex nonlinear system, it is often impossible to isolate causes.

This quality of complex systems collides with our culture's general approach to problem-solving, which is first to identify the cause, the culprit, the germ, the pest, the bad guy, the disease, the wrong idea, or the bad personal quality, and second to dominate, defeat, or destroy that culprit. Problem: crime; solution: lock up the criminals. Problem: terrorist acts; solution: kill the terrorists. Problem: immigration; solution: keep out the immigrants. Problem: Lyme Disease; solution: identify the pathogen and find a way to kill it. Problem: ignorance; solution: education. Problem: climate change; solution: reduce carbon emissions. Problem: obesity; solution: reduce caloric intake.

You can see from the above examples how reductionistic thinking pervades the entire political spectrum. When no proximate cause is obvious, we tend to feel uncomfortable, often hurrying then to find some convenient candidate for 'the cause' and going to war against that. Perhaps what we are facing in the multiple crises converging upon us is a breakdown in our basic problem-solving strategy, which itself rests on deeper narratives that I call 'The Story of Separation'. One of its threads is the idea that nature is something outside ourselves that is amenable to our control and that human progress consists in the endless expansion of that control.

Learning of the die-off of the estuary, I myself felt the impulse to find the culprit, to find someone to hate and something to blame. I wish solving our problems were that easy! If we could identify one thing as THE cause, the solution would be so much more accessible. But what is comfortable is not always true. What if the cause is a thousand interrelated things that implicate all of us and how we live? What if it is something so all-encompassing and so intertwined with life as we know it, that when we glimpse its enormity, we do not know what to do?

That moment of humble, powerless unknowing where the sadness of an ongoing loss washes through us and we cannot escape into facile solutioneering is a powerful and necessary moment. It has the power to reach into us deeply enough to wipe away frozen ways of seeing and ingrained patterns of

Fig. 2. What does an eel look like?

Credits: James St. John. URL: https://www.flickr.com/photos/jsjgeology/52520155186/in/photostream/. License: CC-BY 2.0.

response. It gives us fresh eyes, and it loosens the tentacles of fear that hold us in normality. The ready solution is like a narcotic, diverting attention from the pain without healing the wound.

You may have noticed this narcotic effect, the quick escape into *"let's do something about it"*. Of course, in those instances where cause and effect are simple and we know exactly what to do, then the quick escape is the right one. If you have a splinter in your foot, remove the splinter. But most situations are more complicated than that, including the ecological crisis on this planet. In such cases, the habit of rushing to the most convenient, superficially obvious causal agent distracts us from a more meaningful response. It prevents us from looking underneath that, and underneath that, and underneath that.

What is underneath the callous cruelty of those horseshoe crab flippers? What is underneath the massive use of lawn chemicals? What is underneath the huge suburban mansions? The system of chemical agriculture? The overfishing of the coastal waters? We get to the foundational systems, stories, and psychologies of our civilization.

Am I saying never to take direct action because, after all, the systemic roots are unfathomably deep? No. Where the unknowing, perplexity, and grief takes us is to a place where we can act on multiple levels simultaneously, because we see each dimension of cause within a bigger picture and we do not jump to easy, false solutions.

The mother of all causes

When I wondered about the cause of the estuary die-off, a hypothesis may have jumped into your mind—climate change, the culprit of the day for nearly every environmental problem. 'If we could identify one thing as THE cause, the solution would be so much more accessible'. For example, I googled 'effect of soil erosion on climate change,' and the first two pages of results showed the converse of my search—the effect of climate change on soil erosion.

The same for biodiversity. No doubt it is true that climate change exacerbates all kinds of environmental problems, but the rush to name a unitary cause for a complex problem should give us pause. The pattern is familiar. Do you think the 'fight against climate change', which starts by identifying an enemy, CO_2, will bring better results than the War on Terror, the War on Drugs, or the War on Poverty?

Now I am certainly not saying that eliminating fossil fuels is an 'easy, false solution'. It does not represent as thorough a change, however, as the change required to halt ecocide here, there, and everywhere. Conceivably, we could eliminate carbon emissions by finding alternative fuel sources to power industrial civilization. It may be unrealistic upon deeper investigation, but it is at least conceivable that our basic way of life could continue more or less unchanged. Not so for ecosystem destruction generally, which implicates every aspect of the modern way of life—mines, quarries, agriculture, pharmaceuticals, military technology, global transport, housing…

By the same token, the phenomenon of climate scepticism attests to the possibility of disbelieving in anthropogenic global warming entirely, since it requires that we unify multiple phenomena into a single theory that depends on the authority of scientists. No such faith is required to believe something has happened to the Narrow River estuary or one of the destroyed places from your own childhood. It is undeniable and has the power to penetrate us deeply whether we 'believe in' something or not.

It may sound like I am advocating refocusing on local environmental issues at the expense of climate change, but this is a false and dangerous distinction. As I have researched climate change, it has become increasingly apparent that the contribution of deforestation, industrial agriculture, wetlands destruction, biodiversity loss, overfishing, and other maltreatment of land and sea toward climate change is far greater than most scientists had believed. By the same token, the capacity of intact ecosystems to modulate climate and absorb carbon is much greater than had been appreciated. This means that even if we cut carbon emissions to zero, if we do not also reverse ongoing ecocide on the local level everywhere, the climate will still die a death of a million cuts.

Contrary to the presupposition implied in my aforementioned Google search results, the global depends on the health of the local. There may not be any global solution to the climate crisis, except to say that we need, globally, to restore and protect millions of local ecosystems. To focus on globally applicable solutions tends to diminish the importance of local environmental issues. We see that already with the growing identification of 'green' with 'low carbon'. We might, therefore, be wary of hurrying to implement globalized solutions that entail giving even more power to global institutions. Indeed, global carbon policies have already generated much ecological damage from hydroelectric and biofuel projects.

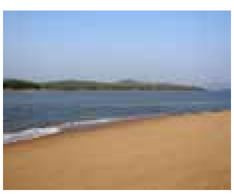
Again, am I advocating that we stop seeking to cut carbon emissions? No. But when we overemphasize that global factor, which fits so easily into our customary find-an-enemy approach to problem-solving, we risk overlooking the deeper matrix of causes and worsening the problem, just as our other 'Wars on (fill in the blank)' have done.

If everyone focused their love, care, and commitment on protecting and regenerating their local places, while respecting the local places of others, then a side effect would be the resolution of the climate crisis. If we strove to restore every estuary, every forest, every wetland, every piece of damaged and desertified land, every coral reef, every lake, and every mountain, not only would most drilling, fracking, and pipelining have to stop, but the biosphere would become far more resilient too.

But where do such love, care, courage, and commitment come from? It can only come from a personal relationship to the damage being suffered. That is why we need to tell stories like Stella's. We need to share our experiences of beauty, of sorrow, and of love for our land so as to infect others with the same. I am sure something stirred in you at Stella's words, even if your own childhood was in the mountains, not near oceans. When we transmit our love of earth, mountain, water, and sea to others, and stir the grief over what has been lost; when we hold ourselves and others in the rawness of it without jumping right away to reflexive postures of solution and blame, we are penetrated deep to the place where commitment lives. We grow in our empathy. We come back to our senses.

Is this 'the solution' to climate change? I am not offering it as a solution. Without it, though, no solution, no matter how cleverly designed a policy it may be, is going to work.

Key takeaways

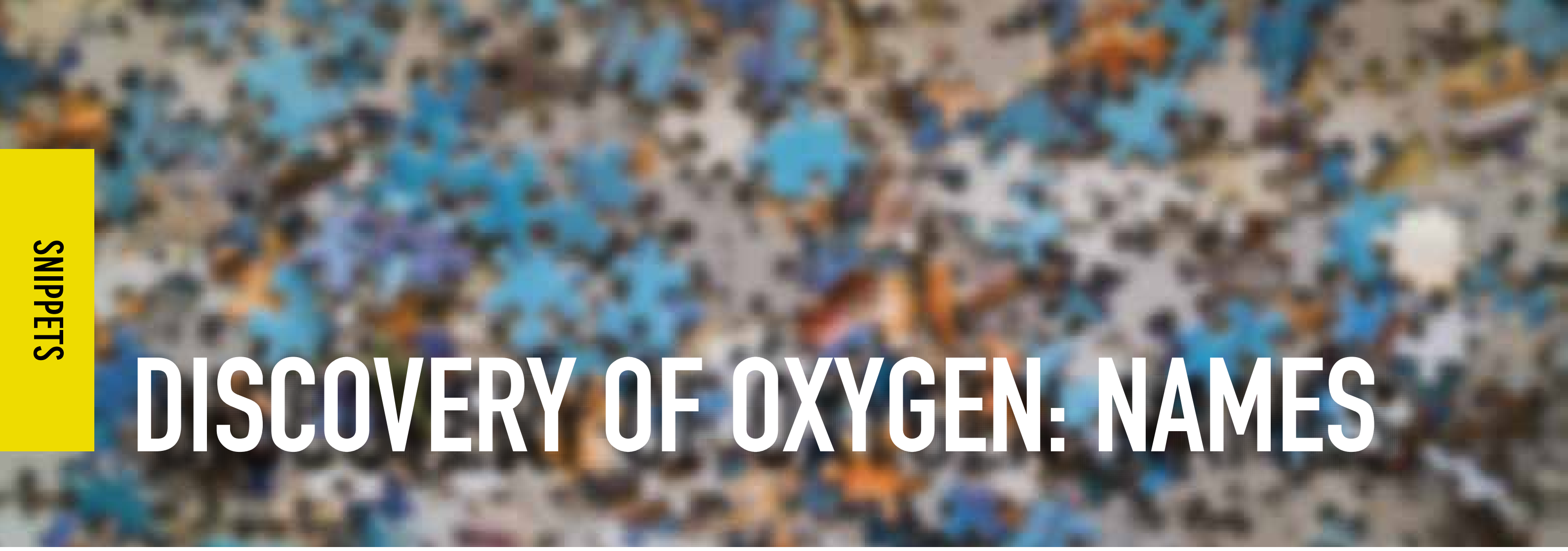


- Ecosystem destruction implicates every aspect of the modern way of life.
- Since most local and global ecosystems are complex nonlinear systems, it is often impossible to isolate single causes for their destruction and for the global ecological crises.
- The nonlinearity of complex systems collides with our culture's general approach to problem-solving, which is to identify 'the' cause or culprit and to dominate, defeat, or destroy that culprit.
- This basic problem-solving strategy rests on a deeper narrative of separation. One of its threads is the idea that nature is something outside ourselves that is amenable to our control and human progress consists in the endless expansion of that control.
- One example of this approach to problem-solving is seen in the tendency to overemphasize the role of an isolated and superficially obvious global factor (like climate change) in the ecological crisis at the risk of ignoring its deeper matrix of causes (especially local ones).
- To resolve the ecological and climate crisis, each of us needs to focus our love, care, and commitment towards protecting and regenerating our local places, while respecting the local places of others.
- The commitment to protect and regenerate local places comes from a personal relationship to the ecological damage that they suffer. This personal relationship helps builds our empathy, which is the source of our commitment.

Notes:

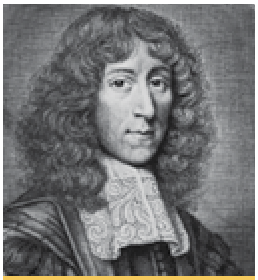
1. This article was first published in July 2016 on https://charleseisenstein.org/about/. It is licensed under a Creative Commons Attribution 4.0 International License. This version has been edited in minor ways for relevance to the Indian context. It is published in i wonder… with the author's permission.
2. Source of the image used in the background of the article title: Estuary, Karnataka. URL: https://pxhere.com/en/photo/754282. License: CC0 Public Domain.

Charles Eisenstein is an American public speaker and author. His work covers a wide range of topics, including the history of human civilization, economics, spirituality, and the ecology movement. The key themes he explores include anti-consumerism, interdependence, and how myth and narrative influence culture. Charles can be contacted here: https://charleseisenstein.org/contact/.



DISCOVERY OF OXYGEN: NAMES

Here are the 10 scientists again. Below each of them is a plaque that carries their correct names.

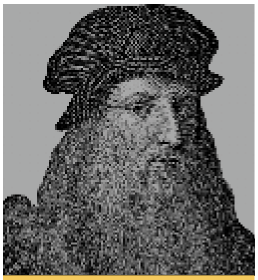


(a) John Mayow (1640–1679)

(b) Antoine Lavoisier (1743–1794)

(c) Philo Mechanicus (280–220 BC)

(d) Georg Ernst Stahl (1659–1734)



(e) Leonardo da Vinci (1452–1519)

(f) Robert Hooke (1635–1703)

(g) Johann Joachim Becher (1635–1682)

(h) Joseph Priestley (1733–1804)

(i) Robert Boyle (1627–1691)

(j) Carl Wilhelm Scheele (1742–1786)

Some quick questions:

- How many names did you guess correctly?
- Which ones were particularly difficult to guess? Why?
- Which of these scientists do you find most interesting? Whose lives would you want to learn more about?
- If you were invited to share clues that you had written yourself, what would you write about each of these scientists?

The story of the discovery of oxygen reveals many interesting aspects of the nature and practice of science. To read a brief version of the story, turn to the article 'The Discovery of Oxygen' by Vijay Kumar Upadhyay on page 44 of this issue. If you would like to explore some of these aspects in more detail, please turn to page 61 of this issue.

Notes:

1. Source of the image used in the background of the article title: Jigsaw pieces. Credits: Wounds_and_Cracks, Pixabay. URL: https://pixabay.com/photos/puzzle-piece-tile-jig-jigsaw-game-3306859/. License: CC0.
2. Sources of the images used in the Hall of Fame:

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(i) Robert Boyle. Credits: https://pixel17.com, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Honorable_Robert_Boyle_Sketch.jpg. License: CC-BY-SA-2.0.

(j) Carl Wilhelm Scheele. Credits: Ida Falander (1842—1927), Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Carl_Wilhelm_Scheele.png. License: Public Domain.

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PERSPECTIVES

TEACHING THE NATURE OF SCIENCE

ARVIND KUMAR

Understanding the nature of science (NOS) is widely perceived to be a vital learning outcome of science education. But is it necessary to include this in the school science curriculum? Do we introduce school students to its evolving perspectives? What pedagogical approaches can help teach NOS?

Most science textbooks begin with an introductory chapter on the nature of science (NOS), devote a few paragraphs to it, then quickly move on to what is regarded as the main stuff of science—its empirical facts, laws, theories, etc. Naturally, this raises the question—why is it necessary to teach NOS when there is so little time to finish the 'more important' parts of the subject?

Why teach NOS?

Science is a compulsory subject till the end of secondary school. At this stage, most students end their engagement with the formal education system. Among those who pursue higher education, only a small fraction chooses to continue in the science stream. A smaller fraction of this number goes on to choose professions (like that of a research scientist) that need a robust understanding of science and its applications. This means that the scientific content knowledge taught in school is unlikely to be of direct help to the professional lives of a majority of middle and high school students. Then why is science education compulsory at the school level? Clearly, this would make sense only if its main purpose was somewhat broader than imparting specific science content.

While the goals of school science education have been debated endlessly, often from differing ideological stances, few would disagree that a principal goal is to generate an informed science citizenry. It is important for students to grow into citizens who have a feel for what science is about, what methods and processes are involved in generating new science, and how science is related to technology and society. For example, some would argue that science can help encourage a rational outlook on life. Others may argue that it is becoming increasingly necessary for us to become familiar with modern technology—its benefits, risks, impacts on our health and environment, etc. Given the many ways in which science and technology impact our lives today, this familiarity can help us formulate more mature opinions about these issues and make more informed choices. These and several other allied objectives are sometimes clubbed under the head 'science and technology literacy'. There are numerous variants of this term as well as many shades and nuances, but it may be safe to say that the rationale for teaching NOS is tied closely to this general goal of school science education.

Does this mean that we incorporate the teaching of NOS at the expense of the 'real' content of science? In doing so, do we not jeopardise the quality of knowledge of future scientists? Will our country not lose out on its competitive edge in science? Also, will the teaching of NOS be of any real use to the large majority of students we have in mind? These concerns, widely shared among teachers (and scientists), arise mainly because there is not enough clarity on how the teaching and learning of NOS is relevant to the rest of the science curriculum.

First, it is inaccurate to suppose that NOS is relevant only for students who end their formal engagement with science in Grade X, or that it is irrelevant for students training to be future scientists. Many detailed studies show that the epistemic and ontological beliefs that students hold about their subject have a bearing on their critical understanding of the content itself. This suggests that understanding NOS is relevant not only in meeting the general goal of promoting science and technology literacy but also in helping science students develop a deeper understanding of this subject. Secondly, what is envisaged is not to 'dilute' the content of science, but rather to use it imaginatively as a means to teach NOS. In other words, NOS is to be taught not by preaching abstract generalities set aside in a separate unit of the textbook, but by interleaving it with the content of science.

What to teach?

The few paragraphs that textbooks devote to NOS typically state some version of the following: *'Science involves a process of making systematic unbiased observations of nature, doing careful experiments, and drawing logical inferences from them. In this way, we arrive at the laws of nature. We suggest hypotheses to understand empirical laws, which leads us to build elaborate theories to explain known physical phenomena. Theories also predict new phenomena. If the predictions are verified, the theory is confirmed. Science bows to no authority; it is objective knowledge obtained from observations and experiments'.* There is much that makes sense in this description of NOS, simplistic though it will seem as we discuss it further.

NOS has been the subject of philosophical inquiry all through history and continues to be so even today. Rapid advances in science in the last four centuries have led to many active discourses on our ideas on NOS (see **Box 1**). These have led to some new insights. First, science is not just a

Box 1. Emerging Perspectives on NOS:

Modern science emerged in the 16th and 17th centuries from the work of Galileo, Descartes, Kepler, and Newton. It was at this time that Francis Bacon, an English philosopher, formulated what is now known as the scientific method (see **Fig. 1**). Roughly speaking, the introductory paragraphs of school science textbooks replicate Bacon's ideas on NOS. The essence of Bacon's ideas is that science is an inductive generalization from unbiased observations of nature and controlled experiments. Bacon foresaw the immense power of this new method in predicting and controlling natural phenomena.

At the beginning of the 20th century, an influential group of philosophers of science known as the Vienna circle (that included Moritz Schlick, Rudolph Carnap, and others) undertook the effort to formulate a more rigorous version of the scientific method. Briefly, they regarded a statement or an assertion meaningful only if it was either logically self-evident or could be put forth in a verifiable form. This meant that while one may use theoretical terms like 'atom', 'gene', and 'valency' for convenience, all scientific concepts and assertions must ultimately be reducible to observation statements. By this strict criterion, for example, poetry was considered meaningless and harmless, while a metaphysical assertion was meaningless but harmful (since it purported to be true). However, the proponents of this philosophical position, called logical positivism (and later, in a more moderate version, logical empiricism), could not realise their ambition of translating all of science in these terms.

Fig. 1. Francis Bacon formulated the scientific method.

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At around the same time, the Austrian-British philosopher Karl Popper suggested a philosophical position that was also in the spirit of analysing the scientific method, but distinct from logical positivism in many ways (see **Fig. 2**). Popper was driven by a desire to differentiate between 'science' and what he regarded as 'pseudoscience'. He is most widely known for his falsification criterion—a theory is not scientific if there is no way to refute it. Good scientific theories give unambiguous predictions that are falsifiable. This means that verification of these predictions does not confirm the theory; the theory is simply shown to not be false yet. Inspired by Einstein's work, Popper advocated that science should 'stick its neck out', give bold new predictions, and suggest critical experiments that have the potential to falsify a theory. Popper's ideas resonate with scientists, and he is often called the scientists' philosopher.

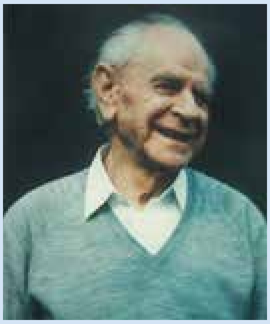

Fig. 2. Karl Popper is most widely known for the falsification criteria.

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Around the 1950s, the American philosopher Willard Van Orman Quine offered an incisive criticism of these dominant ideas. He argued that a scientific theory is a complex web of interconnected assumptions and claims that relate to experience as a whole. Consequently, it may not be possible to test or falsify each statement of the theory in isolation. He called for a holistic theory of meaning and testing.

Philosophies seeking a rational basis for science separated the context of discovery (the intuitive creative phase of science embedded in specific social settings) from the context of justification (critical philosophical scrutiny of theories claimed to be correct). Since the former was believed to belong to the realm of psychology or sociology, it was seen as being beyond the purview of science.

Around the 1960s, the American historian and philosopher Thomas Kuhn published his now-famous book, titled 'The Structure of Scientific Revolutions' (see **Fig. 4**). This book marked the beginning of a major transformation in our ideas on NOS. By analysing some key milestones in the history of science, such as the Copernican revolution, Kuhn concluded that scientists normally work within a certain paradigm. They are conservative in that they do not abandon existing theories in the face of minor anomalies or disagreements with experimental data. However, stark anomalies that accumulate over time cause a crisis in the normal process of science and lead to questioning of the existing paradigm. All kinds of alternative ideas float around during such periods of crisis. Some promising new ideas begin to attract consensus, often because of some particularly striking exemplars. In this manner, a new paradigm is born. This leads to a return to 'normal' science, with scientists attempting to work out details and applications of the changed paradigm. Significantly, the paradigm shift that Kuhn refers to is not governed by a purely rational process. It involves the building of a social consensus in the scientific community at large. Adherence to a paradigm that has won the consensus of the scientific community at a certain point in time is secured by training students in colleges and graduate schools in accordance to it.

Not everybody agreed with Kuhn. On the one hand, the Hungarian philosopher Imre Lakatos found the undermining of the rational basis of scientific progress implied in Kuhn's ideas unacceptable. Lakatos went on to develop a theory that explained paradigm shifts in science in terms of competing 'research programmes'. On the other hand, the Austrian philosopher Paul Feyerabend dismissed the idea of there being a clear method in the way science evolves. The idea of a normal process of science had a very significant role in Kuhn's perspective. He believed that it is this process that delves deeply into an accepted paradigm, making it possible to discover anomalies that eventually result in a change in the paradigm. Feyerabend, in contrast, criticized the routine mind-

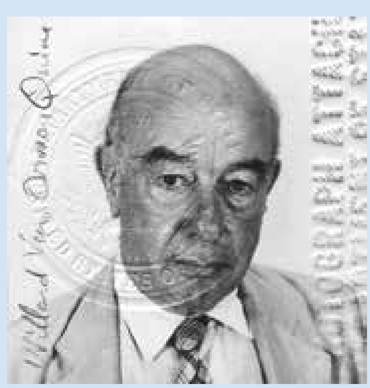

Fig. 3. Willard Van Orman Quine argued that a scientific theory is a complex web of interconnected assumptions and claims that relate to experience as a whole.

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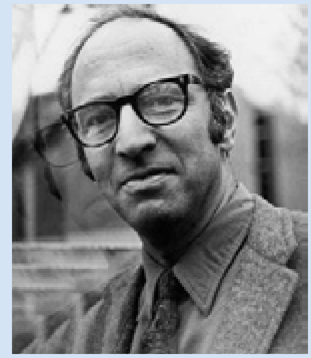

Fig. 4. Thomas Kuhn suggested that scientific fields undergo periodic 'paradigm shifts'.

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numbing activities of normal science. He asserted that science progresses through creative leaps of imagination that defy existing ideas. Feyerabend's philosophy is often summarized by the catchy phrase 'anything goes'. His noted book 'Against Method' celebrates creativity in science and advocates the freedom of imagination. Thus, while Lakatos found the disorder inherent in Kuhn's view of science alarming, Feyerabend criticized Kuhn's view for its orderly and mechanical view of scientific progress.

Whatever its merits, Kuhn's theory was responsible for the introduction of a sociological dimension to the philosophy of science in the second half of the 20th century. Indeed, some sociologists found the standard philosophy of science irrelevant. They asserted that NOS could be understood only by a critical and detailed probing of the actual way in which scientists work. This development has pushed the debate on NOS into many different directions that cannot be adequately described here. What is possible, however, is to acknowledge the role this development has had on our understanding of the sociocultural norms that enable progress in science. It is clear, for example, that the formation of robust social institutions of science (notably scientific societies in Europe, such as the Royal Society) that practised norms of open and democratic discussion, peer review of research, and common ownership of scientific laws was as crucial in the growth of science as the ingenuity of individual scientists.

process of induction from observations and experimental data. It often involves imaginative and radical new ideas that are not necessarily suggested by empirical evidence. Some of the most successful theories of science have arisen, for example, from a drive for unification or general considerations of simplicity and symmetry. Second, though observations of nature are often the starting point of all scientific inquiry, not all observations are neutral. They are often 'theory-laden'. This means that theories implicitly or explicitly guide what we observe and the kind of experiments we design. This does not necessarily undermine the objectivity of science. Third, observations and experimental data underdetermine correct theories; several different theories can all be consistent with them. Fourth, science is not a purely cognitive endeavour. While it is certainly constrained by the empirical facts of nature, science involves some social consensus among scientists. It also requires enabling sociocultural norms and conditions for its growth. Fifth, science, technology, and society are intertwined in complex ways—impacting and being impacted by one another. As a corollary to this, it is important to be alert to possible pitfalls in scientific practice as well as the harmful consequences of the uncritical and unwise use of technology.

With so much of the historical debate on NOS continuing into the present, what is it that we would wish for students to learn about it in school? While a wide range of perspectives and complex philosophical positions are related to NOS, it is widely believed that a core of generally accepted new ideas is learnable by young students. This can be used to frame some broad objectives for the school science curriculum. To briefly highlight these, NOS should help students appreciate the following aspects of science:

- **Scope:** Science seeks to describe and explain the physical world based on empirical evidence. Some domains may be beyond its scope.
- **Methods:** Science adopts a variety of approaches and methods. There is no one universal method of science. It does not involve induction alone. Creativity and imagination are equally important in generating hypotheses and building theories. Observations and experiments are often insufficient to determine a theory. Science involves expert judgments and not just logical deductions. Hence, there can be disagreements in science.
- **Social aspects:** Science is a cooperative multicultural human enterprise that includes contributions by countless women and men, including some noted individuals who play a significant role. Social institutions that practice norms of open debate, peer reviewing, and common ownership of knowledge are also vital for the growth of science. Links between science and technology may lead to issues that need sociocultural resolution.
- **Scientific knowledge:** This is dynamic and subject to revision in the face of new empirical evidence.

How to teach NOS

The most important but difficult question related to NOS is—what pedagogy do we use to teach it at the school level? The idea that content alone is not enough in science education is not new. This is seen in the history of curriculum reforms since the 1960s (or even earlier). Around the 1970s, some educational reforms emphasized the importance of teaching processes of science more than just its content. These included—observing, measuring, classifying, analysing, inferring, interpreting, experimenting, predicting, and communicating. However, in critical appraisals of this approach, some educators have questioned the premise that these constituted a set of general transferable processes common to all sciences.

For some time now, there seems to be a broad convergence on an inquiry-based approach to science learning and teaching. Informed by the constructivist philosophy, this approach does not just involve learning the processes of science; but extends beyond to include skills such as posing questions, critical thinking, giving evidence-based explanations, justifying explanations, and connecting explanations to existing scientific knowledge. In other words, this approach advocates that students learn science in a manner that resembles the way in which professional scientists conduct scientific investigations. This involves designing a range of inquiry tasks, all of which pose a question and seek an evidence-based explanation. These tasks can be relatively simple for younger children and quite elaborate for more mature students. They can have different foci—some may relate to Science, Technology, and Society (STS) issues, while others may be more discipline-oriented. An inquiry may also include reflections on the mode of inquiry itself and, thus, naturally incorporate the educational objectives of NOS.

Another approach recommends the use of the History of Science (HOS) to teach NOS. While this too is not a new idea, some key points in its favour are:

- HOS involves human narratives which enliven science and engage students' interest.
- HOS often has parallels with students' spontaneous conceptions and thus helps us in anticipating and remedying their content-specific ideas.
- Knowing how present science arose from competing ideas at different times in history can promote critical thinking.
- Lastly, HOS provides the most natural setting for learning NOS.

Parting thoughts

As Norman Lederman, a Distinguished Professor of Mathematics and Science Education at the Illinois Institute of Technology (IIT), has forcefully argued, NOS objectives should be regarded primarily as cognitive outcomes that can be properly assessed. Since these objectives are unlikely to be assimilated implicitly, instruction needs to bring them out explicitly, irrespective of whether we adopt an inquiry-based or history-based approach to do this. In other words, a whole range of inquiry tasks and HOS-based vignettes that are explicitly focussed on NOS need to be developed if we aim to improve student understanding of NOS.

Key takeaways

- Numerous studies show that the nature of science (NOS) is relevant not only in meeting the general goal of promoting science and technology literacy but also in helping science students develop a deeper understanding of this subject.
- NOS is to be taught not by preaching abstract generalities set aside in a separate unit of the textbook, but by interleaving it with the content of science.
- What is taught about NOS at the school-level should help students appreciate the scope of science; its many methods and approaches, including the role of expert judgments and the possibility of disagreements; the social aspects of this cooperative multicultural human enterprise; and the dynamic nature of scientific knowledge.
- Two pedagogical approaches—Inquiry-based and History of Science (HOS) based—are recommended to teach NOS at the school level.
- NOS objectives need to be regarded primarily as cognitive outcomes that are explicitly drawn out by instruction and can be properly assessed.

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References:

1. Godfrey-Smith P (2003). 'Introduction to Philosophy of Science'. The University of Chicago Press: Chicago.
2. NGSS (2013). 'Next-generation Science Standards: For States, by States'. Appendix H. URL: www.nextgenscience.org.
3. Pumfrey S (1991). 'History of Science in the National Science Curriculum: a critical review of resources and their aims'. British Journal of the History of Science. 24, 61–78.
4. Osborne J, Ratcliffe M, Bartholomew H, Collins S, & Duschl R (2002). 'EPSE Project 3: Teaching pupils ideas-about-science'. School Science Review, 84 (307), 29–33.
5. Taylor JL & Hunt A (2014). In Matthews MR (ed.) op. cit. 2045-2082. 'History and Philosophy of Science and the Teaching of Science in England'. Springer: Dordrecht, Netherlands.
6. Erduran S & Dagher ZR (2014). 'Reconceptualizing the Nature of Science for Science Education'. Springer: Dordrecht, Netherlands.
7. Millar R & Driver R (1987). 'Beyond Processes'. Studies in Science Education, (14) 33–62.
8. Flick LB & Lederman NG (eds.). (2006). 'Scientific Inquiry and Nature of Science'. Springer: Dordrecht, Netherlands.
9. Holton G & Brush SG, 3rd ed. (2001). 'Physics, the Human Adventure'. Rutgers University Press: New Brunswick, NJ.
10. Matthews MR (ed.) (2014). 'International Handbook of Research in History, Philosophy, and Science Teaching'. Springer: Dordrecht, Netherlands.
11. Lederman NG (2006). In Flick LB & Lederman NG (eds.) 2006. op. cit, 301-317. 'Syntax of Nature of Science within Inquiry and Science Instruction'. Springer: Dordrecht, Netherlands.

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DISCOVERY OF OXYGEN: QUESTIONS TO PONDER ABOUT

Have you tried guessing the names of the scientists in the 'Hall of Fame' on page 10? Did the clues on page 35 help?

The story of the discovery of oxygen is filled with many interesting examples of the nature and practice of science. Only four such examples have been shared here. Questions related to these examples are aimed at inviting reflection and discussion. Each question can be explored from different angles and with different lenses.

Q1. One of the scientists in this 'Hall of Fame' managed to isolate oxygen in 1771. However, the details of his discovery were published only in 1777. A second scientist made the same discovery in 1774. His findings were published in 1775. A third scientist recognised the significance of this discovery. He proposed that the gas that had been discovered was a chemical element. His experiments to support this proposal were published in 1777.

- Who do **you** think should be given credit for this discovery? Can you think of some arguments in favour of crediting each of these three scientists? What about arguments against each of their claims?
- How do you think we know that the first of these three scientists had discovered oxygen in 1771? Is it through the records he kept of his experiments and observations? Or through details that he shared in his correspondence with other scientists? If you were asked to verify the time of this discovery, what other ways would you use to do so? Do you think this process of verification would be easier or harder for discoveries made today compared to ones made in the 18th century?

Q2. Some argue that a number of other scientists may have independently discovered oxygen. For example, the Polish alchemist and medical doctor Michael Sendivogius is believed to have discovered oxygen in 1601. Sendivogius proposed that air was a mixture of components, one of which contained a life-giving substance. He also indicated that this component was the same gas that was released when saltpetre (potassium nitrate, KNO_3) was gently heated. Unfortunately, while Sendivogius did publish these discoveries, he chose to write about them in the arcane language of alchemy and under a variety of pseudonyms (some argue that this was deliberate; Sendivogius wanted to remain anonymous). Others point out that the Dutch engineer and inventor Cornelius Drebbel had, in 1608, reported that heating saltpetre produced a gas. While Drebbel did not identify it, we know that the gas he had observed is oxygen.

- Do you think either of these scientists deserves credit for the discovery of oxygen? What arguments can you think of in favour of and against giving them credit?
- We now know of five scientists who could claim credit for the discovery of oxygen. There may be more that we do not know of at present, but may discover later. Some have argued that credit for a discovery should be assigned to each such scientist. Can you think of some reasons in favour of and against this position?
- The scientific community uses certain conventions to decide who should be credited for a scientific discovery. One of these is called the priority rule. According to this rule, priority is given to the scientist who first shares their discovery with the scientific community. This rule only applies if their findings are considered valid, accurate, and relevant by the scientific community. Why do you think scientists came up with this rule? Can you think of any situations where this rule may give one scientist an unfair advantage over another scientist?
- Are there any other criteria that you think may be useful to consider in assigning credit?

Q3. We learnt that one of the scientists in this 'Hall of Fame' had a mixed reputation. On the one hand, other scientists often wrote to him or met with him to share and discuss their experiments and ideas. On the other hand, the scientific community knew him to be capable of taking credit for the ideas of lesser-known scientists.

- This seems to suggest that the practice of science has an important social aspect. It may not be enough for a scientist to make a claim. Their claims need to be verified and supported by the scientific community.

Who do you think is considered part of the scientific community? How do you think one gains membership to this community? What do you think the incident with this particular scientist reveals about the role of a scientist's reputation in the practice of science?

- Taking credit for someone else's work is an act of academic dishonesty. How do you think such acts would have been discovered at the time? How would they be discovered today? If you were a member of the scientific community, what guidelines would you frame to discourage such instances of dishonesty?
- This scientist claimed credit for the discovery of oxygen. This claim was not taken seriously. He also claimed that oxygen was a unique element. This was taken seriously by the scientific community. In fact, his ideas about oxygen discredited the phlogiston theory—one of the most widely accepted theories of the time. What do you think may have caused the scientific community to treat two related claims by the same scientist in different ways? Would you have done the same?

Q4. We read of how two scientists in this 'Hall of Fame' are known to have used themselves as the subjects of some of their own experiments. These experiments involved chemicals about which little was known at the time. One of these scientists inhaled a 'new' gas. The other scientist was known to taste the chemicals he worked with. Today, science laboratories across the world expect scientists to assess the risks involved in the experiments they perform. They are also expected to follow work practices that reduce any safety risks to themselves, those they work with, the lab, the public, and the environment.

- How do you think the scientific community develops such safety guidelines?
- If you were a member of the scientific community, would you expect scientists working with new chemicals or organisms as well as those performing risky experiments for the first time to analyse and communicate potential risks and safety practices? What do you think are some of the advantages and disadvantages of this approach?
- How do you think the scientific community ensures that such safety guidelines are followed?
- Some may argue that these safety practices may hamper the pace of new discoveries. How would you respond to this?
- Others may argue that these practices may be necessary to ensure that we do not cause harm to others. However, the choice to experiment on oneself is personal. A scientist should have the right to make an informed choice about taking such risks. What arguments can you think of in favour of and against this position? Can you think of some conditions under which this argument is likely to prevail?

What other aspects of this story would you like to explore more deeply?

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WHY DO SO MANY INDIAN MEN HAVE HAIRY EARS?

STEVEN M CARR & DURGADAS P KASBEKAR

Like the beard, hairy ears are rarely if ever seen in women. Unlike the beard, only a small minority of men have hairy ears. Many of these men are from India. Why is this so? And how is this trait inherited? How do scientists investigate such questions?

It is not uncommon to see men with hair growing from the fleshy part of their outer ears (or pinnae). While the amount and quality of this hair growth can vary, the presence of excessively coarse and long black ear hair is known medically as hypertrichosis pinnae auris (see **Fig. 1**). This trait or distinguishing feature is most common in men from India and Sri Lanka. In fact, the record for the longest ear hair is currently held by Anthony Victor, a retired school headmaster, from Madurai, Tamil Nadu. Why is this so? This question has captured the attention of many scientists.

Early hypotheses

Interestingly, hairy ears, like beards, are rarely if ever seen in women. For example, as far back as 1907, the Italian physician C Tomassi documented the occurrence of hairy ears through five generations of an Italian family (see **Fig. 2**). His pedigree chart showed that **only men** have hairy ears, that **all sons** of hairy-eared men have hairy ears, and **none** of their **daughters** do. This suggested that the trait had a genetic basis and that it was passed only from father to son, and all sons, but not to daughters.

As other such pedigrees were described, the internationally-known geneticist JBS Haldane, who was born in England but later became an Indian citizen, first sketched a hypothesis of Y-linked inheritance for hairy ears in 1936 (see **Box 1**). He ascribed hairy ears to a mutation in a gene (or an allele) on the Y chromosome. Since only men have this chromosome and receive it from their fathers, the trait was expressed only in men and was transmitted to them from their fathers.

Box 1. The genetic basis of hairy ears:

Tomassi made his observations shortly after Mendel's laws of inheritance were rediscovered in 1900. Those laws said that traits such as seed colour or shape in peas were determined by pairs of factors (now called **alleles**), one inherited from each parent. The combination of alleles that the offspring inherited (genotype) determined the nature of the trait they expressed (phenotype). Alleles are different forms of the same **gene**. Typically, one of the two alleles for any gene is expressed if it is present in either one or two copies in the offspring. This is called the dominant allele. The other allele, which is expressed only if present in two copies, is called the recessive allele.

What does this have to do with hairy ears and beards? As you know, genes are located on chromosomes. Males and females have 22 pairs of identical chromosomes, one inherited from each parent. These are called autosomes. Although Mendel's Laws explained the behaviour of typical genes, it turns out that they do not apply to all genes or traits. In humans and other mammals, sex is determined by a pair of non-identical chromosomes, called X and Y, a fact recognized by WE Castle in 1922 (These are just names, and not descriptions of what these chromosomes look like under the microscope. For example, a Y chromosome is not an X chromosome missing one leg). Females are XX—they have two X chromosomes. Each female receives one of these X chromosomes from her father, and another from her mother. Males are XY—they have one X and one Y. Each male receives the X chromosome from his mother and the Y chromosome from his father. Alleles of genes on the X and Y chromosomes are said to be sex-linked. In XX females, sex-linked alleles behave like the alleles on autosomes. In XY males, whichever allele is present on the single X chromosome determines what trait is expressed. Genes on the Y chromosome determine sex. In particular a gene called SRY (Sex-determining region Y) triggers differentiation of male from female development in the early embryo. Every male inherits his Y chromosome from his father. It is due to the presence of the Y chromosome that he develops as a male, and exhibits male traits, such as beard growth.

What about traits like hairy ears, that occur only in males, and only in a few males? This is where it gets interesting. Let's suppose that the inheritance of hairy ears is determined by a single gene with two alleles—call them H and h, where H is the allele for non-hairy ears, and h the allele for hairy ears.

Let's also suppose that this gene lies on the Y chromosome. Then, Tomassi's pedigree is easily explained. The great-grandfather II-3, with hairy ears, has five sons and two daughters (by two wives). All five sons have hairy ears, while the two daughters do not.

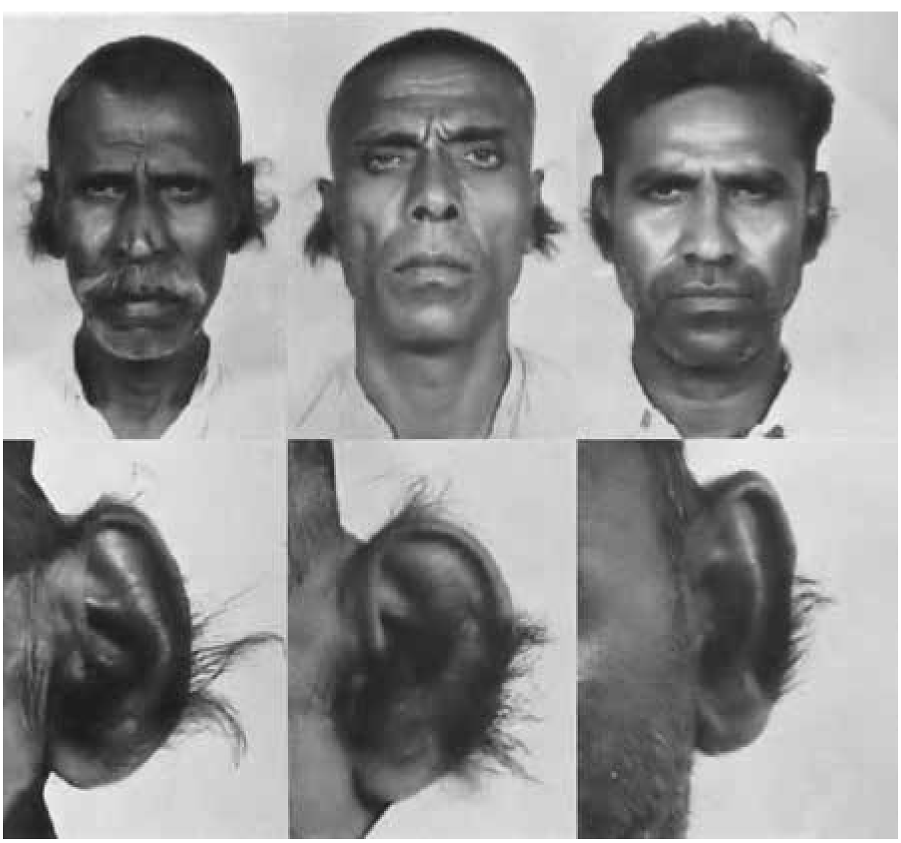

Fig. 1. Hypertrichosis in three men from the southern Indian city of Vellore. Slightly modified from Figure 1 of Stern et al. (1964). The caption of their image reads: *"Vellore. Three Muslim brothers. ± 60, 50-55, and 45-50, with grades of hairiness 5, 5, and 4, respectively,"* based on the system of Slatis and Apelbaum (1963).

One of the first modern experimental investigations of Haldane's hypothesis was by the Indian scientist KR Dronamraju. In 1960, Dronamraju simply counted the occurrence of hairy ears among 400 persons traveling on public buses in Andhra Pradesh. Among 345 men, 21 had hairy ears to some degree; none of the 55 women did. When Dronamraju looked at the pedigrees of three of the men with hairy ears, he found that **all** of their sons above age 17 (when the trait becomes apparent) also had hairy ears, but **none** of their daughters had any. Further, **none** of the affected sons had affected daughters. Haldane used statistical calculations to show that the Y-linkage hypothesis best explained Dronamraju's pedigrees (see **Box 2**).

Curt Stern, another eminent geneticist, and his colleagues had also reviewed pedigree data for several cases of hairy ears. In 1957, they suggested that this data *"... did not permit unequivocal discrimination between the hypotheses of Y-linked and autosomal inheritance".* In 1961, Stern, Sarkar, and their

The fifth son (III-8) has two affected sons, and one unaffected daughter. His sons (IV-2 and IV-4) have multiple unaffected daughters between them. One of his sons (IV-2) has three sons, of which only one (V-4) had, at the time when this pedigree was being prepared, reached the age when hairy ears first begin to be seen. Prove this to yourself—simply write down h next to I-1, his sons, their sons, and so on, and the pedigree is exactly what you would expect for a Y-linked gene. Case closed, right?

Not really. Is it possible that the allele for hairy ears is not Y-linked, but instead an autosomal h recessive to a dominant H? Go back now and add a second h to every male h you wrote in before, and write one H next to every mother of an affected son. Now add an h to every one of these mothers, making them Hh. You will see that it is just possible to explain the pedigree by chance. How? Imagine the possibility that every son gets an h from his mother and an h from his father; every daughter gets an H from her mother and an h from her father; and this happens in every case. Then, all hairy-eared sons would be hh and all daughters would be Hh, with H dominating h.

Another alternative is that hypertrichosis is due to an autosomal H dominant to a recessive h, with sex-limited expression. This would mean that even if women had the genotype for the trait, the trait would be expressed exclusively in men, like male pattern baldness. Try this out for yourself. Get a clean copy of Tomassi's pedigree, but this time let H be the allele for hairy ears, h for non-hairy ears, and let Hh individuals have hairy ears. What do you get? What assumptions must be made?

How do we decide which of these three possibilities is most plausible? Let us do what we do in science, and look at some more evidence.

colleagues published a pedigree of a South Indian man with hairy ears. The man had three sons, all of whom were well past the typical age of onset for hairy ears. Yet, only one of them had hairy ears; the other two did not. Stern, Sarkar, and their colleagues claimed that this unusual pattern could be explained by autosomal inheritance of the trait (mutations of genes on autosomes, not sex chromosomes) and incomplete penetrance (see **Box 3**).

In 1962, Dronamraju and Haldane suggested that the inconsistency between the results predicted by the Y-linked hypothesis and the results that Stern, Sarkar, and their colleagues had documented in their pedigree could be explained by *"illegitimacy"* in the *"lower-caste"*. The two sons who did not have hairy ears may have the **same mother** as the son with hairy ears but might have a **different, unaffected father.** This, they implied, **could not** (of course) happen in the *"upper-caste"* pedigrees studied by Dronamraju. That such discriminatory arguments made it to the scientific literature of the time shows us the distance that we have travelled since then.

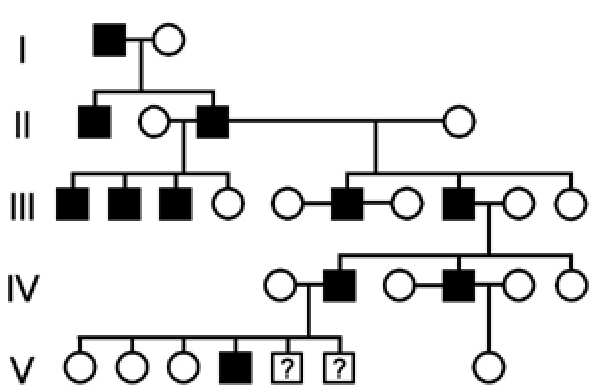

Fig. 2. Occurrence of hypertrichosis in an Italian family. Redrawn from Figure 8A of Stern (1957), after C Tomassi (1907): *Ipertricosi auricolare famigliare*. Giorn Pysch Clin Tech Manic 35: 1-21. Circles are women, squares are men; filled-in squares are affected men. Individuals are identified by generation (Roman numerals) and left-to-right order in each line. In the fifth generation, V-4 was 19 years of age at onset; V-5 and V-6 died before the expected age of onset.

Dronamraju and Haldane also countered Stern's claim that this pedigree challenged the possibility of Y-linked inheritance of hairy ears. What would be required to disprove Y-linked inheritance, they suggested, was to identify an **affected man** (or a man with hairy ears) whose father was **unaffected** but whose **maternal** grandfather **was** affected. In such a case, the trait would be 'skipping a generation' because it would be transmitted to a man from his mother's side. Since the man would only receive an X chromosome from his mother, such a case would show that the transmission of hairy ears could occur without the transmission of a Y chromosome (see **Fig. 3**).

Finding such a specific case was admittedly difficult. In the event, it has not yet been reported. As an example of the way science works, note Dronamraju and Haldane's assumption that the Y-linked hypothesis was now, by default, the 'correct' explanation; and that any alternative hypothesis required a higher standard of proof to be accepted.

Box 2. What statistical calculations did Haldane use?

Let us go back to Tomassi's pedigree. The probability that any one daughter would get an H allele from an Hh mother is 1/2. That all six daughters of affected hh men in the pedigree would inherit H from an Hh mother is $(1/2)^6 = 1/64$. This makes an autosomal recessive model pretty unlikely. It is also pretty unlikely that every hh man in the pedigree just happened to marry an Hh woman. This calculation is further complicated when an affected father has daughters but no sons (which proves nothing either way).

Once Haldane had shared these calculations, hairy ears began to be used as a standard example of Y-linked inheritance, alongside the four standard modes expected in classical genetics (autosomal dominant or recessive, and X-linked dominant or recessive).

In 1964, Stern and his colleagues objected to Dronamraju and Haldane's suggestion that the unusual pattern in their pedigree chart could be explained by illegitimacy. They also pointed to a 1963 study by the geneticists HM Slatis and A Apelbaum that showed that the degree of ear hair growth varied greatly (variable penetrance again) among Israeli men, and was often delayed until advanced age. This age-related pattern, Stern and his colleagues suggested, would explain at least some cases of the absence of the trait in men in whom it would otherwise be expected.

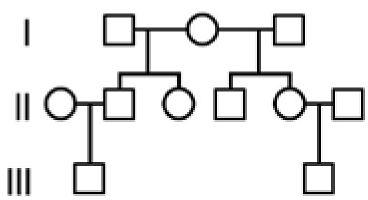

Fig. 3. A theoretical test of Y-linked inheritance of hypertrichosis. JBS Haldane suggested that the Y-linked model for the inheritance of hairy ears could be disproved by a pedigree of an affected man whose maternal grandfather was also affected. If an affected man's father and paternal grandfather were both affected, it would support the Y-linked hypothesis. Fill in the appropriate boxes in the pedigree above to show these two possibilities. Explain why the two scenarios disprove and support the Y-linked hypothesis, respectively.

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Box 3. What does incomplete penetrance mean?

Incomplete penetrance occurs when individuals with the same genotype (genetic makeup) do not all express the same phenotype (trait characteristics)—the genotype fails to 'penetrate' through to the phenotype. This may be due to differences in environment or the influence of other genes. For example, a genotype predisposing to lung cancer may not be expressed in a non-smoker, and a genotype predisposing to breast cancer is more likely to be expressed in women than men. Because facial hair is strongly associated with male hormones, hairy ears might be a good candidate for this explanation.

Despite lingering doubts, Haldane's argument established the transmission of hairy ears as a textbook example of Y-linked inheritance. Dronamraju's pedigree chart even appeared in Stern's standard textbook on human genetics (3rd edition, 1973). There things sat until the new era of molecular genetics (see **Box 4**).

More recent advances

In 2004, the scientist AC Lee and his colleagues brought molecular thinking to bear on the Y-linked model for hairy ears. Previous classical studies had looked at pedigrees of hairy ears within a single family. Lee and his colleagues looked at the yDNA haplotypes of 50 men with hairy ears from across southern India (see **Box 5**). These men were deliberately chosen from multiple families. For their control group, they looked at the yDNA haplotypes from a matched sample of 50 men without hairy ears, who were deliberately chosen from the same geographic area as the affected men. The yDNA haplotypes that they examined were not known to be associated with hairy ears. They were just representative samples of the whole Y chromosome sequence in these 100 men.

Box 4. The era of molecular genetics:

That genes on chromosomes were made of Deoxyribonucleic Acid (DNA) was not discovered until 1953, and the Genetic Code that determines how any sequence of DNA's four bases A, C, G, and T are expressed as a protein was not 'cracked' until 1965. Methods for routine and rapid determination of the base sequences of DNA molecules did not become widespread until the late 1980s, and accelerated rapidly in the 1990s. Identification of the exact chromosomal locations of the DNA sequences responsible for many genes of interest had to wait till the Human Genome Organization (HuGO) was started in 1990 and the epoch-making Human Genome Project (HGP) was completed in 2003.

Box 5. What does a yDNA haplotype mean?

Classical genetics had assumed that there were typically only two alleles for any gene—the 'wild type' for the trait as it was usually seen; and a variant or a 'mutant' (changed) type that was typically rare and often harmful. It recognised that some genes were more variable, with multiple favourable alleles that allowed humans to artificially select for better breeds of plants and livestock, but these were considered the exception.

As DNA sequencing began, it became apparent that most genes comprised multiple molecular alleles. These could be recognized by numerous small variations in their DNA sequence (or single nucleotide polymorphisms, referred to as SNPs or 'snips'), each of which had originated by single mutations (one base pair becomes different) in single individuals, and which were now widespread in populations. These SNPs allowed the construction of molecular pedigrees, in which individual gene changes could be tracked in the same way as phenotypic traits. This means that if a man carried a certain mutation, one could use sequencing to see which of his children inherited this mutation.

The DNA sequence of any gene is multiple thousands of bases long. It includes dozens of SNPs that, when taken together, could define hundreds of alleles. The combination of SNPs on any single chromosome is called a haplotype. Each Y chromosome is unique because it acts like a single yDNA haplotype in being inherited as a unit, present only in males, and in only one copy for each male. This means that all the mutations in the Y chromosome of a man, however minor, will be inherited by all his sons.

If hairy ears were caused by a single allele on the Y chromosome, a single haplotype (equivalent to an allele) would have been found in the yDNA of all the men with hairy ears. Further, this haplotype would have been missing from the yDNA of the men who did not have hairy ears. However, Lee and his colleagues found that the yDNA of affected men occurred in several different extended families as distinct haplogroups (related lineages of haplotypes). In other words, two unrelated men with hairy ears need not carry the same mutations in their Y chromosomes. This ruled out the single-allele model. It remained possible that the different haplotypes that were responsible for hairy ears had diverged from a single original mutation that was inherited from a recent common ancestor. However, the data showed that the affected men had last shared a common ancestor more than 68,000 years ago, well before the arrival of the various peoples that now make up the population of the Indian subcontinent. Finally, the range of yDNA haplotypes in affected men was not very much different from that in the control group. In other words, the DNA sequences of the Y chromosome of men with hairy ears were not very different from those of unaffected men from the same geographic area. Taken together, these data indicated that the possibility that any gene responsible for hypertrichosis could be Y-linked was very slim. For it to be possible, the same mutation would need to have occurred on multiple occasions in haplotype lineages that were otherwise distinct.

The final nail in the Y-linked hairy ears hypothesis comes from our increased knowledge of the gene content of individual chromosomes, including the Y chromosome. The locations of all 20,050 human genes across 22 autosomes and the X and Y chromosome are stored in a free online library called GenBank. A search of the complete DNA sequence of the Y chromosome does not suggest any candidate genes for hypertrichosis anywhere on the Y chromosome.

Box 6. Our hypothesis:

It is so tempting to speculate. When asked to review the question of hairy ears, we discussed some of the newer options in genetics. One of these is epigenesis. Unlike a mutation, an epigenetic modification does not change the DNA sequence, but makes small chemical modifications that affect gene expression. Such changes are usually reversed ('reset') during the formation of sperm and eggs for the next generation. One form of epigenetic modification is paramutation, where one of the two alleles of a gene changes the expression of the other.

Paramutation at an autosomal gene might mimic Y-linkage. How? Imagine a paramutagenic allele h* received by both a son and a daughter from their hairy-eared father, along with an h from their unaffected mother. Both have the hh* genotype. In the son, after the fusion of egg and sperm, the h* allele paramutates the h allele ($h \rightarrow h^*$)—his 'molecular' phenotype is now h*h* and his 'ear' phenotype is hairy. In the daughter, during development of her eggs, the h* is reset ($h^* \rightarrow h$)—her molecular and genetic phenotypes are the same (hh), and her ear phenotype is unaffected. The bottom line is that h always paramutates to h* in male zygotes, and h* is always reset to h in developing eggs. Consequently, the epigenetic condition will persist in men between generations, and will never show up in women, mimicking Y-linked inheritance.

If this seems confusing, it may be because we are still working on it. Let us know what you think.

Parting thoughts

Attempts to explain the genetic basis of hypertrichosis have now completed their centenary. The inheritance of this trait is among the earliest research problems in human genetics. It has been vetted throughout the period of classical genetics, tested in the molecular era, and remains unresolved down to the present. JBS Haldane, asked why there are so many competing ideas in this investigation, might have smiled and replied, *"We have an inordinate fondness for hypotheses".*

While hypertrichosis is not a medical concern, and the extra hair can easily be trimmed or shaved off, understanding its genetic basis might provide us with broader insights into more medically important traits. For example, it may help us understand why many neuropsychiatric disorders such as attention deficit hyperactivity disorder (ADHD) are, like hairy ears, more common in boys than in girls. But, ultimately, understanding the inheritance of hypertrichosis is a matter of simple curiosity. Scientists like to observe differences among peas, pachyderms, and people, and come up with explanations for these differences (see **Box 6**).

Given that Y-linkage is ruled out and evidence for autosomal dominant sex-limited inheritance has not been forthcoming, have we reached a dead-end in the search for an explanation for inheritance of hairy ears? Hardly. This may be one of those instances where Nature yields her secrets slowly.

Key takeaways

- The presence of excessively coarse and long black hair on the fleshy part of our outer ears is called hypertrichosis. This condition is most common in men from India and Sri Lanka.
- In 1907, the Italian physician C Tomassi published a pedigree chart documenting the occurrence of hairy ears through five generations of men in an Italian family. This suggested that the trait had a genetic basis and that it was passed only from father to son, and all sons, but not to daughters.
- Later pedigrees showed that while all the sons of a hairy-eared man may inherit the trait, the amount of hair growth and the age at which it appears may vary within the same family.
- The transmission pattern of the trait lent itself to two competing possibilities in classical genetics—the allele for hairy ears was either Y-linked or autosomal recessive.
- The eminent Indian geneticist JBS Haldane attributed hairy ears to a mutant allele on the Y chromosome. His hypothesis was supported by evidence from a study of hairy ears from southern India by the Indian scientist KR Dronamraju.
- Curt Stern, another eminent geneticist, argued that the available evidence did not unequivocally support the Y-linked inheritance of hairy ears. Autosomal recessive inheritance remained a plausible alternative explanation.
- In 2004, the scientist AC Lee and his colleagues used molecular evidence to show that it is extremely unlikely that this trait is caused by a single allele or is Y-linked. The genetic basis of this trait remains a mystery.
- While hairy ears are not a medical concern, the genetic basis for this trait has for long captured the curiosity of many scientists. Understanding it may give scientists broader insights into more medically important traits that are more common in men than in women.

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Note: Source of the image used in the background of the article title: Karyotype of a human male. Credits: Talking Glossary of Genetics, National Human Genome Research Institute, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:NHGRI_human_male_karyotype.png. License: Public Domain.

References:

1. Castle WE (1922). 'The Y-chromosome type of sex-linked inheritance in man'. Science 55: 703-704.
2. Cockayne EA (1933). 'Inherited abnormalities of the skin and its appendages'. London: Oxford Univ Press.
3. Dronamraju KR (1960). 'Hypertrichosis of the pinna of the human ear, Y-linked pedigrees'. J Genet 57: 230–244.
4. Dronamraju KR (1964). 'Y-linkage in man'. Nature 201: 424-425.
5. Dronamraju KR & Haldane JBS (1962). 'Inheritance of hairy pinnae'. Am J Hum Genet 14: 102–103.
6. Haldane JBS (1936). 'A search for incomplete sex-linkage in man'. Ann Eugen 7: 28-57.
7. Lee AC, Kamalam A, Adams SM & Jobling MA (2004). 'Molecular evidence for absence of Y-linkage of the Hairy Ears trait'. Eur J Hum. Genet 12: 1077-1079.
8. Sarkar SS, Banerjee AR, Bhattacharjee P & Stern C (1961). 'A contribution to the genetics of hypertrichosis of the ear rims'. Am J Hum Genet 13: 214–223.
9. Slatis HM & Apelbaum A (1963). 'Hair pinna of the ear in Israeli men'. Am J Hum Genet 15: 74-85.
10. Stern C (1957). 'The problem of complete Y-linkage in man'. Am J Hum Genet 9: 147–166.
11. Stern C, Centerwall WR & Sarkar SS (1964). 'New data on the problem of Y-linkage of hairy pinnae'. Am J Hum Genet 16: 455-471.

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AN ELEMENTAL CROSSWORD: ANSWERS

Did you try the crossword on page 27 of this issue? Here are the correct answers:

Down:

1. Polonium. 2. Krypton. 4. Tellurium. 6. Dysprosium. 10. Francium. 11. Zirconium. 12. Europium.

Across:

3. Lithium. 5. Chlorine. 7. Magnesium. 8. Rubidium. 9. Beryllium. 13. Aluminium. 14. Neon. 15. Osmium. 16. Gallium. 17. Indium. 18. Helium. 19. Scandium.

Some questions to think about:

Q1. Which elements did you identify almost immediately? Which ones took longer to identify?

Q2. How did you go about identifying the elements? Did you rely on what you have heard or learnt or know about them already? Did you refer to a book or an internet search?

Q3. Which of the clues was most fascinating to you and why?

Q4. Some of these 19 elements derive their names from Latin or Greek words. Some are named after regions, countries, or continents. If you were asked to rename each of these elements, what criteria would you use to choose new names for them and why?

Q5. This crossword features only 19 of the 118 elements in the modern periodic table. If you were composing a crossword with any 10 elements other than the ones in this crossword, which ones would you choose? What clues would you provide for them?

Note: Source of the image used in the background of the article title: Jigsaw pieces.
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Write for us

If you are a practising **school science teacher, teacher educator**, or a researcher with an interest in the teaching and learning of school science—we would love to hear from you.

We welcome articles that offer:

- critical perspectives on science and science education,
- a deeper exploration of the foundational concepts and underlying principles in the school science curriculum,
- common student conceptions, ways of identifying, challenging or building on them.
- unit plans, activities, thought experiments, field guides and stories in science that engage the curiosity and imagination of your young learners, and
- examples of practice that encourage the learning of science in more meaningful and inquiry-based ways.

Topics of special interest:

Keeping our target audience in mind, we are particularly interested in submissions that are grounded in, connect, or emerge from these topics in the school science curriculum:

- **Physics:** Motion; Mass and weight; Density; Force and pressure; Momentum; Energy; Work; Power; Light; Sound; Heat; Electricity and Circuits; Gravitation; Stars and the Solar System; and Magnetism.
- **Chemistry:** Atomic Structure; Periodic Table; Particulate Nature of Matter; Structure and Bonding; Chemical Reactions; Acids, Bases, and Salts; Air and water; Materials—Metals and Nonmetals; and Fuels.
- **Biology:** Living and Non-living; Cell Structure and Organisation; Biological Molecules; Movement in and out of Cells; Plant Nutrition and Transport; Human Nutrition and Transport in Animals; Diseases and Immunity; Respiration; Excretion; Coordination and Response; Inheritance; Variation and Selection; Organisms and their Environment; and Human Influences on Ecosystems.

Themes for long articles (1500 words):

- **The Science Lab:** Tried-and-tested thought or practical experiments to teach a concept.
- **Annals of History:** The history of an important perspective, discovery, concept or invention.
- **In Here, Out There:** The 'life history' of one component within living systems (stomach) or in the extreme reaches of our physical world (black holes), preferably written in first-person.
- **Biography of a Scientist:** Their life and times through the prism of their contributions to science.
- **Teaching as if the Earth Matters:** Perspectives and teaching-learning approaches to sustainability, earth sciences, climate-sciences, and systems thinking.
- **The Science Educator at Work:** Perspectives and practices in teaching science written in first-person.
- **Big Ideas:** How do we introduce students to those powerful or illuminating ideas in science that help us make better sense of lots of confusing experiences and seemingly isolated facts?
- **I am a Scientist:** What does it mean to be a scientist, what inspired you to choose this path, what kind of questions excite you, and what you wish you'd learnt in school.
- **Hot off the Press:** Why recent headlines are of interest to students and teachers alike.
- **Book Review:** Why and how a book you've read could contribute to the teaching and learning of school science.

Themes for short pieces (200-600 words):

- **Myth or Fact:** Commonly held incorrect beliefs versus corresponding objective and verifiable observations.
- **10 Things You Didn't Know About:** A concept, topic or theme that are not commonly written or heard about.
- **How Do We Know:** How do we know how far a star is from the Earth? Or, how many microbes live in the human body? Share your answers with us.
- **Snippets:** Do you know of a funny, fascinating, mysterious, or inspiring facet of science or scientists?
- **Posters:** On any topic or theme that teachers can use as a resource in the classroom.

Share your ideas with us:

1. Write a **brief outline (< 100 words)** that tells us:
   - What you want to write about
   - The key questions you hope to address
   - Why you think this will interest school science teachers
2. Include a **brief bio (< 50 words)** that tells us something about your:
   - Background in science and/or science education, and
   - Areas of interest in school science

Your outline and bio can be in English, Hindi or Kannada. **Send these to us at: iwonder@apu.edu.in. We accept submissions throughout the year.**

CONNECT WITH US

Read

We publish **two issues a year**, in **English, Hindi and Kannada.** Each issue has one theme section and many non-theme sections. Themes from our latest issues include: Our Chemical World, Ask A Question, and Teaching as if the Earth Matters. Non-theme sections include: The Science Lab, Annals of History, The Science Educator at Work, Nature of Science/Why Science Matters, Life in your Backyard, I am a Scientist, Book Review, Biography, Research to Practice and Ten Things You Didn't Know About. Each issue also features some short snippets, posters, activity sheets, or school-level field guides.

Ask and discuss

If you have questions for our authors, ask them directly by joining our **free, live, online discussions on the 2nd Wednesday of every month.** Some of our latest themes include:

- **Asking Questions in the Science Classroom** with Madhav Kelkar and Saurav Shome
- **Explore Your Surroundings with the Foldscope** with Rafikh Rashid Shaikh and Radha Gopalan
- **Measuring Earth's Size** with Amol Kate and Saurav Shome
- **Paying Attention to What Children Do** with Anish Mokashi and Vinay Suram
- **Eleven Characteristics of Pseudoscience** with Melanie Trecek-King and Vijeta Raghuram
- **Nature Learning: Enriching the EVS Curriculum** with Vena Kapoor, Roshni Ravi, and Radha Gopalan

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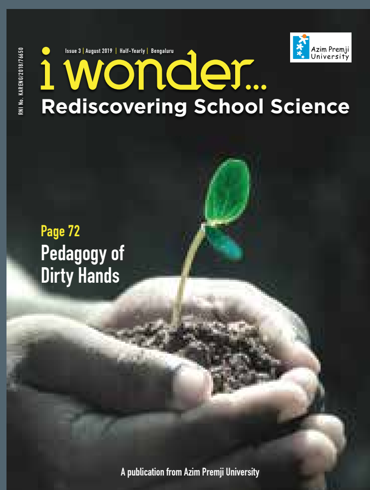

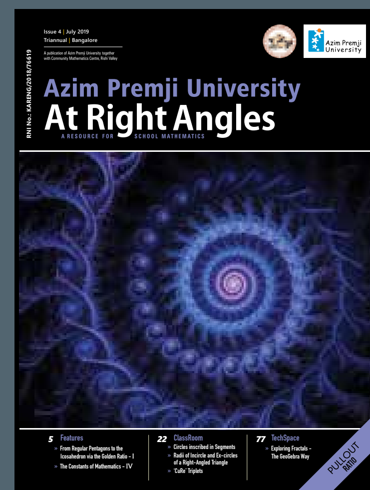

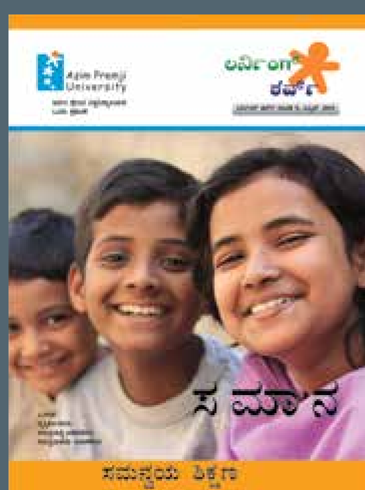

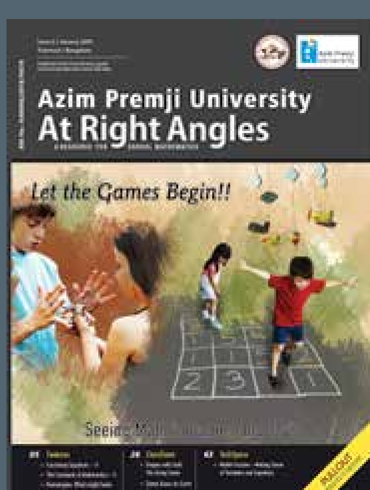

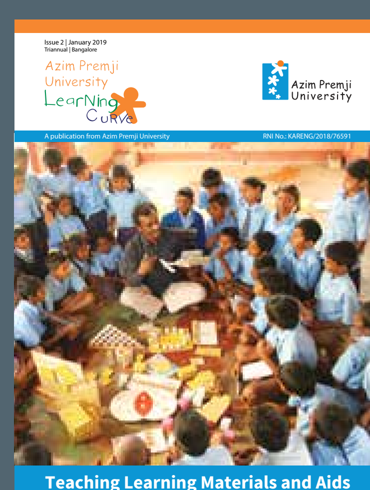

Join us as we revisit some of our attempts at flying in the next issue of **i wonder...**

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