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i wonder...

Rediscovering School Science

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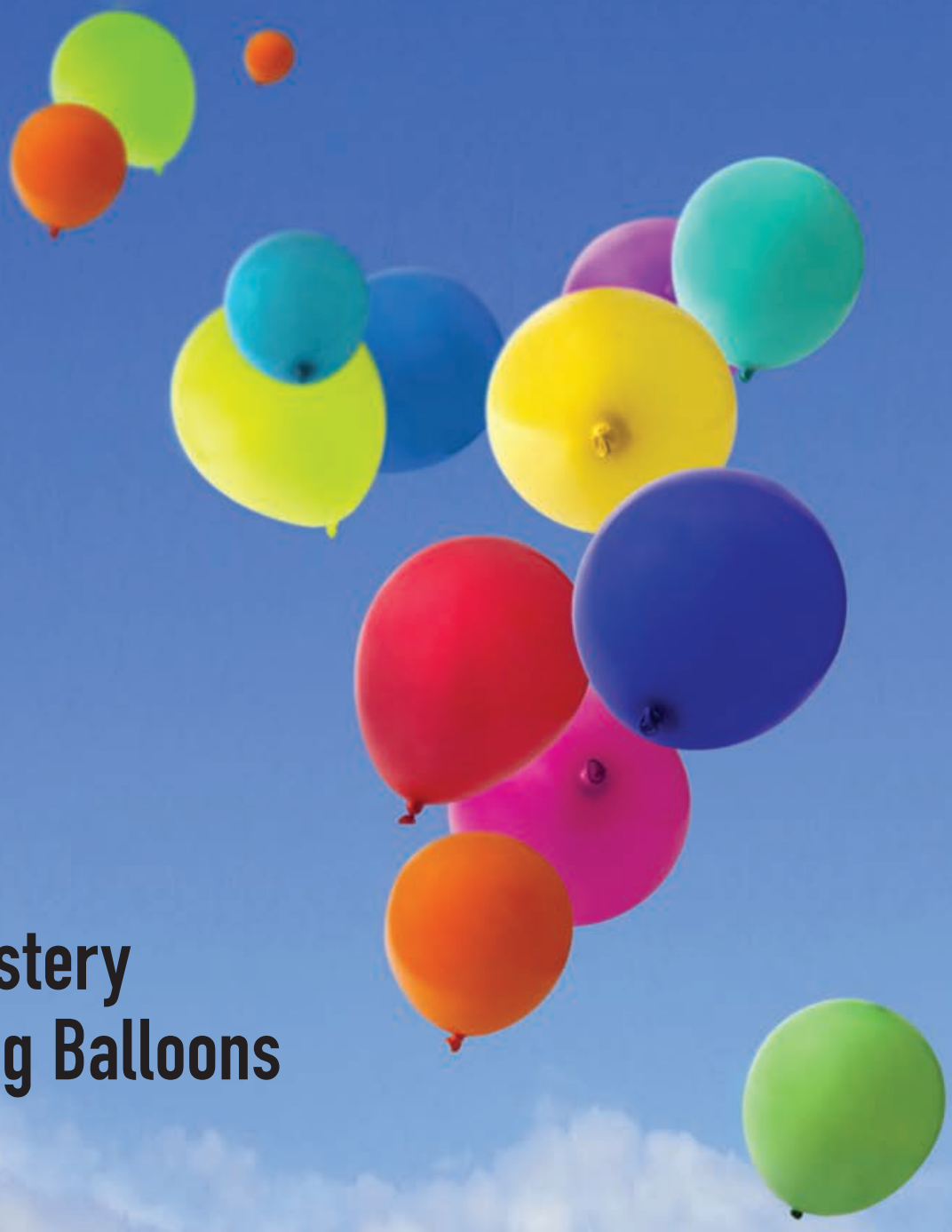
Azim Premji University



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The Mystery of Rising Balloons

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...** is also a great read for students and science enthusiasts.

i wonder...
REDISCOVERING SCHOOL SCIENCE

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Editorial

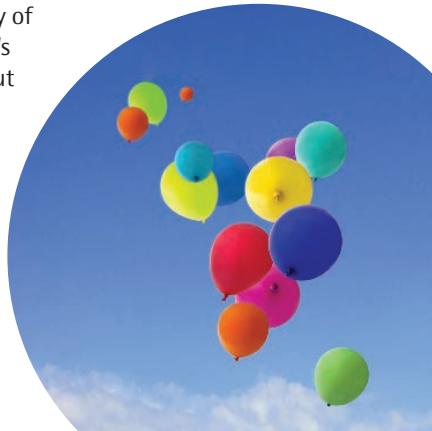
In this issue of iwonder..., we explore a somewhat unusual question — do feeling, empathy, and intuition have any role in the way we learn, teach, and do science?

According to the cytogeneticist Barbara McClintock, nurturing a *"feeling for the organism"* one is studying is vital to being a good scientist. This belief was grounded in more than 50 years of quiet, dedicated study of maize chromosomes at the Cold Spring Harbor Laboratory on Long Island. Changes in the life cycle of maize were slow enough to allow McClintock the time and the *"great pleasure"* of getting to know each plant in her study *"intimately"*. Rather than attempting to impose an answer on what she saw, she preferred to become part of the system and let answers come to her through sustained observation. Through this sense of collaboration with her subjects, McClintock amassed extensive data on what was for a long time dismissed as fringe research by her contemporaries. She went on to receive an unshared Nobel Prize for Physiology (1983) for her revolutionary discovery of mobile genetic elements or transposons. In McClintock's words, *"It might seem unfair to reward a person for having so much pleasure over the years, asking the maize plant to solve specific problems and then watching its responses."* Rather than abandon objectivity, McClintock invites us to consider how a close, interactive, and reciprocal relationship with our subjects may influence the questions we ask, and the ways in which we seek to answer them. The theoretical physicist Evelyn Fox Keller contrasts McClintock's approach with a long-standing tradition of scientific endeavour that is fuelled not just by the desire to understand 'nature', but to control and dominate it. She draws our attention to how this desire is reflected in the language we use to describe scientific achievements. And to the many ways in which it reinforces the belief that nature needs to be vexed, twisted, subdued, or steered by us. Arguing that humans are purposive beings, Keller urges us to examine how this feeling of being *"engaged in a battle, in a struggle, in a state of opposition"* with nature influences the goals and practice of science. Robin Wall Kimmerer, an American Distinguished Teaching Professor of Environmental and Forest Biology, explores how choosing English as the language of science influences the way we relate to the nonhuman living world. She points to how we use pronouns of personhood, like he, she, or they, only for (living and dead) human beings. In contrast, *"Bulldozers, buttons, berries, and butterflies are all referred to as 'it', as things, whether they are inanimate industrial products or living beings..."*. Kimmerer invites us to consider how seeing the nonhuman living world as kin, rather than just 'objects' of study or 'natural resources' for human use, would change the way we teach and learn science.

Both articles in our theme section 'Teaching as if the Earth Matters' explore this question by approaching education as a way of connecting with and caring for nature. The Nature Classrooms Group invites us to recognise how our own sense of identity may draw upon our many immediate, direct, and everyday connections with the living world. How essential are our formative childhood memories and immersive sensory experiences of 'nearby nature' in cultivating a personal sense of interconnectedness? They offer a learning framework and pedagogy that could enrich the EVS curriculum by providing age-appropriate and contextually-relevant opportunities for children to develop deep emotional connections with nature. Continuing a conversation they started in our last issue, Poornima and Nishant invite us to reflect upon how we relate to our earth. Do we see it largely in terms of physical 'space' — tangible, measurable, with clearly defined boundaries? Or as more — a fluid 'place' that derives its identity from the many intangible, dynamic relationships between the living and nonliving, human and non-human? From this approach of nurturing relationships, they share their experiences of teaching science so that it is part of a child's journey of growing up and meeting the larger world. Science, then, offers a way of revealing interconnections between more and more things in a child's immediate experience, while also providing a framework to talk about the changing world.

How do you engage with this question in learning, teaching, and doing science? Share your thoughts and experiences with us at iwonder@apu.edu.in.

Chitra Ravi
Editor



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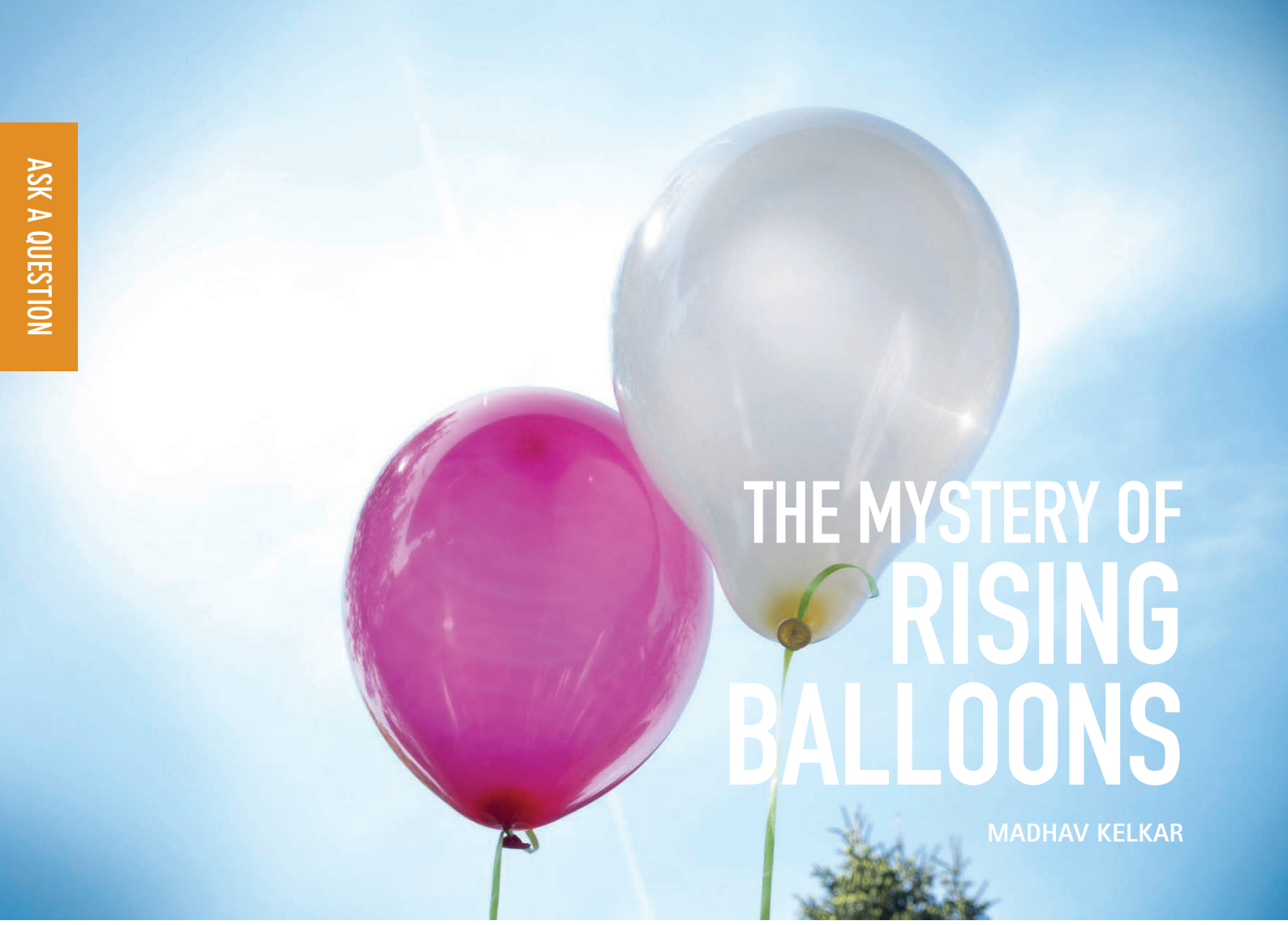


THE MYSTERY OF RISING BALLOONS

MADHAV KELKAR

Why do balloons rise in air? How high can they go? When do they drift to the ground? How do we test these possibilities?

For many of us, the sight of a balloon bobbing in the air can evoke many memories. Like that of watching the ceremonial release of a bunch of gaily coloured balloons at a function. Or of one of our balloons flying out of reach when the string accidentally slipped out of our grasp — a sight that may have driven many of us, as children, to tears. I remember racing after such balloons, hoping that they would eventually land on the ground. But those rascals always escaped me!

Have you ever wondered why balloons rise in air? A textbook will tell you that an object surrounded by air rises upwards when the weight of air displaced by it is equal to the lifting force (buoyancy) acting on it. But what does this cryptic-seeming explanation mean? Under conditions of normal temperature and atmospheric pressure, one cubic meter of air weighs 1250 grams. Therefore, an object with a volume of one cubic metre will float in air if its weight is 1250 grams, fall to the ground if its weight exceeds 1250 grams, and rise upwards if its weight is less than 1250 grams. In other words, any object whose weight is less than the weight of the same volume of air will rise upwards. The gas balloons that we see in celebrations are usually filled with helium gas — the second lightest gas. This means that the combined weight of the balloon, the gas within it, and the string attached to it is still less than the weight of air displaced by the inflated balloon. This is why gas-filled balloons rise in air.

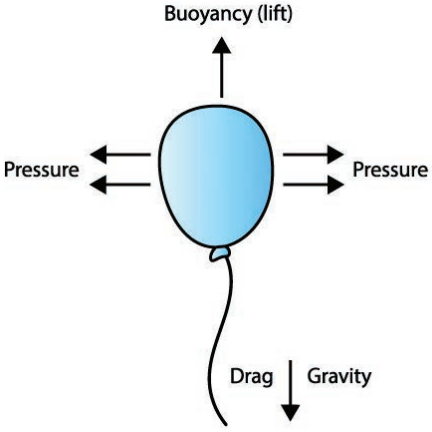


Fig. 1. A helium balloon rises to height where the buoyant force pulling it upwards will equal the gravity pulling it downwards. As it moves higher, the air pressure outside it decreases. When it falls lower than the air pressure inside, the gas within the balloon expands. License: CC0.

Box 1. The game of bobbing balloons:

Releasing the second balloon in my room reminded me of a game I had read about somewhere. Two or three balloons filled with gas are released in a room. The balloons immediately nest at the ceiling of the room. When they are sprayed with a few drops of water from a syringe, the balloons start descending. They rest on the floor till the water drops dry off before they begin to ascend towards the ceiling again. Depending on when and how much water they are sprayed with, they can change course — flying upwards or floating in the middle like Trishanku personified. Having thought of this, I spent the next few minutes playing this game with the balloon in my room. I had such fun that I paid no heed to the question that provoked this experiment. But you may have guessed that the weight of the balloon remains more than the weight of the air displaced by the balloon as long as the water droplets stay on the balloon. If the water evaporates or the droplets roll off its surface, the weight of the balloon goes back to what it was before, and the balloon rises towards the ceiling once again.

How high would a rising balloon go? It will continue to rise as long as the weight of the air displaced by the balloon is greater than the weight of the inflated balloon. As it moves higher, the density of air around it decreases. Thus, the weight of air displaced by the rising balloon also decreases. When the weight of this displaced air becomes equal to the weight of the helium in the balloon, the balloon will stop rising (~ 32 km above the Earth's surface). At this point, the buoyant force pulling the balloon upwards will equal the gravity pulling it downwards (see **Fig. 1**).

What will happen to the balloon once it reaches this height? One possibility is that the gas in the balloon will slowly leak out. This could happen if the mouth of the balloon is not tied tightly enough or tiny holes appear in its thin stretched rubber when it is inflated. This will reduce the speed with which it ascends in air. When the balloon reaches the height at which its weight equals the buoyant force acting on it, it will stop and sway in the sky for a while before drifting down to the ground. To test this possibility, I used a 3-metre-long string to tie a tightly stretched balloon to the railing on the roof of my house. Eager to fly off, the released balloon went as high as it could, after which it stood tall and proud, swaying just a bit in the wind. The string by which it was attached to the railing was taut. I released another balloon in my room (see **Box 1**). Almost immediately, it hit the ceiling. I decided to leave both balloons like that for a day. By the next day, both had gone limp, and were lying on the floor. The gas had leaked out of them. This confirmed the first possibility.

Another possibility is that the balloon will burst somewhere up in the sky. Since atmospheric pressure decreases with increasing altitude, the higher the balloon goes, the greater the difference between the pressure inside and outside it. This difference in pressure will cause the gas inside the balloon to expand and the volume of the balloon to increase. This will eventually stretch the rubber of the balloon to a point where it bursts. The height at which a balloon reaches this point will depend on the altitude to which it rises (the higher the altitude, the lower the pressure, and the more likely the balloon is to burst) and the quality of rubber used to make it (the weaker the rubber, the sooner the balloon will burst). To test this possibility, I would have to release a balloon at a substantial height. I released one, with its string attached, at a height of 300 metres above sea level, where the atmospheric pressure is about 734 mmHg. The balloon flew upwards for a while, before the wind carried it away from me. I used a toy telescope to follow its movement. Till the time I could see it, it hadn't burst. Also, and this could just be my perception, it did not seem to rise beyond a certain height. If this was a height of about 50 metres, the balloon would have reached a total height of 350 metres above sea level, where it would experience an atmospheric pressure of 730 mmHg. (I have calculated the atmospheric pressure for these altitudes with the help of a calculator on this website: http://www.altitude.org. I don't know whether this calculation takes account of temperature, humidity, and the latitude-longitude of my location). At this point, it is likely that the pressure outside would be very different from the pressure within the balloon, but I haven't thought of a way to test whether the balloon will burst due to this difference. If you could offer any suggestions, it would help take this experiment forward.

Key takeaways

- A helium balloon rises in air because the combined weight of the rubber with which it is made, the gas filled into it, and the string attached to it is still less than the weight of air displaced by it.
- A balloon will continue to rise in air till the weight of air it displaces becomes equal to the weight of the balloon.
- As it rises upwards, the air pressure outside the balloon will decrease, becoming lower than the air pressure inside it. Whether the balloon drifts to the ground or bursts in the sky will depend on the altitude to which it rises, the quality of rubber, and how leak proof it is.

Notes:

1. This article was first published in response to a Sawaliram question in Sandarbh, Issue 88, pg 21-25. URL: https://www.eklavya.in/magazine-activity/sandarbh-magazines/250-sandarbh-from-issue-81-to-90/sandarbh-88/978-sawaliram-88.
2. Source of the image used in the background of the article title: Helium Balloons. Credits: stux, Pixabay. URL: https://pixabay.com/photos/balloon-helium-air-flying-bright-3360126/. License: CC0.

Madhav Kelkar is part of the editorial team of the teacher's magazine Sandarbh. He is also in charge of the Eklavya Foundation's Hoshangabad Centre in Madhya Pradesh. He can be contacted at: madhav.kelkar@eklavya.in.

WATER LOSS IN PLANTS

KISHORE PANWAR

How do plants lose water? How is transpiration different from guttation? Can plants regulate these processes? How do these processes affect plant function?

While most terrestrial plants absorb large quantities of water from the soil, only a very small amount of this water is utilised for their growth and development. The rest is lost from the aerial organs of the plant to the environment. This loss can occur through two processes — transpiration and guttation. Leaves often play an important role in both.

Transpiration

Transpiration refers to a process in which a plant loses water (~ 80-90% of what is absorbed by its roots) as water vapour from special pores, called **stomata** (singular: stoma), that are found on the aerial parts of a plant (see **Box 1**). While the number, size, and distribution of stomata can vary widely, they are usually most abundant on the leaves of a plant.

The amount and rate at which water loss occurs is finely regulated by the number of stomata that are open to gaseous exchange at a given time of the day. This means that the rate of transpiration is highest during the day, in the presence of sunlight. It also means that most of this water loss occurs through leaves. The anatomy of the leaf often puts the plant in a condition that is compared to being 'between the devil and the deep blue sea'. On the one hand, the abundant stomata on the leaf cause the unavoidable loss of water through transpiration (see **Box 2**). On the other hand, these structures along with the intercellular spaces and the air cavities in the internal structure of the leaf facilitate the exchange of gases (oxygen and carbon dioxide) needed for photosynthesis and respiration. Thus, the closing of stomata may limit water loss through transpiration, but may also adversely affect the rate of photosynthesis and respiration by inhibiting gaseous exchange.

Box 1. What are stomata?

Found on the outer surface of the stem, leaves, and even the flowers of a plant, each stoma consists of:

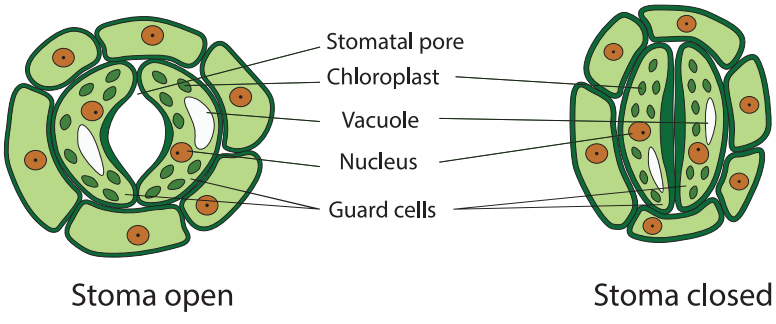
(a) An aperture through which gases (like water vapour, carbon dioxide, and oxygen) are exchanged between the plant and its immediate environment.

(b) Two specialised epidermal cells, called **guard cells**, that line the aperture, and regulate its opening and closing. When these cells are turgid with water, they are stretched away from the pore, opening the stoma to gas exchange. When these cells are flaccid, the stoma closes.

(c) A cavity called the **substomatal cavity** or **respiratory chamber**. This cavity allows rapid diffusion of oxygen, carbon dioxide, and water vapour between the inner layers of the plant and its outer environment.

While some wavelengths of light can induce the opening of stomata; water stress, high temperatures, and high carbon dioxide concentrations can induce their closing. For example, sunlight triggers the stomata of most plants to open completely during the day, which helps facilitate the efficient intake of the carbon dioxide needed for photosynthesis. In the absence of sunlight, the stomata close, which reduces water loss through transpiration. This is also why it is widely believed that stomata remain completely closed at night. If this were true, plants would no longer be able to respire. However, we know that, unlike photosynthesis, respiration can continue to occur in the absence of sunlight. How? Plants respire at night (at a much slower rate) through stomata that are largely, but not completely, closed. In woody plants and trees, this gaseous exchange also occurs through many special raised pores, called **lenticels**, that are found on their barks.

Interestingly, the stomata (called **scotoactive stomata**) of some succulents remain completely open at night and largely closed in the day. In these plants, the carbon dioxide for photosynthesis is absorbed during the night (which is then converted to organic acids, stored in vacuoles, and used for photosynthesis in the day). This helps reduce the amount of water these succulents lose through transpiration in hot and arid climate.



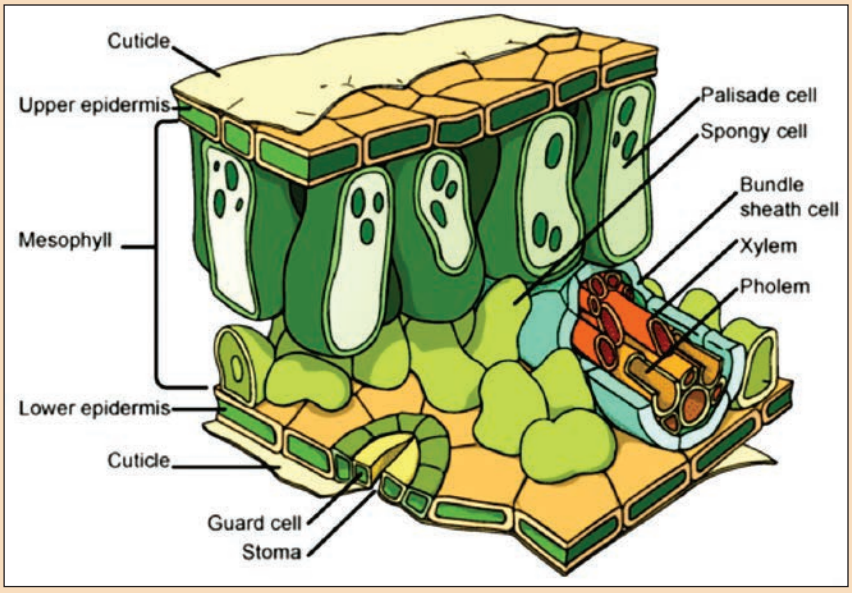
Guard cells regulate the opening and closing of stoma.

Box 2. How do leaves transpire?

Defined as a lateral, flat, thin and generally green appendage of the stem, a leaf consists of the following layers:

- The outermost layer on its upper and lower surface is called **cuticle**. This is made up of a waxy and nearly water-impermeable substance called **cutin**.
- Below the cuticle is the epidermis. This usually consists of one layer of cells (called **epidermal cells**), but can have more layers in plants that grow under very hot or very cold conditions. Its main function is to protect the plant against infection. It is also in this layer that stomata are located. Stomata are more numerous on the lower epidermis of a dicot leaf; and are found in almost equal frequency on both layers of a monocot leaf.
- The green coloured tissue that lies between the upper and lower epidermis is called **mesophyll**. This layer is composed of two kinds of tissues, called **palisade** and **spongy parenchyma**. The palisade tissue is a compact layer of cells, without any intercellular spaces. Its main function is photosynthesis. The spongy tissue is made up of irregularly-shaped cells that are

How does transpiration affect plant function? It creates a negative water pressure gradient, called **transpiration pull**, in the leaves of a plant. This gradient pulls xylem sap from the roots to the leaves (where it is used for photosynthesis), and water from the soil to move into the roots. In other words, it is because of transpiration that the water absorbed by roots reaches the extremities of even the tallest of trees. This process also helps lower the surface temperature of leaves to what is near optimal for metabolic functions like photosynthesis to occur efficiently.



The internal structure of a leaf consists of many layers of cells.

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loosely arranged into a layer with many intercellular spaces and air cavities (that are connected to the substomatal cavities in the epidermis). The main function of this layer is to store gases, sugars, and amino acids.

- The vein of the leaf consists of a tightly packed sheath of photosynthetic cells which enclose xylem vessels and phloem tubes in a structure that is called a **vascular bundle**. Xylem vessels bring xylem sap (water with dissolved minerals) from the soil to the leaf, while the phloem tubes carry sugars, amino acids, and certain hormones from the leaf to other parts of the plant.

Transpiration from leaves occurs in two steps:

1. The diffusion of water from the cells in the mesophyll into the intercellular spaces, air cavities, and substomatal cavities: we know that the water absorbed by the roots reaches the leaves of a plant through a fine network of xylem vessels. Once the cells in the mesophyll become turgid, some of this water diffuses into the intercellular spaces in the form of water vapour.
2. The diffusion of water vapour from the intercellular spaces, air cavities, and substomatal chambers in the mesophyll layer to the external environment: As the intercellular spaces and air cavities in the mesophyll layer become saturated with water vapour, the vapour pressure within the leaf becomes greater than the vapour pressure of its immediate environment. The speed with which this happens depends on how hot and dry the environment is (the hotter and drier it is, the sooner the vapour pressure in the leaf exceeds that of its environment). The difference in vapour pressure causes the diffusion of water vapour into the atmosphere through the opening of the stomata. This process continues till an equilibrium in vapour pressure is reached within and outside the leaf. The speed with which this equilibrium is reached depends on how humid the immediate outer environment of the plant is (the more humid the environment, the sooner an equilibrium is reached).

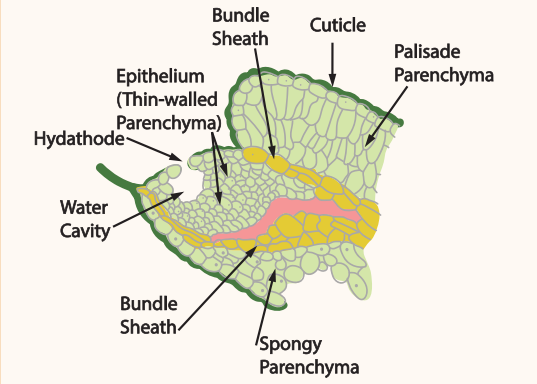
Guttation

Guttation refers to a process in which a plant discharges excess water as droplets of xylem sap from special pores, called **hydathodes** or **water stomata** (see **Box 3**).

Guttation occurs under conditions of high-water uptake and limited transpiration, like in warm soils with high humidity. Thus, unlike transpiration, this process usually happens in the night or early mornings (see **Box 4**). The roots exert a positive water pressure gradient that drives the ascent of xylem sap to the leaves. This sap is released by the xylem vessels in the vascular bundle into the proximal cavity. When this cavity

Box 3. What are hydathodes?

A hydathode is a stoma-like opening (with a proximal substomatal chamber like cavity) in the leaf epidermis, which is uncovered by the cuticle. It is different from a stoma in being larger in size, and remaining open (or unregulated) at all times. Hydathodes are found at leaf tips and margins of plants like tomato, strawberry, rose, water hyacinth, water lettuce, and many grasses.



Hydathodes are pores, uncovered by the cuticle, found at leaf tips and margins of many plants.

Adapted from https://slideplayer.cz/17948281/105/images/slide_16.jpg. Credits: Felix Byrd in his deck on Plant physiology. License: CC-BY-NC.

Box 4. How to tell the difference between dew and guttation?

Since guttation occurs in the night and early morning, it can often be mistaken for dew. Here are two important differences:

- While dew drops are smaller in size and distributed across exposed leaf (and plant) surfaces, the fluid from guttation is released in larger drops only from the tip and margins of leaves.
- While dew drops consist of water (atmospheric moisture condensing on cold surfaces), guttation releases xylem sap (moisture secreted from within the plant).

Xylem sap exuded by guttation from the leaf of a balsam plant.

Credits: Kishore Panwar. License: CC-BY-NC.

is completely filled, the sap is exuded from leaves (on drying, this exudation can sometimes leave a whitish crust on leaves). Thus, guttation offers direct evidence of root pressure.

How does guttation affect plant function? It is through this process that roots retain the lower water potential that allows them to draw water with dissolved minerals from the soil. Unlike transpiration, however, this process has no effect on leaf surface temperature.

Key takeaways

- Plants lose most of the water they absorb through their roots by transpiration and guttation.
- Transpiration is the regulated loss of water in the form of water vapour from the stomata found on the aerial parts of the plant. The rate of transpiration is highest in the day, and occurs largely through leaves.
- Guttation is the unregulated loss of water in the form of xylem sap from hydathodes found on the tips and margins of leaves. The rate of guttation is highest in the night and early morning.

Notes:

1. More details about measuring transpiration rate using a low-cost potometer can be found in another article ('My experiences with a Potometer') by the same author in the June 2021 issue of iwonder... (URL: http://publications.azimpremjifoundation.org/2848/), and the recording of an online discussion ('Experiences with a Potometer') with him (URL: https://www.youtube.com/watch?v=FzH43W89E2g).
2. Source of the image used in the background of the article title: Guttation on a rose leaf. Credits: Buntysmum, Pixabay. URL: https://pixabay.com/photos/leaf-foliage-rose-plant-dew-drops-5257161/. License: CC0.

Kishore Panwar is a retired professor of Botany from Holkar Science College, Indore. His area of interest and field of research lies in environmental science. Dr. Panwar is actively involved in teacher training programmes, and has designed many teacher– and student–friendly scientific experiments. He has authored six books on popular science, and his articles have been published in various magazines and newspapers. He can be contacted at kishore.panwar@gmail.com.

A NEW HOME FOR AJIRI

What is it about?

A new home for Ajiri is a delightful story for 8-10-year-olds that is based in Kachchh. A young chinkara fawn named Ajiri gets injured by a pack of dogs and separated from her mother. She is nursed back to health by Shivam, a young boy, and his father, who knows how to treat injured animals. Later, she is cared for by Mitti, a young girl, and her pastoralist family. The story ends with some rather dramatic scenes of reunion between Ajiri and her mother, and Ajiri's response to a poacher who fires on a herd of chinkara.

Two values form the base of this story — caring and trust. The human characters in the story (except for the poacher, of course) display a deep **caring** for Ajiri through many of their actions and decisions. And this makes Ajiri **trust** humans... to the extent that it guides her reaction to the poacher!

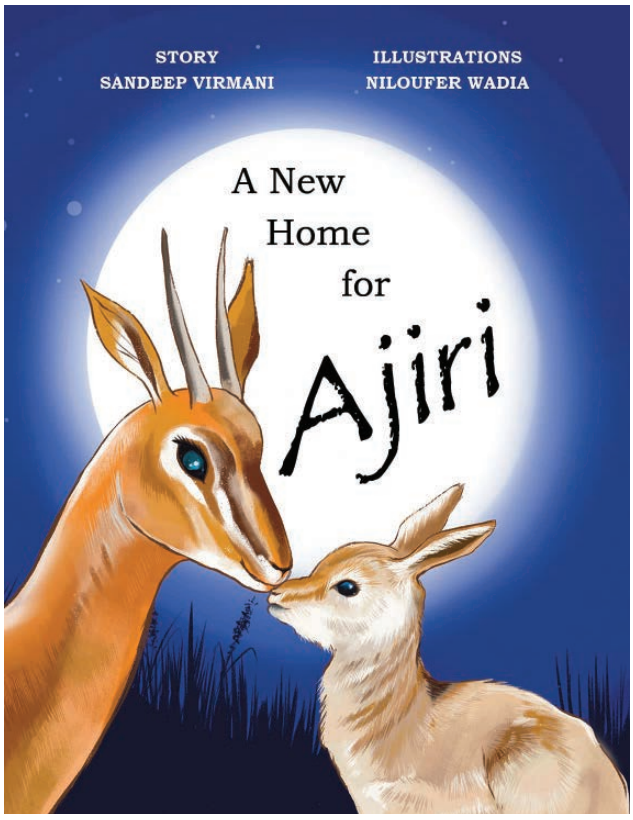
Discuss with children

Each of these values can be the basis of great discussions and thinking points for children. Here are some related to the value of caring:

- When have they felt cared for by family members or friends? What do they feel when someone cares for them?
- When have they cared for others? And what do they feel in such situations?
- Have they had or do they have a pet? How do they care for it?
- What are some different ways of caring for wildlife?
- What about plants? Is caring for plants different from caring for animals?
- Are there different ways and levels of caring for different living beings?

And some for the value of trust:

- Can they describe instances when they felt trusted by the adults around them? How do they feel when they are trusted?

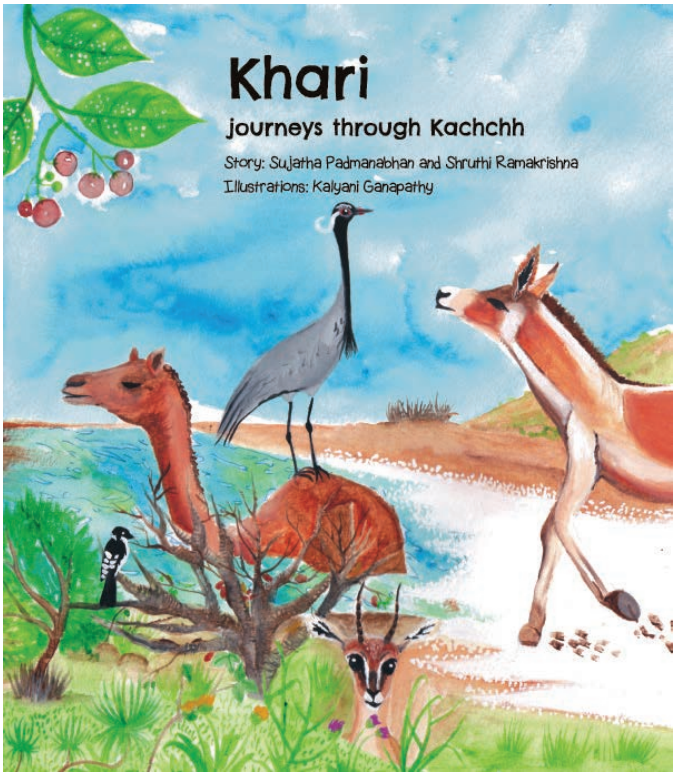


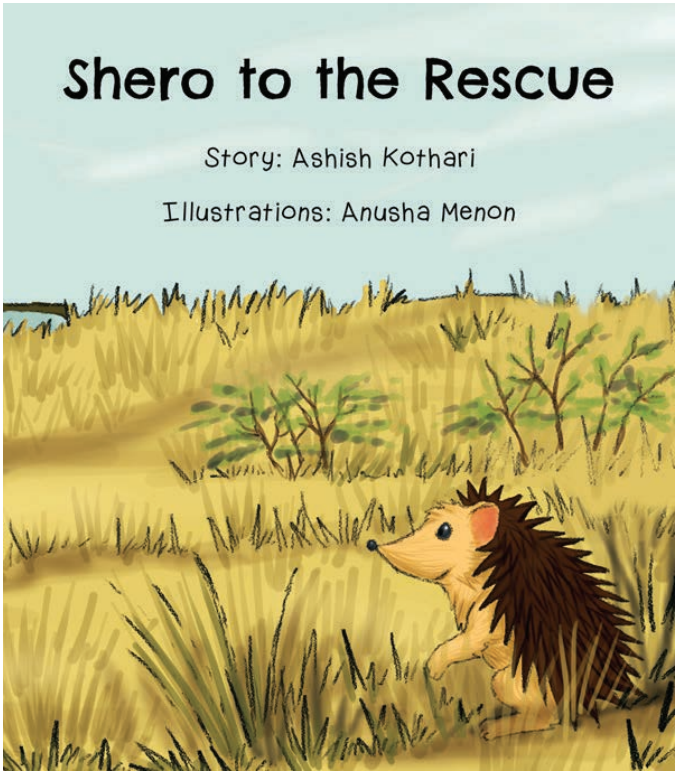
- Do they trust their friends? How have they shown it?
- Have they felt trusted by animals? Were these pets or animals in the wild? How did this trust make them feel?

This story also offers some glimpses of Kachchh and its wildlife as well as nomadic pastoralists and their simple lifestyles. The book ends with a note from the publishers about some provisions under our laws related to wildlife. This could be used to get children to think about what they should do if they come across an injured wild animal.

There's more!

This is the third story from Kachchh that has been published by Kalpavriksh. The first one titled **Khari journeys through Kachchh** introduces children to the different ecosystems of Kachchh through Khari, a demoiselle crane





that is on her first migratory journey through the region. The second, **Shero to the rescue**, introduces children to the many wild animals that inhabit these ecosystems, with a hedgehog (named Shero) as the protagonist. These two books were first published in Gujarati. All three were written as part of a larger programme by local NGOs to develop localized environmental educational material for government school children. We hope that the three books add special dimensions to children's reading programmes not only in the region, but elsewhere in India as well.

How to order

To order a copy of this 32-page book, visit kalpavriksh.org/our-store or write to kvbooks@gmail.com.

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THE STRONGER BOND

ADITI CHANDRASEKAR

Covalent compounds melt at lower temperatures than polar compounds. Does this mean that covalent bonds are weaker than ionic bonds?

We know that ionic or polar compounds such as sodium chloride have melting points close to 1000°C. On the other hand, non-ionic or nonpolar compounds, such as water, hydrochloric acid and chloroform, melt at much lower temperatures. Students often interpret this to mean that ionic bonds are stronger than covalent bonds. This would be true if melting an ionic compound weakens the ionic bond, and melting a nonpolar molecule weakens the covalent bond. But is this really the case?

Which bond is weakened or broken during melting?

We know that ionic or polar solids, like NaCl, are giant lattices held together by strong electrostatic forces between its positive (Na^+) and negative (Cl^-) ions. It is these electrostatic forces that are weakened during the melting of these solids (see **Fig. 1**). From the large amounts of energy needed to melt ionic solids, we can infer that these electrostatic forces are very strong.

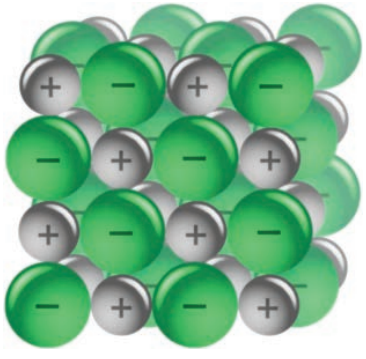

Fig. 1. A schematic representation of an ionic lattice showing the arrangement of positive and negative ions.

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We also know that the atoms in a nonpolar molecule, like HCl, are held by a covalent bond, involving a shared pair of electrons (see **Fig. 2**). However, the 17 protons in the nucleus of the larger chlorine atom exert a greater attractive force on this shared electron pair than the single proton in the nucleus of the smaller hydrogen atom. This results in a partial negative charge on the chlorine atom and a partial positive charge on the hydrogen atom. The partial negative charge on the chlorine atom attracts the positive charge on the hydrogen atom of a neighbouring HCl molecule. It is these intermolecular interactions that are weakened when HCl is melted or boiled; the covalent bond remains intact.

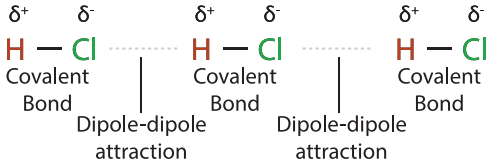

Fig. 2. Depiction of the covalent bond in HCl as well as the permanent dipole interactions between two HCl molecules.

Adapted from https://cdn.kastatic.org/ka-perseus-images/2596bfb5d1f501a78d6693d0a9bd79c17631ffb0.png. Credits: Copyright © Khan Academy's module on Intramolecular and intermolecular forces.

Thus, the low melting points of nonpolar compounds cannot be used to infer the strength of their covalent bonds. They do indicate, however, that the intermolecular forces in nonpolar compounds are much weaker than the electrostatic forces in polar compounds.

How strong are the intermolecular forces in nonpolar compounds?

To understand this better, let's take a deeper look at the structure of covalent compounds. We know that an electric dipole is created when a pair of electric charges of equal magnitude but opposite signs are separated by a small distance. Nonpolar molecules can form two kinds of dipoles — permanent and temporary.

Permanent dipoles are formed when two elements with differing electronegativities are covalently

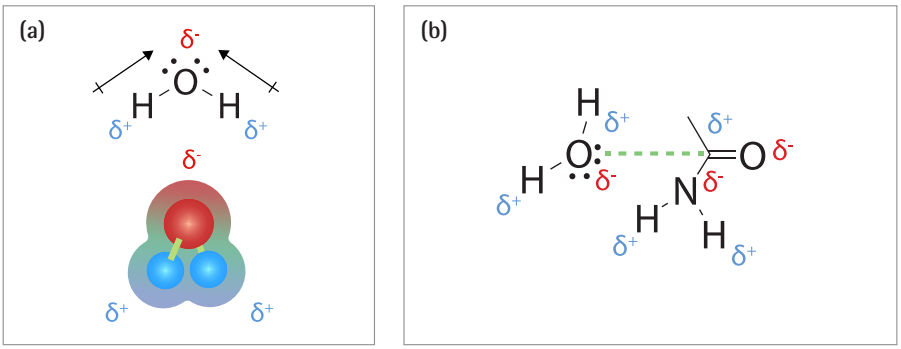

Fig. 3. (a) A permanent dipole is formed in a water molecule due to charge seperation. **(b)** Intermolecular forces between adjacent permanent dipoles are called permanent dipole-permanent dipole interactions.

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bonded, as in the case of HCl. This results in an unequal distribution of electrons within the molecule that then exerts an attractive force on adjacent molecules of the same kind. These are called permanent dipole-permanent dipole interactions (see **Fig 3**).

Temporary dipoles can be induced in a nonpolar molecule when its electrons are attracted by the positive end of a permanent dipole in its vicinity. These permanent dipole-induced dipole interactions occur between adjacent molecules of different kinds (see **Fig. 4a**). Temporary dipoles can also be spontaneously formed in nonpolar molecules (see **Fig. 4b**) when otherwise equally distributed electrons randomly move close enough to repel each other and shift away from the interaction zone (the region where they are closest to each other). This creates a partial positive charge on one end of the molecule that can then attract electrons from and induce the formation of an instantaneous dipole in a similar or different nonpolar molecule in its vicinity (see **Fig. 4c**).

In general, instantaneous dipole-induced dipole interactions are weaker than permanent dipole-induced dipole interactions, which are weaker than permanent dipole-permanent dipole interactions. But the intermolecular electrostatic force involved in even a permanent dipole-permanent dipole interaction, the strongest of these interactions, is much weaker than that in ionic compounds. Why? As we have

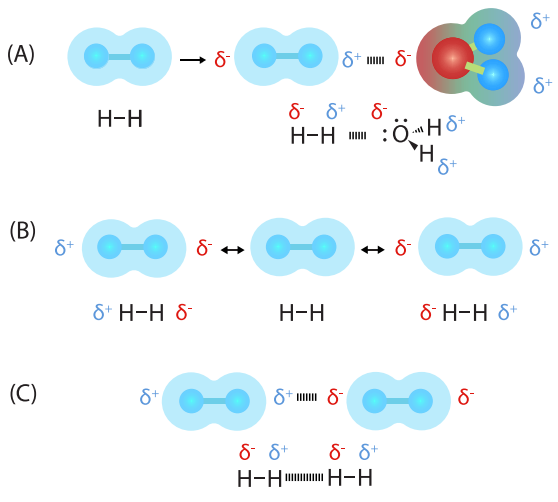

Fig. 4. (a) The permanent dipole in a water molecule induces a dipole in a hydrogen molecule and is then attracted to it. **(b)** Instantaneous dipoles can form spontaneously in nonpolar molecules, like hydrogen, due to the random motion of shared electrons in its nonpolar bond. **(c)** Instantaneous dipoles can induce the formation of instantaneous dipoles in other nonpolar bonds, which are then attracted to one another.

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seen in the HCl example, this interaction occurs between the partial positive end of one nonpolar molecule and the partial negative end of its neighbouring molecule. Thus, the force between these molecules is only a fraction of the force between the complete positive and complete negative charge of an ionic compound like NaCl.

How strong is a covalent bond?

Most covalently bonded substances exist as molecules. In diamond, however, each carbon atom is covalently bonded to four other carbon atoms, forming a giant covalent structure (See **Fig. 5**). We know that the melting point of diamond is as high as 4000°C. Since diamond is not a molecule, there are no intermolecular interactions to account for its melting point. In other words, when diamond melts, its covalent bonds break. From this, we can conclude that covalent bonds are no weaker than ionic bonds.

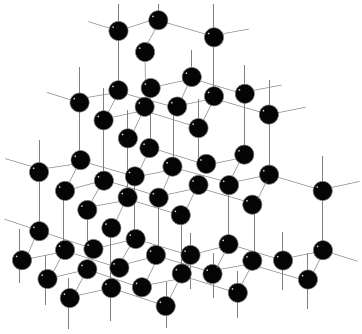
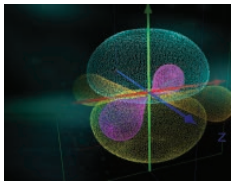


Fig. 5. A schematic representation of the carbon atoms in diamond forming a giant covalent structure. Each atom is covalently bonded with its neighbouring atoms, forming a network of bonds in an arrangement that extends in 3D space.

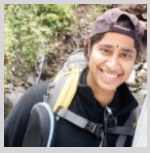
Adapted from https://igcse-chemistry-2017.blogspot.com/2017/07/150-explain-how-structures-of-diamond.html. Credits: Keisho Inoue, IGCSE Chemistry 2017.

Key takeaways



- Stronger forces require higher temperatures to weaken them.
- Since ionic solids are held together by strong electrostatic forces, they have high melting points.
- While nonpolar compounds have covalently bonded molecules, melting breaks intermolecular interactions between these molecules. The covalent bond remains intact during this phase change.
- Intermolecular interactions in nonpolar compounds are of three kinds — permanent dipole-permanent dipole, permanent dipole-induced dipole, and instantaneous dipole-induced dipole. Permanent dipole-permanent dipole is the strongest of these interactions.
- The low melting points of nonpolar compounds is because the electrostatic force in even a permanent dipole-permanent dipole interaction is much weaker than the electrostatic force in ionic solids.
- Since very high temperatures are needed to break covalent bonds, these bonds are no weaker than ionic bonds.

Note: Source of the image used in the background of the article title: Covalent Bonding Atom Orbitals. URL: https://www.maxpixel.net/Covalent-Bonding-Molecule-Bonding-Atom-Orbitals-2146393. License: CC0.



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GROWING A FOREST

ANAND NARAYANAN & RADHA GOPALAN

We know that forests help in temperature regulation, flood control, building soil fertility, supporting pollination, and carbon sequestration. But how do forests grow? Can we grow one in congested urban spaces or degraded land? Can we grow a dense forest of native species in 25–30 years?

Contrary to the popular image of forests, it is possible to rapidly restore forest cover in small spaces using the Miyawaki method. Developed by Akira Miyawaki, a Japanese botanist, this method offers a systematic approach to growing dense multilayered forests of native species within a short period of time (see **Box 1**). Each forest grown by this method is therefore a microcosm of local forests. This approach has been used in diverse locations — from small urban spaces and degraded land, to large stretches of semi-arid land — in many countries, all over the world.

Box 1. Who is Akira Miyawaki?

Born on 29th January 1928, Akira Miyawaki grew up in a farming community to Wakichi Miyawaki and Tsune Miyawaki in the Okayama Prefecture of Japan. He studied and worked as a researcher in the fields of ecology and plant biology at universities in Japan and Germany. Inspired by remnants of natural forests preserved around temples and cemeteries in Japan, Miyawaki came up with the idea of growing such forests in the 1970s. First implemented for the Nippon Steel Corporation, today there are more than 4000 Miyawaki forests spread across the world.

In Miyawaki's own words (2006), *"Rather than simply restoring forests that were there before, this work involves creating genuine native forests through rigorous field surveys and research into the ecology of the vegetation in order to ensure a future without making mistakes that have been made so far... Native forests protect the lives of all the people born and raised in the area, and the people who go to school or work there. They sharpen the senses of the people for the creation of culture and give rise to their intellect for new developments.... The conviction and the activities with which I devote myself to creating forests for life are not something that came about overnight; I hope you will look at them as the way I have lived for 78 years."* Akira Miyawaki remained actively involved in several afforestation activities till his death on 16th July 2021.

Akira Miyawaki.

Fig. 1. The soil is prepared and grids are used to designate where each sapling will be planted. Each square in the grid holds one sapling. The depth of the pit varies depending on the size of the sapling, and the plant it will eventually grow into.

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Planting a Miyawaki forest

Step 1. Analyse the soil at the location for its texture, pH, organic carbon and nitrogen content, and the presence of micro- and macro-fauna. While the last parameter can be assessed visually, soil samples will need to be sent for lab testing for the others. This step will help identify any additional nourishment that the soil may need.

Step 2. Prepare and condition the soil based on the results of the soil analysis in Step 1 (see **Fig. 1**). For example, if the top soil is too hard to allow the percolation of water, groundnut shells or the husk from wheat, corn, or rice can be used to improve porosity. Since soil moisture is crucial in the initial years of sapling growth, dry soils may need mulching with straw, coco peat etc., to retain soil moisture. Similarly, degraded soils may need to be enriched up to a depth of one metre with organic soil conditioners, like cattle and goat manure or vermicompost (a mixture of decomposing vegetable, food waste, and other decomposing organic material).

Step 3. Prepare a list of plants to be grown through visits to local forests, referring to books, or through conversations with people about local natural history. Choose native species because they are better adapted to local ecological conditions. Selecting a mix of plant species (like some flowering plants and vines, some shrubs, some tall trees with a canopy, and some trees that grow taller than a shrub or to sub-tree level) is recommended.

Step 4. Procure healthy saplings of plants from reliable nurseries, like those run by the Forest Department in many states in India. Typically, it takes three months in a nursery for saplings of forest species to become well-rooted.

Fig. 3. Coir pith is spread around the saplings to prevent the loss of soil moisture in the heat of the sun. Photo from Shantapara in Munnar, Kerala.

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Fig. 2. The saplings are procured and planted. (a) The saplings of various plants are grown in grow bags and pots. **(b)** Care is taken to ensure that the saplings of plants that are likely to grow into big trees are not planted next to each other. Photo from Thiruvananthapuram, Kerala.

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Fig. 4. Growth at different stages. (a) After 6 months. **(b)** After 12 months. **(c)** After 2 years.

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Step 5. Plant each sapling in a pit, and then cover with soil (see **Fig. 2**). The size of the pit will need to be determined based on the species to be planted, particularly its rooting system. If needed, the soil (particularly degraded soils) can be enriched with additional soil conditioners. To prevent moisture loss, mulch each sapling pit with a six-inch-thick layer of dried leaves, flakes of tree bark, wood shavings, rice straw, corn stalk, or compost (see **Fig. 3**). Support the saplings with bamboo stalks or other locally available firm supports. This method can be used to plant around 30 saplings in a 10 square meters area, as long as plants of the same species are separated from each other to avoid competition for resources (access to light, water, nutrients).

Step 6. Care for the saplings by watering them at least once a day for the first two years of growth (see **Fig. 4**). The frequency of watering may need to be increased in summer to offset any water loss due to the higher temperature. To ensure regular watering, access to a reliable water source is necessary. Depending upon the size of the forest and available water resources, a water distribution system or micro-irrigation system (drip or sprinkler) may be set up. Weeds need to be managed, again, for the first two years, after which the forest will self-regulate weed growth. Regarding long-term care, Akira Miyawaki says: *"No maintenance is the best maintenance. If a forest requires maintenance after the first 2-3 years, then it's a fake forest."*

While this method has captured the imagination of several people and organizations, the high costs of its early stages of implementation can pose a challenge. These include costs of procuring saplings, soil conditioners, and access to a water source for two years. Since this method involves dense planting, the number of saplings required to raise such a forest can further raise costs. Given that urban land is often in a degraded state, the cost of preparing the soil and land can also be quite high.

Miyawaki forests as learning spaces

This method has inspired students of some schools in Thiruvananthapuram to set up small Miyawaki forests on their campuses. Apart from being an effort in creating or restoring vegetative cover and serving to sequester carbon, such forests can also support a range of student explorations. For example, the soil investigation needed in Step 1 of growing these forests can make an interesting middle or high school biology and chemistry activity. Students can also be encouraged to observe and document plant growth, the diversity of fauna and other life forms that the forest supports, as well as any changes in microclimate at different stages of forest growth.

Key takeaways

- Dense multi-layered forests of native species can be grown in a short period of time in small urban spaces and degraded land using the Miyawaki method.
- This method was developed by Akira Miyawaki, a Japanese botanist, who was inspired by remnants of natural forests preserved around temples and cemeteries in Japan.
- When grown in school campuses, such forests not only help create or restore vegetative cover but also support a range of student explorations of interactions between the flora, fauna, and abiotic components of a forest ecosystem.

Note: Source of the image used in the background of the article title: Miyawaki forest — 9 months after planting. Credits: BemanHerish, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Miyawaki_forest_-_9_months_after_planting.jpg. License: CC-BY-SA.

Additional Resources:

1. To walk through a 15-month-old forest grown bottom-up the Miyawaki way, visit: https://youtu.be/I4tvAizYfGw.
2. For more information on the Miyawaki method, including several success stories of forests created through this method, visit: https://www.crowdforesting.org/.
3. For more specific things to consider before choosing this method: https://www.thehindu.com/sci-tech/energy-and-environment/they-grow-fast-and-easy-but-do-miyawaki-forests-meet-the-fundamental-principles-of-ecological-restoration/article65258901.ece.

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REVELING IN OUR SOUNDSCAPE

The teacher entered a classroom full of chattering students. She clapped a couple of times to get their attention. Once she had their ears, she asked them, *"What is sound?"*

Flummoxed by her sudden question, students mumbled some responses: *"It is noise"*, *"It is energy"*, *"It is just a feeling"*.

Sensing their confusion, the teacher said, *"Let's try and understand it better. Carefully observe and describe all the sounds that we are hearing in this room right now."*

The students listed the sounds of vehicles, students in the next class, drums on the street across, etc. As they continued to list the sounds around them, their observations became sharper. They started describing subtler sounds like that of the footsteps of someone walking in the corridor.

The teacher let them list more sounds, then asked *"What else do you observe about these sounds?"*

"Some are softer, some are louder", a student replied. *"Also, from the way we hear the sound, we can tell if its source is moving or stationary"*, her friend added.

"Wonderful!" the teacher exclaimed. *"Is there anything else common between all these sounds?"* she probed them further.

"I think sound is produced only when two things touch each other, for example, two vessels banging", a student observed. Her friend countered this with a question, *"But what kind of things touch each other in a loudspeaker or a flute? How is sound produced there?"*

"Interesting. Shall we play a game to see if we can figure this out?" The teacher distributed a few plastic straws, and asked the students to modify it in any way that they could to produce sound. *"Whoever creates the loudest sound wins"*, the teacher announced.

Students started blowing air into their straws and noticing the sounds that were produced. *"Great"*, said the teacher, *"Can any of you produce a louder sound?"* Some of the students tried piercing holes in their straws, others cut their edges. *"It is a little louder than the original straw,"* they shared. Another student said, *"I have noticed that a flute has many holes on its surface. I am going to modify my straw into a flute." "That's a great idea. Let's see what happens,"* said the teacher.

The class was startled by a sudden loud sound. As everyone looked around for the source, the student who had managed to produce the sound looked elated. The teacher walked over to this student's desk to look more closely at what she had done to her straw. In the meanwhile, many other students started working faster than before to get the same result from their own straws. In no time, a few more students had figured out the trick and made similar models. The trick was to cut the straw at one end to create a pair of free flaps. The class exploded with loud sounds.

As they were playing around with the different models of straws, a student observed, *"The sound produced by different straws is different. Some produce duller sounds; some produce sharper sounds."*

"That is a wonderful observation. You are saying that apart from its volume, the quality of sound is also changing in different models", the teacher said. She introduced some of the different attributes of sound, like intensity and amplitude.

Students brainstorming on ways to modify their straws to produce sound. On the right are the different designs that students came up with, each producing varying levels of sound. The one that appears second last is the one that produced the loudest sound.

As students were recovering from their sound party, the teacher posed the next question. *"How is this sound travelling from its source to our ears?"*

After some time of thinking in silence, one of them replied, *"I think sound is made up of small particles. These particles are carried from the source to our ears with the help of air"*. Others nodded in agreement.

A little surprised by the reply, the teacher asked *"If sound is made up of particles, where are these particles coming from? When we speak, are we throwing out some particles from our mouth? When we beat a drum, do particles come out from the drum?"*

"I don't think so", said a student.

Sensing their confusion, the teacher asked them to feel the free flaps of the straw as the sound was being produced. *"What do you feel?"* she asked.

"The flaps are vibrating very fast", they said with excitement.

"What about when you speak? If you touch your throat, what do you feel?"

"Something is moving."

"Very nice. So that's how all sound is produced and that's also how it travels. Particles in an object vibrate to produce sound. These vibrations are passed on to neighbouring particles, and this continues till they finally reach our ears", the teacher said. Then posed the next question: *"And can you guess what happens in our ears?"*

"Something must be vibrating!", a student replied confidently. *"I have heard of an eardrum that helps in hearing,"* someone else added.

The teacher concluded the class by telling the students about our eardrum — how it has a membrane that vibrates when sound waves reach it; and how these vibrations send signals to our brain, which we interpret as sound. The students seemed amazed by all the new things that they had discovered together about 'sounds' — even ones they routinely heard. They continued to revel in the musical soundscapes of their straw flutes and feel the vibrations of their free flaps long after the class had come to an end.

Note: The activity with straws has been adapted from Arvind Gupta's Splendid straws. URL: http://www.arvindguptatoys.com/arvindgupta/DH-AG-SPLENDID-STRAWS.pdf.

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MEASURING EARTH'S SIZE

AMOL ANANDRAO KATE

When was the first accurate measurement of the earth's size made? Who were the first people to make this measurement? How did they make it?

It is widely believed that the earliest efforts to measure the size of the earth coincided with the first voyages on the high seas. However, we now know that the first near-accurate measurement of the size of the earth was made much earlier (and more than 2000 years ago) by a Greek called Eratosthenes. Eratosthenes accomplished this feat at a time when Europe had not yet discovered continents like America, Australia, and Antarctica, or details of the Pacific, Atlantic, or Indian Oceans (see **Fig. 1**).

Who was Eratosthenes?

Eratosthenes was a scholar and philosopher, who was born in 276 BC in a town named Cyrene that was then part of the Greek Empire. This place is today known as Shahat, and is part of Libya. After an early education in his home town, Eratosthenes travelled to Athens to study philosophy and poetry. At the age of thirty, Ptolemy III, the ruler of Alexandria, in Egypt, offered Eratosthenes the position of a librarian in The Great Library of Alexandria, one of the largest and most important libraries in the ancient world. Eratosthenes accepted this offer and moved to Alexandria, where he lived till his death in 194 BC. During this period, he rose to the position of Chief Librarian, expanded the library's collection of books, and tutored Ptolemy's children.

Eratosthenes was a polymath. Not only did he make many important contributions to mathematics and science, he was well versed in subjects like geography, literature, poetry, and history. Much of his work has been lost to the ages, but we know of some of his contributions through the writings of other philosophers

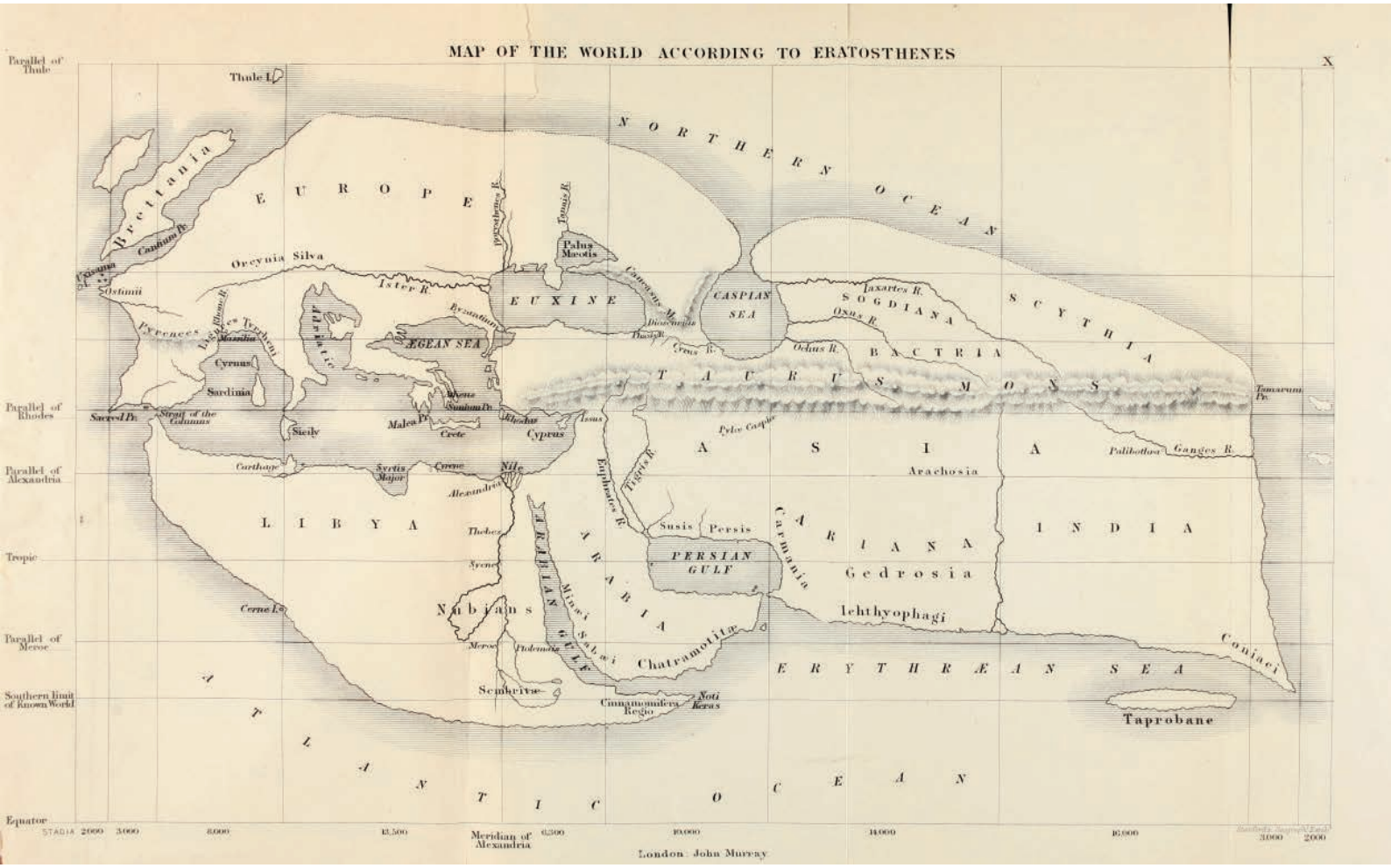

Fig. 1. A 19th century reconstruction of Eratosthenes' map of the known world.

Credits: Bunbury, E.H. (1811-1895), A History of Ancient Geography among the Greeks and Romans from the Earliest Ages till the Fall of the Roman Empire, page 667. London: John Murray, 1883. Uploaded by Sette-quattro on Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Mappa_di_Eratostene.jpg. License: CC-BY.

like Cleomedes, Pappo, and Strabo. In fact, it is Cleomedes who shares a simplified version of the method used by Eratosthenes to measure the circumference of the earth.

How did Eratosthenes measure the size of the earth?

By this time, it was widely believed that the earth was shaped like a sphere. Many people had tried to measure its circumference, but had failed. Eratosthenes used his knowledge of geometry to arrive at this measurement. He knew that objects in a town called Syene, which was to the south of Alexandria, seemed to cast no shadow at noon of a summer solstice. One could see the sun's rays shining straight down a well – its reflection fell only on the water at the bottom, and did not extend to the sides. This was because the sun was directly above (at a 90° angle) Syene at this time. Syene, now known as Aswan, is located very near the Tropic of Cancer, where the sun is directly overhead at noon around 21st June, the summer solstice of the Northern Hemisphere.

In contrast, Eratosthenes had noticed that even when the noon sun of the summer solstice in Alexandria looked as if it were directly overhead, objects around him, including a pole that he had erected, cast longer shadows than the ones he had seen in Syene (see **Fig. 2**). This difference in the length of shadows meant that the rays of the sun fell at an angle at Alexandria. He surmised that he could measure the size of the earth if he knew the distance between Alexandria and Syene, and could measure the angle by which the rays of the sun at Alexandria deviated from those at Syene. How? In the same way that we can determine the perimeter of a circle if we know the angle subtended by an arc of the circle, and the length of the arc for that angle.

Eratosthenes used a stick to measure the angle by which the rays of the sun deviated from the normal at

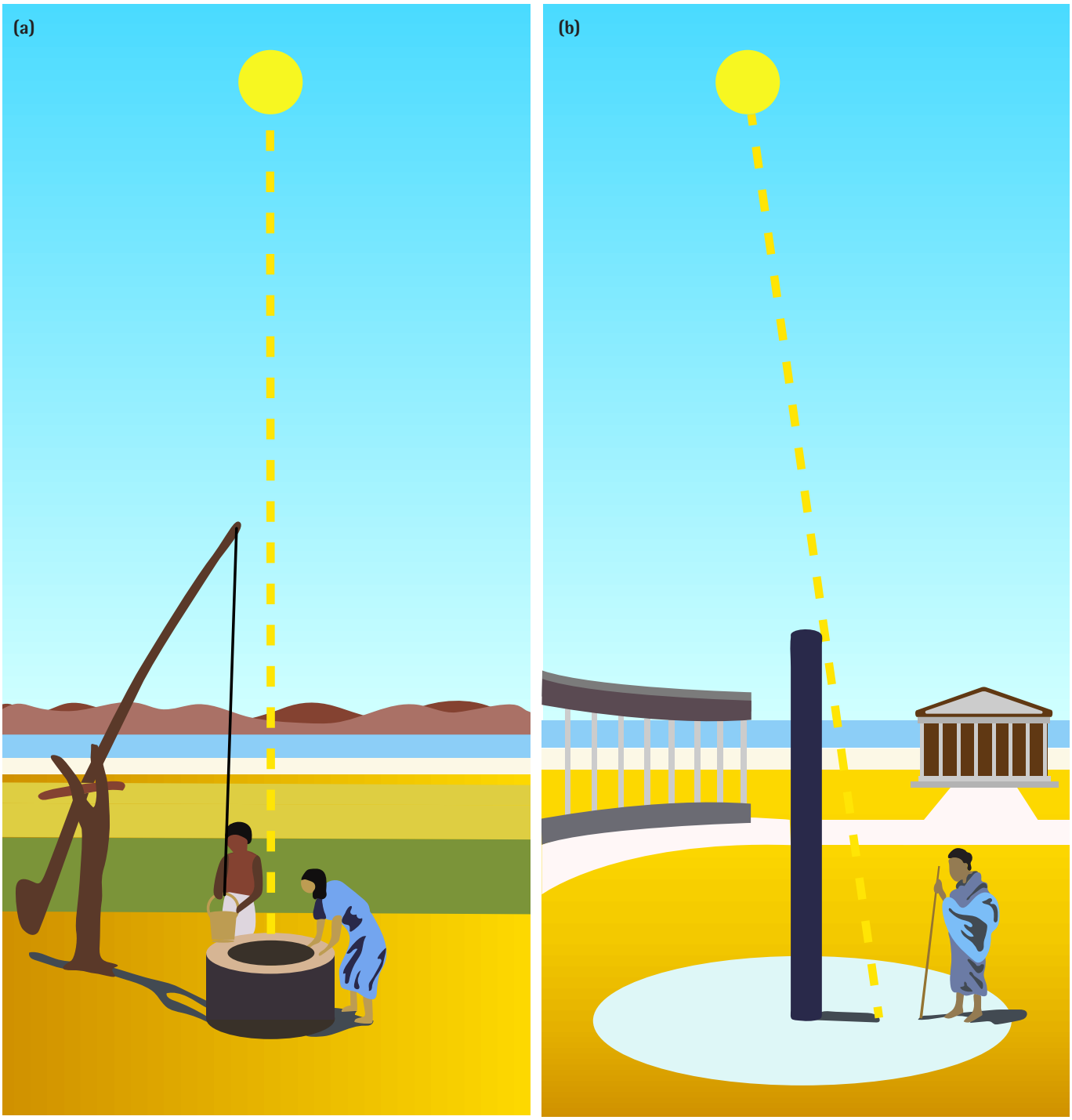

Fig. 2. Eratosthenes knew that the angle of the shadow under the noon sun on the day of the summer solstice in the Northern Hemisphere was different in (a) Syene and (b) Alexandria.

Adapted from http://karidiscience.blogspot.com/2013/03/blog-post.html. Credits: Agios Nikolaos on 'Karydis Manos'. License: CC-BY-NC.

Alexandria, and found it to be 7.2 degrees. Eratosthenes hired someone to measure the distance between Syene and Alexandria, which he learnt was about 5000 stadia (a Greek measure of distance that equalled about 157 m in Egypt). This distance was the arc of the earth's circle that was equivalent to an angle of 7.2 degrees (see **Fig. 3**). By comparing the length of the arc for this angle with that of the full circle, Eratosthenes calculated the circumference of the earth to be about 250,000 stadia (see **Box 1**). In other words,

The circumference of earth/ Distance between Alexandria and Syene = 360°/ angle subtended by the arc made by the two cities at the centre of the earth.

The distance between Alexandria and Syene = 5000 stadia.

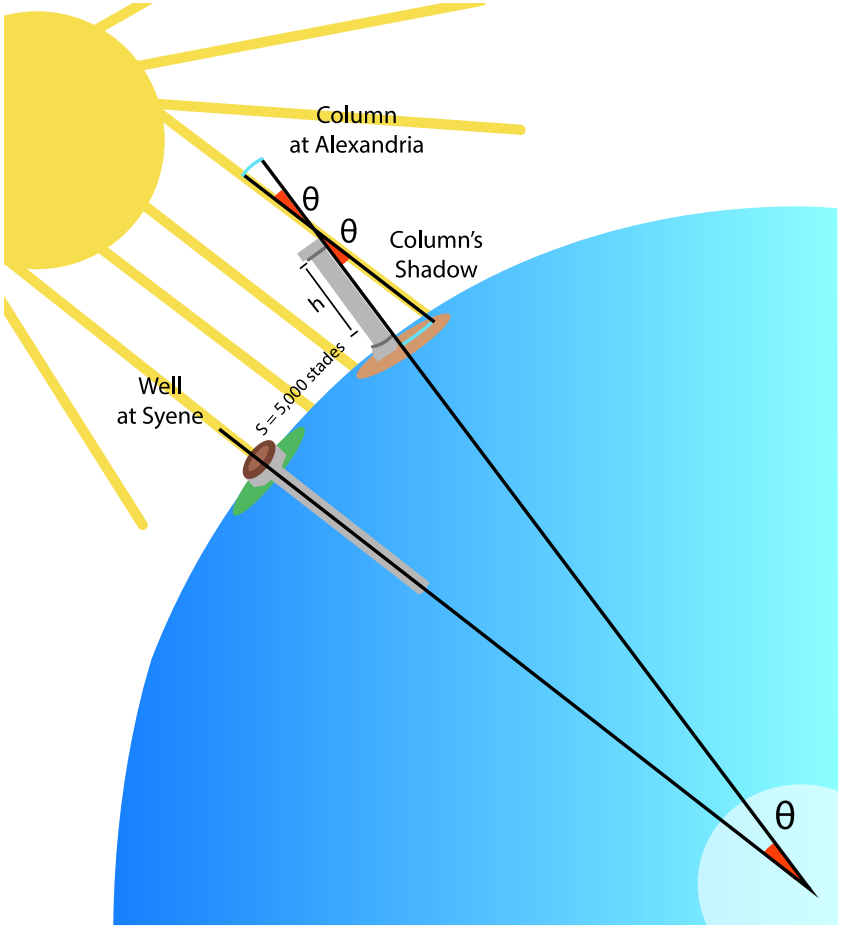

Fig. 3. Measuring the angle by which the rays of the sun at Alexandria deviated from those at Syene at noon on summer solstice. Eratosthenes made one assumption — because the sun was so far away, the rays of the sun would fall parallelly on earth. He measured the angle at which the rays of the sun fell upon a stick in Alexandria to be 7.2 degrees. Based on his knowledge of geometry, he knew that this was an alternate (interior) angle to the angle that the distance between Alexandria to Syene subtended at the centre of the earth. Thus, both angles would be equal.

Adapted from https://www.flickr.com/photos/nasablueshift/9411406224. Credits: NOAA Ocean Service Education. License: CC-BY.

Box 1. Try Eratosthenes' method for yourself

Isn't it remarkable that Eratosthenes was able to arrive at such an accurate measurement with just a stick and some elementary geometry? If you and your students would like to try his method out for yourselves, check out our **Activity Sheet** titled: **How do we measure the size of the earth?**

The angle subtending the distance between the two cities (measured by him) = 7.2°.

Therefore, the circumference of earth/5000 stadia = 360°/7.2°.

This meant that the circumference of earth = 50 × 5000 = 250,000 stadia.

The metric equivalence of Eratosthenes' measurement of the earth's circumference would be 250,000 stadia × 157 m = 39,250,000 m or 39,250 km. This is very close to the value we have today (40,075 km)!

Key takeaways

- The first near-accurate measurement of the size of the earth was made more than 2000 years ago by a Greek called Eratosthenes.
- While much of Eratosthenes' work is lost to the ages, we know of the method he used to arrive at this measurement from the writings of the philosopher Cleomedes.
- Eratosthenes was able to arrive at an accurate measurement with just a stick and some elementary geometry. Any of us can replicate this method to measure the earth's size for ourselves.

Notes:

1. Eratosthenes' method was described by Carl Sagan in this video: https://www.youtube.com/watch?v=G8cbIWMv0rI.
2. Source of the image used in the background of the article title: 'Eratosthenes Teaching in Alexandria' by Bernardo Strozzi. Credits: mark6mauno, Flickr. URL: https://www.flickr.com/photos/mark6mauno/10832052985. License: CC-BY.

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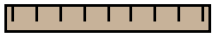
ACTIVITY SHEET : HOW DO WE MEASURE THE SIZE OF THE EARTH?

You can use this simple activity to measure the circumference of earth for yourself. To do this, you will need to know the shortest distance of your city/town/village from the equator. Your task will become easier on the two days of each year when the sun is directly overhead at high-noon at the equator — 20th March and 21st September. Since this method involves measuring angles and comparing numbers, you will need the math you learned in middle school.

You will also need:



A metre scale, or a straight stick that is a metre in length.

A flat surface on which the meter stick can be placed at an angle of 90°. Make sure that this surface receives sunlight.

A piece of chalk with which to mark the shadow of the stick.

A protractor

A long thread

A plumb line

A companion to measure the length of the shadow

What to take care of:

- Pick a day when the sky is clear. If it is cloudy, you may not see a shadow. If you are doing this activity in March, the sky is generally clear in most parts of India. If you are doing this activity in September, and the sky is cloudy, you can postpone it by a day or two.
- Use a calendar or almanac to find out in advance the time of the day when the sun will be directly overhead in your location (solar noon).
- Keep all the equipment ready 10 minutes prior to the actual activity.

What to do:

1. Set up the meter stick on a flat surface that receives direct sunlight. The stick should be vertical to the surface — you can check this with a plumb line.

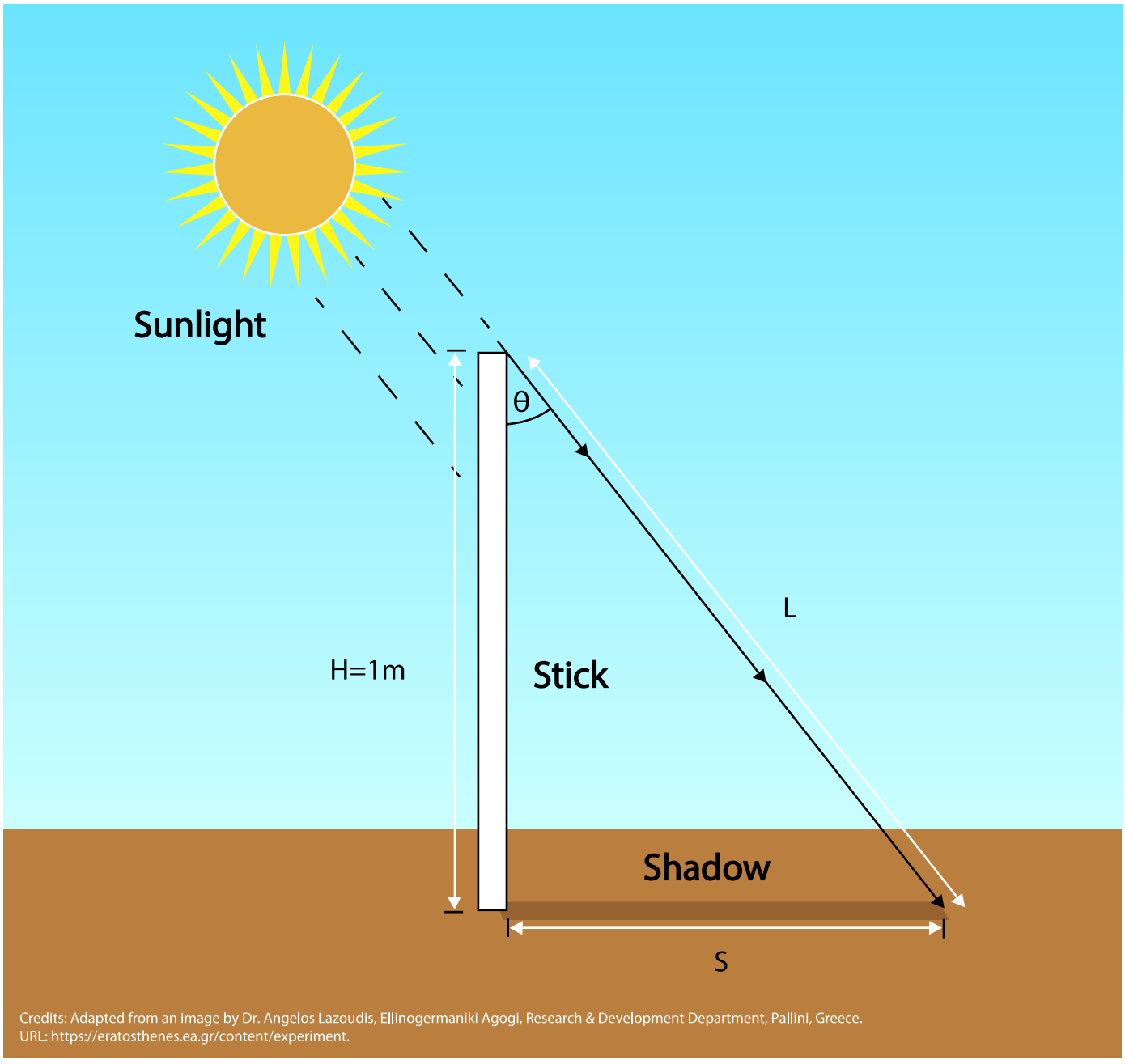
2. When the sun is directly overhead (highest in the sky), use the chalk piece to mark the length of the shadow of the stick that falls on the flat surface. In India, this shadow will be towards the north of the stick. (Why? Find out.)

3. To measure the angle at which sunlight falls on the stick, stretch a thread from the top of the stick to the tip of its shadow with your companion's help.

4. Also measure the angle between the thread and your stick with a protractor. Note it down.

5. You can use the distance of your location (town or city) from the equator to calculate the circumference of the earth using the following formula:

$$\frac{360 \text{ degrees}}{\text{Angle of the shadow}} = \frac{\text{Circumference of the earth}}{\text{Distance of your location from the equator}}$$



Credits: Adapted from an image by Dr. Angelos Lazoudis, Ellinogermaniki Agogi, Research & Development Department, Pallini, Greece.
URL: https://eratosthenes.ea.gr/content/experiment.

Think about:

- If you were to use this method to measure the circumference of the earth on different days, would the value you get be different? Why? Can you design an experiment to test your hypothesis?

- If we wanted to use this method on some other day of the year, what changes do you think we'd need to make to it?

i wonder... Rediscovering school science

Contributed by:
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Azim Premji University

ACTIVITY SHEET:
HOW DO WE MEASURE THE SIZE OF THE EARTH?

On 20th March and 21st September, the sun is directly overhead at any point on the equator. All of India is North of the equator and the latitude varies from 804' North of the equator at the southernmost point on the mainland to 3706' North of the equator at the northernmost point. All locations in our country fall within this range. This means that when the sun is directly overhead at the equator on one of these two days, a location in India at the same longitude will see the sun at an angle to the South of that vertical. In other words, at 12 noon at any location in our country, the sun would be at the highest point in its trajectory of East to West, but at an angle to the South. If we know this angle, and the distance of that location to the equator, calculating the circumference of the earth is simple.

However, depending on where we are in India in terms of longitude, the sun may not be exactly at the highest point of the trajectory at 12 noon. Indian Standard Time (IST) is the time at 82.5 degrees East of Greenwich. The sun would be at its highest point in the trajectory at 12 noon IST on all points at this longitude. At locations to the East of this, the sun would be at the highest point in the trajectory earlier than 12 noon; and at locations west of this longitude, later than at 12 noon. An almanac can tell us at what time this will happen. Alternately, if one can identify one's location on a map and its longitude, one can calculate at what time the sun will be at the highest point in that location. How? Since each degree East will add 4 minutes and each degree West will reduce 4 minutes, multiply the difference in longitude (from 82.5 degrees) by 4. Add or subtract the product from 12 noon depending on whether one is East or West of the equator.

i wonder...
Rediscovering school science

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Azim Premji University

PLACE-BASED LEARNING OF SCIENCE: EXPERIENCES IN INTEGRATION

POORNIMA ARUN & NISHANT

Our journey to deeply connect to the living-scape that we inhabit as local citizens is a long, ongoing process — collective and individual. Seen from this lens, what role does science play in a child's journey of growing up and meeting the world? How do we encourage science learning that goes beyond textbook knowledge?

"There are no unsacred places, only desecrated places" — Wendell Berry.

For the earth as a whole to matter, it is important for us to care for the place that we are in first. Our journey to reconnect to this living-scape is a long, ongoing process — collective and individual — of understanding, enjoying, and caring at deeper and deeper levels. This principle underlies a lot of the work at Marudam (see **Box 1**).

In terms of teaching, we don't always have ecology or earth science as subjects, but all the class groups take time to build relationships with the natural landscape and its lifeforms (see **Fig. 1**). This process

Box 1. An introduction to Marudam Farm School:

Marudam Farm School runs under the umbrella of The Forest Way — a registered non-profit charitable trust involved in education, afforestation, environmental education, organic farming, and more near the town of Tiruvannamalai in Tamil Nadu. The journey of the school, the campus, and the land are the result of the passion and energy of several committed individuals, and the generous support of a large community of friends and donors from all over the world.

As of 2020, Marudam hosts some 130 children between the ages of 4 and 16 years; about 30 teachers and staff in different capacity; roughly 20 residents; numerous dogs, cats, cows, chickens; and a rich, diverse, and ever-growing wildlife population of all kinds. Located on an organic farm, and spread over eight acres, land is something we constantly engage with as a rich, real-life, educational resource, integral to the learning process.

Being an immensely diverse group, originating from various cultural and social backgrounds, the richness of integration is a key element in our ethos. Working and learning closely together in such an environment, with very little formal structure, can be challenging at times. At the same time, it is endlessly enthralling, deeply rewarding, and never ever boring!

Fig. 1. Children connecting with each other, to the natural landscape, and its lifeforms.
Credits: Teacher at Marudam Farm School. License: CC-BY-NC.

of reconnecting with nature is not an intellectual exercise, but one that emerges from experience, action, and reflection. Relationships between people are as important as other relationships. If we acknowledge that we are all on a journey to reconnect with nature, then it becomes important for us to learn from and with each other. Teachers must also learn from those they teach because children often have keener senses and sensitivities. On the other hand, everyone, including children, must take responsibility for their own learning. In this sense, classes can be seen as ongoing agreements that are discussed and arrived at as a group. Seen from this lens, what is science and what is its place in education? As teachers engaging with science, how do we bring our own understanding to these questions (see **Box 2**)?

Including differences

A key principle of our core philosophy is that we value a diversity of backgrounds and family lives, both among the children and the adults. We also recognise that each child's journey is different. For example, while some children respond to the approach of science, others prefer to work on a craft, and still others come alive in interpersonal relationships. This is where we, as facilitators of learning, may question our own focus on the conceptual and make space for other forms of communication and intelligence.

In another example, the way in which some children engage with science can show a growing momentum as it comes to interconnect more and more things for them. For others, science can make lesser and lesser sense, as any disconnection with its fundamental ideas only grows bigger. In some cases, the lack of participation in science could come from an emotional block. It is for this reason that we create multiple spaces for children to share their feelings. The regular practice of a sharing circle as well as theatre classes provide a space for such expression. Parallelly,

Box 2. Some of our approaches to science education:

These are some of our approaches to the teaching and learning of science that we described in detail in the first part of this article (published in the June 2021 issue of iwonder...):

- **A ground-up approach to learning science:** The most positive aspects of science can begin with a child observing their surroundings, and asking about the how and why of different things around them. The child learns by engaging in open discussions about their observations, and connecting these to other things they have heard or read, including the body of knowledge that science has to offer. In fact, till middle school, it makes sense to mostly focus on ground-up learning. To feed a child's natural curiosity, we expose them to different things around the neighbourhood and beyond.
- **Bringing together multiple perspectives to science:** Often, it can seem as if science is the only systematic body of knowledge. Also, a lot of scientific knowledge has been created with the assumption of human mastery over the earth. These aspects of science have to be questioned as they come up and, going beyond questioning, have to be integrated as different perspectives. It is important to understand science as found in textbooks as just one form of knowledge, and recognise that emphasis on universal laws can often cause us to ignore the beautiful complexities in nature.
- **Building an understanding of context:** Apart from bringing together multiple perspectives to science, it is also important to place science in its proper context. To do this, we often have to go into its history and sociology.
- **Weaving a web of concepts:** Since all the seemingly different divisions of science are actually interconnected and rest on each other, explaining almost any concept of science often brings up ten other concepts! To address the problem of interrelated concepts all hanging in the air, it often helps to reorganise the syllabus. This can be done along themes that help us draw from the rich experiences of a child in a particular place.

teachers are encouraged to share their individual understanding of a child's learning journey with each other in the course of regular formal and informal meetings. This is important even in a child-centric system because it is possible to not notice a block in a child's overall journey when their teachers don't communicate. What is important is to ensure that the child feels okay with the disconnection. If the child is open to it, we work with the fundamentals again. If not, we accept that the perspective of science may not be part of their learning journey at the moment.

How it comes together

Despite their many differences, some things are common among the children here. There is an aliveness when they are outdoors; a vitality in their bodies which they enjoy within themselves while trekking, camping, gardening, dancing, playing sports, or doing gymnastics. They do not wait around for something external to stimulate them. They are ready to make up and play their own games. There is a deep connection with themselves that lets them take their own feelings into account even while doing things collectively. They also have a deeply personal relationship with nature that manifests itself in diverse ways. If they recognise that they'd rather be on their own for a while, they don't hesitate to perch on a rock or under a tree (see **Fig. 2**).

Even before they reach middle school, we see that children begin building on their experiences and making connections on their own. They also begin to engage with different degrees of questioning. For example, while observing a pond ecosystem, their questions are not limited to only what they can see. They are likely to envision hypothetical situations, like — what will happen when the pond dries? How does life come back when it rains and the pond fills up? There is depth in their practice of questioning, and also in the enjoyment and appreciation of things. If something, even a scientific fact, doesn't match their experience, they are not quick to agree. At the same time, they may stay open to the mismatch and keep the question alive for themselves knowing that it may get resolved in the future.

With the gradual introduction of universal concepts, we see that children start formalizing their knowledge. The study of ecosystems and the further realization that some beings are ecosystems unto themselves (a fig tree is home to hundreds of species) generates the first concrete understanding and appreciation of concepts like adaptation, reproduction, migrations, ecological niche and so on. We also see that children start to viscerally understand that they are part of a food web, and their experience of nature is altered by this realization. Even the simple facts of one's surroundings that have always been considered 'normal' start taking on a greater significance. For example, the cockroaches, lizards, and ants that have always lived in our houses are no longer seen as just creatures that we share space with; they are now perceived as being part of our own local ecosystem.

Children also begin to develop an understanding of privilege. They experience the gravity of being part of this system with more intensity and more conscious thought than before. They also begin to see, with more clarity, that human participation with natural processes is different from and more capable of causing damage than that by other living beings. This kind of understanding leads to a more personal relationship with nature — one which features empathy and responsibility as much as excitement and curiosity. This takes many forms including, for example, the deeper relationships that children in urban spaces develop with pets and houseplants.

Another aspect of this growth is that children start perceiving sensorial experiences at a deeper, more emotional level than before. For example, we observe that a younger child's experience of rain may be joyful because they love to play in the rain. In contrast, an older child can enjoy the sight of rain and other children playing in the rain internally while understanding the significance of the life support that rain provides. Many of them begin to express their connection with nature in the form of poetry and art. As their connection with nature

Fig. 2. Children at Marudam Farm School have a deeply personal relationship with nature.
Credits: Teacher, Marudam Farm School. License: CC-BY-NC.

deepens, the child becomes ready to understand more complex concepts in ecology, like biodiversity and conservation (see **Fig. 3**).

Meeting life's challenges

To some extent, science is part of each child's journey of growing up and meeting the larger world (see **Box 3**). Topics in biology often allow them to have deeper conversations about their own changing bodies, health, and medicine. The study of ecological concepts adds layers to their time in nature, adding to what they might look for and how they might share their observations. Concepts in physics and chemistry can help appreciate where many of the problems with unsustainable technology come from.

Fig. 3. Many children express their connection with nature in the form of poetry and art.

Credits: Teacher, Marudam Farm School. License: CC-BY-NC.

Fig. 4. Reaching new horizons with one foot on the ground.

Credits: Teacher, Marudam Farm School. License: CC-BY-NC.

Science also gives them a framework to talk about the changing world, and to connect everyday activities with what is happening on a larger scale (see **Fig. 4**). For example, connecting the use of motor vehicles with climate change makes them more conscious about their transport choices. Many of them also develop relationships with walking, running, and cycling.

Box 3. Challenging conditioned thinking:

Many of the practices that we see helping children negotiate life's challenges go beyond the framework of science:

- One core practice is to learn to be outdoors, and find ways to be at ease with it. Being alone in a forest, or learning to swim, or climbing a rock, or having to find one's way through a landscape when lost can bring up many fears. But they are also opportunities for growth, and this growth is deep and continuous. Even someone who's been to the same forest many times will find new ways to challenge themselves. We often experience ourselves deliberately getting lost! Something in us is attracted to it because the adventure of finding our way back is so nourishing. It builds trust in oneself, trust in the landscape, and a sense of belonging to it. There is a rock on the hill that we call *saruku parai* or sliding rock. We often go to it during our weekly walk. Scaling it brings up doubts for many of us. We learn to take up the challenge at our own pace. Some beautiful journeys have begun there, at the base of that rock.
- Another aspect that we emphasise is being open with feelings, while also being emotionally resilient. This is helped by creating safe spaces within which children can express with vulnerability where they are in their lives. Sharing about one's own journey takes reflection on their part, which in turn helps them be more conscious learners. It also encourages us to recognise, appreciate, and care for all that is supporting us — humans and non-humans. Children also learn to listen to others empathetically. This is a skill that is not very common in adults. To listen to someone without immediately responding with advice or consolation or connecting it to aspects of our own lives often takes unlearning for us.
- Questioning and examining what we see happening around us is also critical to meeting life's challenges in a way that, although aided by science, often goes beyond it. Why are we talking about pesticides, but still sometimes eating potatoes grown with it? Why are people living the way they do in the village? What decides where someone's house is? Why do some people believe that the excessive use of mobile phones can be harmful? Thinking through our and our society's most deeply entrenched habits is something each of us has to do for ourselves.

Similarly, studying about chemical and industrial methods of agriculture helps them appreciate the gardens they are tending to with organic methods as well as the food that comes from it and neighbouring farms. They are also able to talk about many of these things with their families.

For a child to meet the world on an even footing, it is also important that they feel empowered in doing positive, life-affirming work. This work could be tending to tree saplings, caring for a garden patch, collecting seeds, taking care of animals, participating in farm work, helping with the learning journeys of other children or even adults, cooking for the community, immersing in a craft, and many other things. It starts within their own local ecosystem of relationships, and slowly grows outwards.

We see that many of the practices that help children meet life's challenges are also practices that are important for a society (adults very much included) that wants to shift into a phase of being more in harmony with the earth. Our approach to science, and education in general, then becomes the same as our approach to reconnect with and care for nature.

Parting thoughts

While we have tried to share some general approaches that are practised at Marudam, there is much more to share in terms of what we actually see in specific individual and collective learning journeys. Articulating these 'experiences of integration' has been an act of self-reflection for us, and will hopefully be interesting to other practitioners.

Key takeaways

- As teachers, we should be able to help students get a grasp of the many interrelated concepts in science in a way that gives them a framework to talk about the changing world. It often helps to reorganize the syllabus by incorporating the rich experiences of our students.
- Children need to be allowed to cultivate a deep connection with themselves that lets them take their own feelings into account even while doing things collectively.
- For a child to meet the changing world on an even footing, it is important that they feel empowered in doing positive, life-affirming work.
- We also need to be prepared to accept that the perspective of science may not be part of a child's learning journey at the moment, and be ready to return to it when it is.
- As teachers, we need to be ready to question our own focus on the conceptual and make space for other forms of communication and intelligence.
- It is also important for us, as teachers, to have formal and informal spaces to share our individual understanding of a child's learning journey.

Note: Source of the image used in the background of the article title: 'Moving beyond'. Credits: Teacher, Marudam Farm School. License: CC-BY-NC

Poornima Arun is a founder member and head teacher of the Marudam Farm School, which started in 2009 with 20 children and has around 120 children now. She is involved in all aspects of running the school — from curriculum development to teacher training and administration. She has also been involved in creating innovative approaches to science in her classrooms for the past 20 years. Poornima has conducted the annual craft week at Marudam for eight years now, where traditional crafts people and artisans from all over come and teach their skills to children from various schools. She has also been an active member of the Alternative Education Network for the past seven years, and was instrumental in starting a Tamil Nadu chapter three years back.

Nishant has been learning to teach for some years now, mostly in Marudam, and over the summers at Marpha Foundation in Nepal. His interest in ecological science is matched by an equal interest in gardening and forests. He is constantly challenged by the process of bringing these together as group learning experiences. He also has a deep interest in practices of harmonious living, especially in the context of community life.

HOW DO WE KNOW
WHAT STARS ARE MADE UP OF?

Scientists identify different elements in any object, even a distant one like a star, by studying the spectrum of radiation emanating from it. Spectrum refers to the way energy is distributed among the different wavelengths of radiation, which correspond to the familiar colours in the case of visible light.

Let us understand this better. We know that the electrons that orbit the nucleus in any atom occupy fixed energy levels. When an electron drops from a higher energy level to a lower energy level, the atom releases energy equal to the difference in the two energy levels. This energy is emitted in the form of a particle of light, which we call a photon. In contrast, to make an electron move from a lower to a higher energy level, the atom needs to receive the energy difference between the two levels from an incoming photon, which is then absorbed. Photons were proposed by Einstein in the early twentieth century, and physicists accept that they can also show wave-like behaviour. Higher energy photons behave as waves with shorter wavelengths. This is why, for example, blue light, which has photons of a higher energy than red light, also has a shorter wavelength than red light. Lastly, we know that the energy levels of different levels are fixed for each element. Thus, a particular element will absorb or emit radiation at certain fixed wavelengths. These wavelengths are defined by differences in the energy levels of its atoms. We use this knowledge to analyse the spectrum of radiation emitted by an object. If certain frequencies are weaker or absent in the radiation we receive from an object, we infer that the radiation is passing through elements that absorb these particular wavelengths.

To understand how we use this to study stars, let us take the example of our sun (see **Fig. 1**). The light that leaves the sun's surface forms what is very nearly a **continuous spectrum**, one containing a range of wavelengths. However, as it passes through the sun's outer atmosphere, specific wavelengths of light are absorbed. This results in a spectrum that shows prominent absorption lines (see **Fig. 2**). Laboratory experiments show similar signatures of sodium, calcium, magnesium, iron, and other elements. We know that these elements filter out very specific wavelengths from a continuous spectrum coming from a hotter inner layer. Astronomers study these lines and match them to lines from known elements. This is how they are able to determine the gases present in the sun's atmosphere.

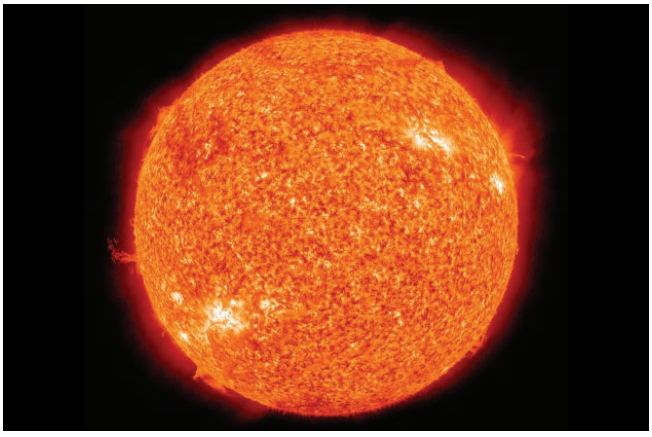

Fig. 1. An image of our sun.

Credits: NASA/SDO (AIA), Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:The_Sun_by_the_Atmospheric_Imaging_Assembly_of_NASA%27s_Solar_Dynamics_Observatory_-_20100819.jpg. License: CC-BY.

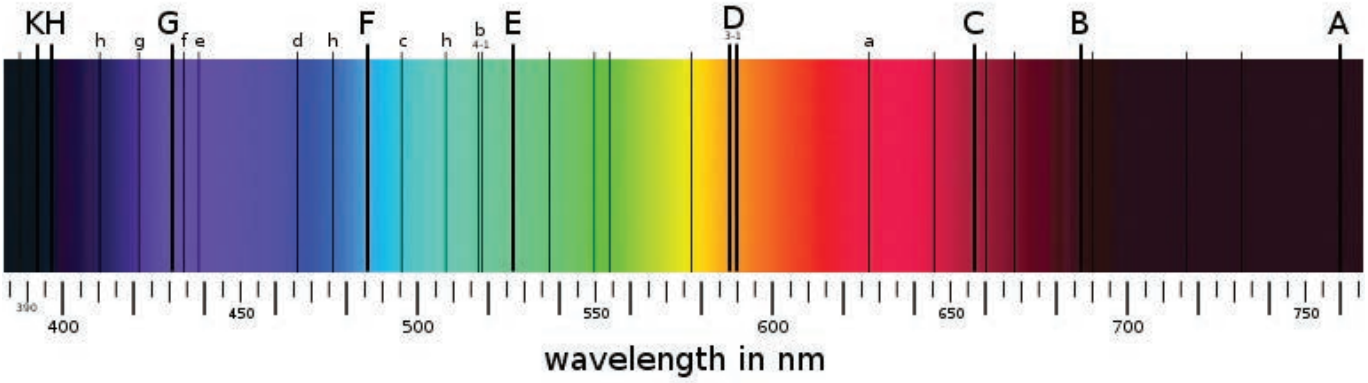

Fig. 2. Solar spectrum with Fraunhofer lines.

Credits: Uploaded by nl:Gebruiker:MaureenV & modified by Cepheiden, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:Fraunhofer_lines.svg. License: Public Domain.

But what if an absorption line in the sun's spectrum does not match that of any known element? One example of this comes from the spectra that the French astronomer Jules Janssen obtained of the sun during a total solar eclipse on 18th August 1868 from Guntur (in today's Andhra Pradesh). Solar eclipses offer a rare opportunity to view emissions from the outermost layers of our sun without the glare of the main disc. On analysis of the bands of light in this spectrum, Janssen observed a very bright yellow emission line that appeared below 588 nm. This did not correspond to any terrestrial element known at the time. On 20th October 1868, the English Astronomer Norman Lockyer spotted the same unusual yellow line independently. Lockyer identified this as a new extraterrestrial element that he named helium after Helios, the Greek personification of the sun. It was only in 1882 that the same spectral line was observed by the Italian physicist Luigi Palmieri, in the form of an almost nonreactive atomic gas, in his analysis of lava from Mount Vesuvius, Italy. This was the first indication that helium existed on earth too. This was confirmed in 1894 when the Scottish chemist William Ramsey isolated helium by treating the mineral cleveite with mineral acids. Helium is the only element to be discovered by astronomers — Jannsen & Lockyer share joint credit for its discovery.

Rajaram Nityananda taught at the Azim Premji University, Bangalore. Prior to this, he was at the National Centre for Radio Astrophysics (NCRA) in Pune, and still earlier at the Raman Research Institute (RRI) in Bangalore. He has been the Chief Editor of Resonance, journal of science education, for one term (~ three years). Much of his research work has been theoretical — in areas of physics relating to light and to astronomy and, hence, involving mathematics and/or computation. Rajaram enjoys collaborating with students and colleagues — many of them experimenters, and many outside his own institution.

CONNECTING LEARNING TO THE NATURAL WORLD

NATURE CLASSROOMS

Imagine all of nature as a classroom — a space where teachers and students observe, learn, and wonder together. What creatures and phenomena in nature will you chance upon and witness? What are some of the questions and learnings that could emerge from these experiences?

"Oh! Look how beautiful she is - look at her emerald colour!" a group of primary school teachers exclaimed as they observed the queen of the red weaver ants *(Oecophylla smaragdina)* during a short walk in the outskirts of Bangalore city (see **Fig. 1**). Twenty minutes of exploring and observing, hand lens and binoculars in tow, brought many delightful creatures and stories into sharper focus for this group (see **Fig. 2**).

The word 'nature' can evoke different images, meanings, and memories for each of us (see **Box 1**). Thus, as part of our nature learning workshops with school teachers and educators, we often begin conversations by understanding and unpacking this word (see **Fig. 3**). Going on a nature walk and creating a nature map that reflects the experience of sights, sounds, smells, tastes, textures

Fig. 1. The weaver ant (*Oecophylla smaragdina*) queen that captured the attention of the teachers.

Credits: Vena Kapoor. License: CC-BY-SA 4.0.

Fig. 2. School teachers encountered many wonders of the natural world during a nature immersion workshop organized in 2019.

Credits: Vena Kapoor. License: CC BY-SA 4.0.

and memories is a great way to begin such conversations (see **Box 2**). It can also help draw attention to the natural world that exists all around us, in every nook and corner. Even a short immersive experience, like the 20-minute walk with primary school teachers, that is focussed on paying close attention to nearby nature can leave participants with a strong, renewed sense of connection to their immediate environment. Participants often share fond childhood memories of tree climbing escapades; making friends and having conversations with various creatures; or spending hours watching birds and insects while walking to school (see **Box 3**). This is often followed by collective nostalgia, regret, and despair that similar opportunities may not exist for their students.

Teachers who are eager to introduce their students to the wonders of nature articulate several challenges — a lack of accessible outdoor spaces, permissions from school management, transport arrangements, concerns for their students' safety in public spaces especially in cities and rapidly changing towns. This raises an important question — how do we ensure that teachers and students have continued connection with their immediate surroundings? This question becomes even more relevant as we navigate the pandemic and all the challenges it poses for teaching-learning spaces.

Fig. 3. A word cloud reflecting teachers' responses to the question: "What is nature?"

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Box 1. What is 'nature'?

What images, thoughts, and memories come to your mind when you think of 'nature'?

Each of us may come with our own imagery, understanding, and positioning of what is 'nature'. This can be based on our own lived experiences, the spaces and its various inhabitants that we have explored, engaged, empathized with, and what fits in our present scheme of life and beliefs. The imagination of what a wild, ecologically rich place is for an ecologist who understands and studies this system will possibly be very different for someone who's only been exposed to nature in a hyper-urban setting. We, at Nature Classrooms, approach nature as everything that inhabits this World with us, and that we humans are part of.

As teachers and educators, let us remind ourselves not to get confused about the various terms and definitions that we encounter. Understanding these positions and accepting them is a great starting point, followed by a shared understanding that we can all learn together. Let us try and empathize, and make more meaningful connections with the mammals, birds, invertebrates, trees, shrubs, rocks, streams and all the rest of the wonderfully diverse forms of life that the earth is home to.

Box 2. Sensory nature maps:

Creating a sensory nature map is an exercise that encourages the use of our senses to focus attention on the natural world. It can help students and teachers closely observe and experience their immediate surroundings. To do this:

a) Choose a comfortable spot where you can spend some time (~ 20 minutes) in silence. This can be a neighbourhood park or garden, around potted plants and other corners at home or even views from your window, balcony or terrace.

b) Use as many of your senses (sight, touch, smell, hearing and taste) as possible to notice what is around you. Be aware of your feelings, thoughts, body sensations, and memories.

c) Describe and draw your experience in a notebook to reflect the time you spent observing nature.

Box 3. Reconnecting with nature:

If we want students to experience the wonders, delights, and secrets the natural world has to offer, we must create similar opportunities for teachers and educators. As adults we often forget the simple joy and wonder that things in nature can offer. From following a line of ants in our kitchen, to listening to birdsong outside our window, to watching a butterfly lay her eggs, to a spider stalking a pesky fly— the natural world is full of fascinating surprises waiting for us to take notice and love.

Creating opportunities for nature walks as well as nature inspired reading, writing, and discussions for teachers will be a great beginning. A few other ideas for teachers and schools:

- **Nature walks:** looking for colours, patterns, shapes, and numbers in nature is a wonderful way to familiarise and re-familiarise oneself with a school campus or neighbourhood. Documenting observations by taking photographs and nature journaling will encourage curiosity and connection for teachers.
- **Access to nature learning resources, guides, and libraries:** a curated repository of nature stories, tree, insect, spider, and bird guides among other activity ideas and resources will be a great way for teachers to continue to learn and find answers along with students.
- **Workshops, courses, and peer networks:** participating in workshops and having access to a community of teachers and educators for inspiring ideas and collective solutions to challenges is a great way to sustain nature learning initiatives in schools.

In what other ways can we reignite our love and connection with our immediate surroundings?

Nature learning as part of EVS

Environment Studies (EVS) is a compulsory subject in primary education across different boards in India, and provides a wonderful opportunity to introduce students to their immediate environment.

However, an underlying narrative in the prescribed EVS curriculum is that 'nature' exists purely as a resource for people. This creates a false dichotomy of people and nature as separate entities. For example, a Grade III lesson on forests discusses the uses of trees for humans and how deforestation would harm human life, but makes no mention of how other plants, insects, and animals interact with trees. Similarly, it is not uncommon for end text questions in EVS chapters to ask students to list the different ways in which animals or plants are "useful" to people. Secondly, the EVS textbook often presents 'nature' as an entity that can be observed only in faraway forests, high mountains, and deep oceans. The fact that our backyards, streets and even buildings and homes are teeming with wonders of the natural world is rarely acknowledged! Lastly, EVS textbooks are often devoid of examples that are relevant to the local and cultural context of students. Since students in many classrooms in India come from diverse landscapes, geographies, and cultures, this separates the curriculum from their many unique lived experiences and connections with the natural world. For instance, while a child from central India may associate rain with rare relief and a child from the north-east may see it as an everyday experience, the curriculum often does not showcase this diversity or create opportunities for these conversations and reflections.

Since the teaching and learning of this subject also often remains largely confined within the four walls of the classroom, there are few opportunities for teachers and students to discover and observe their immediate surroundings themselves. Moreover, while nature education material exists in many different forms in India, school teachers often find it challenging to incorporate these resources in a sustained manner in conjunction with the mandated EVS curriculum. This is because many common resources, like anchor charts, YouTube videos, magazine pictures and murals, often have images and information that require thorough fact-checking or are not contextually or culturally relevant (see **Fig. 4**). If you go looking for nature and wildlife resources at a local bookstore, even

Fig. 4. Existing visual material about the natural world is often not representative of the immediate surroundings of the children they are intended for.

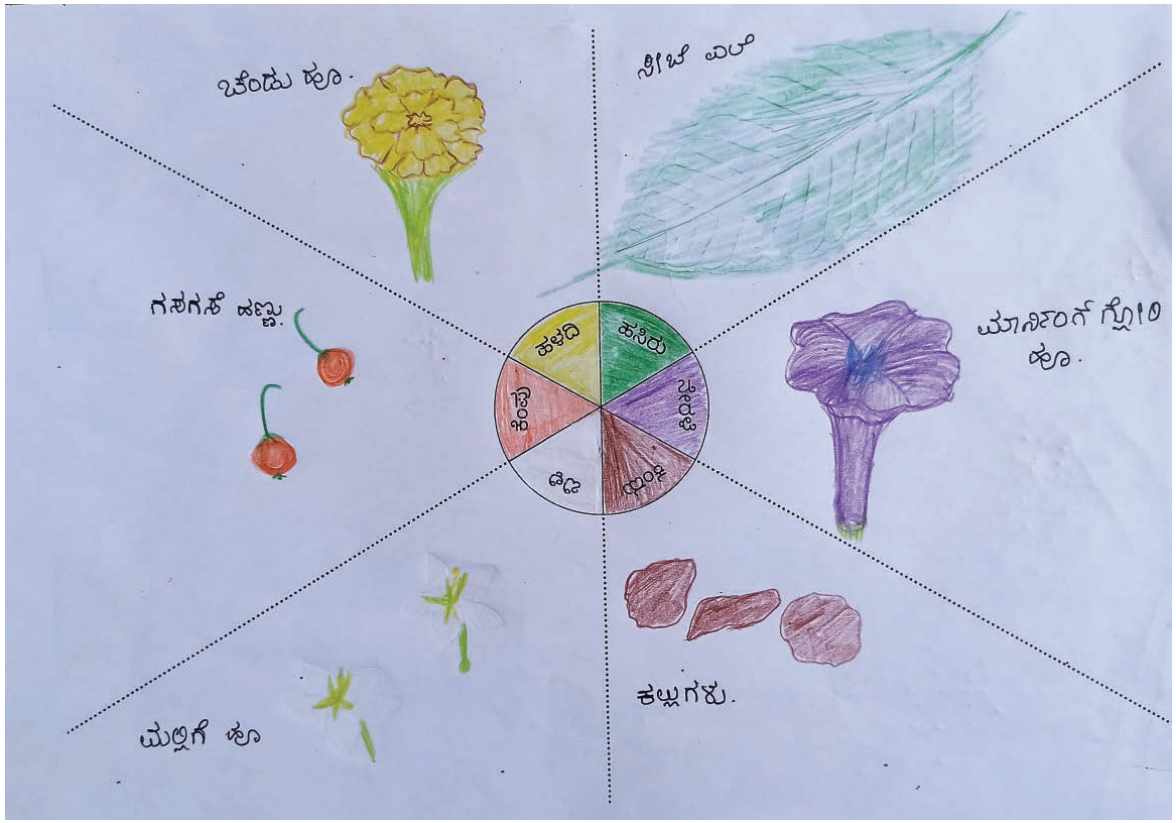
(a) Anchor chart on animals in a bookstore **(b)** Animal mural in a primary school classroom.

Credits: Roshni Ravi. License: CC-BY-SA 4.0.

Colours in Nature

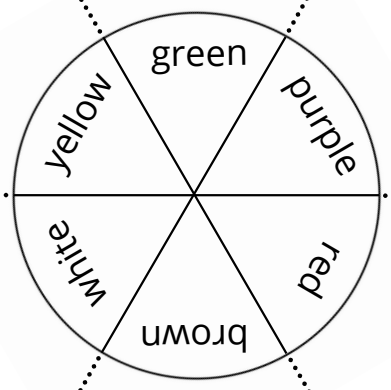
The natural world holds so many different colours — what colours can you spot in nature? Go on a colour walk near your home or school.

- Begin by filling the colour wheel with the colours mentioned in each section. Next, go on your colour walk!
- Draw and write about what you find on your walk.
- You can collect fallen leaves, seeds or flowers and create a display to show your friends and family. If possible, take a picture of your display to share with others.



Here's an example of a filled out sheet.

Credits: Gousia. License: CC-BY-NC.


green
purple
red
brown
white
yellow

in a city like Bangalore, you are likely to find posters with examples of only megafauna like tigers, elephants, rhinos and lions. They also often have visuals of animals, like giraffes, zebras and hippopotamuses, that are not found in the wild in India. These animals are likely to be visually familiar to students because of easy access to television, but how many of these creatures can students see around them? How many can they situate within their own lives and landscapes?

A nature education framework and pedagogy

Enriching and supplementing existing EVS curricula with locally relevant natural history examples, stories, and experiences can help make our and our students' bonds with nature more meaningful and lasting. During school visits over the last few years, we have found that valuing children's lived experiences and using local examples creates opportunities for independent exploration and sustains curiosity about the natural world (see **Box 4**). A child's observations and serendipitous encounters in nature can make EVS classrooms a fascinating space where questions and new learning is encouraged (see **Box 5**). With this in mind, we create age-appropriate resources across various topics that are part of the EVS curricula, and that link and build on each other.

One of these resources is a Nature Learning Framework that has emerged through conversations and consultations with educators, ecologists, and our own experience as trained naturalists and teacher practitioners (see **Fig. 5**). This resource provides a starting framework for teachers and educators who want to include nature learning as part of their education interventions. It typically progresses from more concrete, experiential activities (for young children) to introduce them to nature that is immediately

Box 4. Curiousity and wonder:

One way to encourage wonder and cultivate a culture of inquisitiveness in students is to practise an inquiry-based teaching and learning approach. Making space for student questions not only increases their sense of ownership over their own learning, it is likely to encourage them to be more curious, engaged, and creative. In fact, formulating questions is in itself a creative art that is known to facilitate learning and allow for co-construction of knowledge. Also, if encouraged by the teacher, wonderment questions can help students develop the ability to hypothesize, predict, and generate multiple explanations for natural phenomena.

For instance, when students find a chewed-up leaf, teachers can approach this by asking — are all leaves chewed up by the same creature? Did one animal do this or many? What kind of mouthparts would they have to do this — a straw like in a butterfly, or with teeth like ours?

Nature Classrooms

Nature Learning Framework

nature conservation foundation

Age Group	Goals	Approach
4-6 years (UKG + Std. 1)	To develop and create opportunities for children to experience: wonder, love, curiosity, and fun in nature	Using play, stories, songs, pictures, enactments, art/craft and immersion/exposure in nature and local experiences
6-8 years (Std. 1-3)	To provide opportunities for nature learning and engagement, develop/facilitate observation skills and encourage emotional bonds, asking simple questions and making comparisons between different phenomena in nature	Using experiential/sensorial activities, fascinating facts, stories, teacher-led demos and experiments, class discussions, sharing personal anecdotes in/about nature
9-10 years (Std. 4 + 5)	To help students make connections, develop skills of compare/contrast reasoning, asking and answering simple "why" questions, deeper learning about nature and engage with family/community and cultural experiences	Using AV material, fascinating facts/processes (Did You Know), conversations and discussions, independent and group projects, local case studies, stories, interviews, local action

Nov 2019
Working model

This framework is a guide to shifting the focus of environmental education from a largely human-centred approach to one that highlights that humans are a part of nature and the larger ecosystem.
Effective nature learning is transacted through age appropriate learning goals and moves from the familiar to the unfamiliar; from local to global.

Fig. 5. A Nature Learning Framework serves as a guide for designing age-appropriate nature learning experiences.
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Box 5. Learning from observations of nearby nature:

Like in any classroom, nature learning sessions can be filled with delightful experiences. This could include unexpected and unplanned visits by different creatures, like insects, spiders, reptiles, and birds, to the classroom or school grounds. A flowering or fruiting tree abuzz with activity during a nature walk can create excitement and lead to rich discussions. Serendipitous encounters need to be valued in everyday lessons because they hold immense potential for observation and learning.

In one such instance, a cryptically coloured dragonfly flew in, and settled on one wall of a small Kannada medium government school in peri-urban Bangalore that has almost no outdoor space. The colouration and patterns of the dragonfly were beautifully camouflaged against the school's compound wall. When we drew the students' attention towards this camouflaged insect, their responses were filled with delight at noticing a creature that was hiding in plain sight! This encounter was not part of our lesson, but was a great opportunity to talk, with even very young students, about dragonflies, other flying insects, as well as the idea of camouflage in nature. Some students observed and drew the dragonfly, some created a story or a poem, and some had interesting questions about dragonflies. There was so much that the students already knew and had observed. Rich discussions and several anecdotes followed — dragonflies in their hometowns and villages, swarms during the monsoons and around rain puddles. A brief encounter with a dragonfly on the school wall had so much to offer — a chance to listen to and value past experiences and observations, while simultaneously creating opportunities for new learning.

accessible to offering a more abstract, conceptual understanding of ecology and interconnectedness in nature (see **Activity Sheet: Colours of Nature**). We also highlight a variety of age-appropriate tools that can be used to introduce the natural world, like walks, stories, experiments, and interviews depending on the age group and space available. One example of this is a poster series on common plants, like the Giant Milkweed, Neem, and Singapore Cherry, and the various creatures that visit them (see **Poster: Giant Milkweed**).

We also recognise the need for an approach to teaching and learning about the natural world that puts students at the center of learning. Our Nature Learning Pedagogy has been developed through our own classroom observations and field experiences and, most importantly, through conversations and ideas generated with experienced teachers and nature educators (see **Fig. 6**). Its key features are that it values students' existing knowledge and lived experiences, and gives them the agency to actively ask and answer personally relevant questions while discovering more about phenomena and concepts in nature.

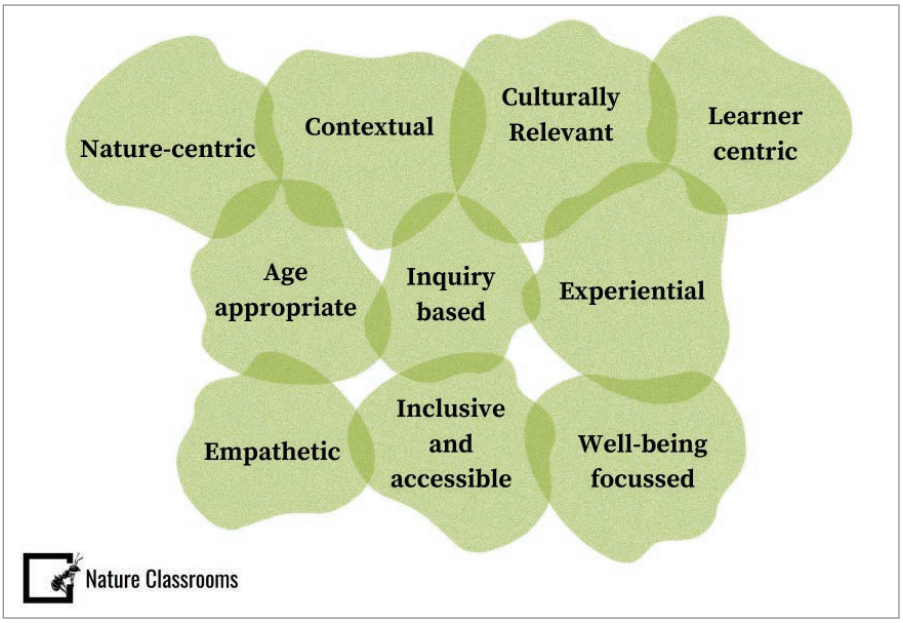

Fig. 6. Nature Learning Pedagogy: what to keep in mind while designing nature learning experiences.

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Our Nature Learning Framework and Nature Learning Pedagogy are living documents, open for review and modifications and incorporate suggestions and lived experiences.

Fostering ecological identities

We believe that learning about and forging connections with nature is as essential for young students as early literacy or numeracy. This belief stems from growing evidence that meaningful connections with and awareness of the immediate natural world are often essential ingredients for our physical and emotional health and wellbeing.

As educator Ann Pelo says, engaging with nearby nature is instrumental in a conscious cultivation of 'ecological identities' in young students. Intimate awareness of one's ecological identity and connection to nearby nature is sure to shape and determine the

relationship young people share with the earth. A deep love and connection for a place and its various inhabitants can motivate us to treasure and take action on behalf of it.

Therefore, through early immersive experiences in nature, by sharing and telling stories, and through opportunities to explore and develop a fascination for nature, we hope that as educators we can foster love, wonder, empathy and curiousity in all students. In time, it is these deep emotional connections that will translate to how all of us treat, respect, and nurture it.

Key takeaways

- The current EVS curriculum in the country presents nature as a distant entity that functions purely as a "resource" for people and is taught largely within the confines of the classroom.
- Enriching and supplementing existing EVS curricula with locally relevant natural history examples, stories, and lived experiences can help make our students' bonds with nature more meaningful and lasting.
- Offering students opportunities for independent exploration and serendipitous encounters in nature can make EVS classrooms a fascinating space where open-ended, inquiry-based questions and co-learning is encouraged.
- Nature Classrooms' Nature Learning Framework serves as a guide for designing age-appropriate nature learning experiences. It progresses from experiential activities that make nature immediately accessible for young students, and builds up to those that offer a more abstract, conceptual understanding of ecology and the interconnectedness in nature.
- Nature Classrooms' Nature Learning Pedagogy provides scope and opportunities for learners to develop wonder, love, curiousity, and a deep connection to nature.
- The framework and pedagogy are dynamic and collaborative, and based on classroom observations, conversations with ecologists, in-service teachers and experienced educators.

Notes:

1. This article is accompanied by an Activity Sheet on Colours in Nature that can be used to document observations from a nature walk. It is also accompanied by a Poster on Giant Milkweed and the many creatures that visit it.
2. Source of the image used in the background of the article title: 'A teacher creating a nature map'. Credits: Roshni Ravi. License: CC-BY-SA 4.0.

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Nature Classrooms at Nature Conservation Foundation (NCF), Bangalore, develops nature learning resources that correspond to existing primary school Environmental Studies (EVS) curricula and conducts capacity building workshops for school teachers. To see more of their work, visit: www.natureclassrooms.org and https://www.ncf-india.org/education-and-public-engagement/a-nature-learning-framework-for-schools.

PAYING ATTENTION TO WHAT CHILDREN DO: EXPLORATIONS OF SOUND

ANISH MOKASHI

What is a child's relationship with the world of phenomena? How do children engage with and explore 'stuff' in their natural and physical environment? Can this understanding inform the teaching and learning of science at school?

As humans, we are more likely to notice the things that we expect to see. More specifically, as teachers and educators, our observations of children tend to be influenced by the images and theories that we hold about them and their capacities. My experiences with teaching and learning science suggest that paying attention to how children explore phenomena, like sound, in their environment can often make us more aware of these images and bring them sharply into focus.

Exploring sound at school

My first opportunity to engage with science education came while working as a middle school science teacher in Vidya Vanam, located in Anaikatti in the Nilgiri foothills, near Coimbatore (see **Box 1**). This english medium school for children from the Irula indigenous or Adivasi community (most of whom are first generation learners) has an atmosphere of free and open dialogue between children and teachers. It is here that I first witnessed the remarkable abilities that 8- to 12-year-olds can bring to their explorations of physical phenomena.

I started a discussion on the topic of sound by inviting my students to notice the different sounds around them, at school and at home, and map these **soundscapes** on paper (see **Box 2**). The soundscapes that the children produced were quite perceptive. For example, a student who was deeply interested in birds, drew the various birds that he could see and hear

Box 1. My approach to teaching and learning science:

As a freshly minted physics PhD, my approach to science education was to bridge the gap between how science is practiced in research and how it is taught and learnt at school (and university). Therefore, I found it relevant to enter the world of teaching and learning of science the way one starts with new areas of research. This meant starting from scratch, asking questions, seeking help from peers, referring to existing literature, stumbling or fumbling at times, modifying one's questions at times, learning new things along the way, and keeping at it.

I also found that the relatively democratic nature of the teaching-learning culture I experienced in a US university (as a graduate student and while teaching undergraduate students) offered some lessons for the Indian context. This included practices like asking questions and asking for help — both of which are related to the idea that not knowing something is not a stigma; making progress in learning is what matters.

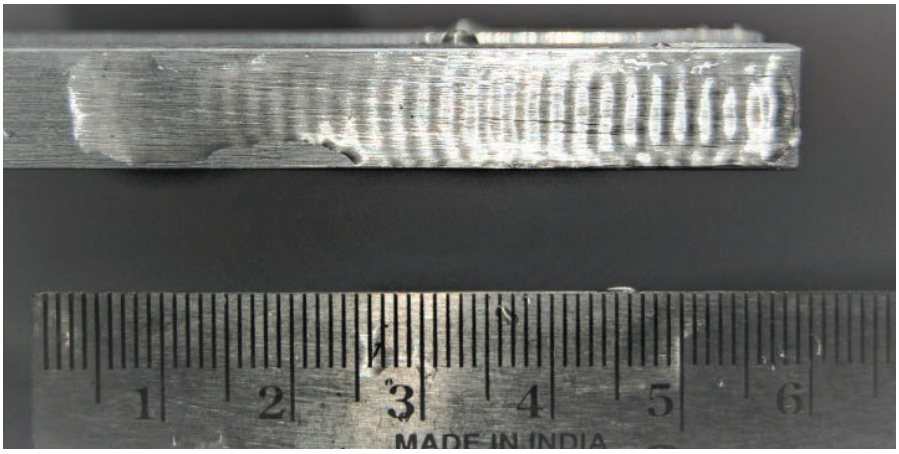


Fig. 1. Standing waves forming on water on the surface of a vibrating tuning fork.
Credits: Anish Mokashi. License: CC-BY-NC.

around his home as well as the trees that he would typically spot them on. Another student noticed 'the sound that a tube light makes in the quiet of the night'. I used this exercise to draw their attention to the fact that sound is produced when something vibrates. For example, we can see guitar strings vibrate, feel a *tabla* vibrate after we strike it, or sense the vibrations of our sound box or muscles by feeling our throats while we speak. Once we were able to reason that all sounds are related to vibrations, I proposed that the sounds we hear are nothing but vibrations that travel to our ears from the things that vibrate.

This led to the question of how these traveling vibrations reach our ears. To help them imagine sound traveling as a wave through air, I had planned a common demonstration — to hold a vibrating tuning fork to the surface of water to create ripples in it. This pedagogic device can help students appreciate how vibrations of the fork can create waves on the water surface that travel away from the fork. This can then be connected with the idea that sound (more concretely, the sound of the tuning fork) is itself a wave that travels through air. But before I could start the demonstration, the children noticed how the slanting rays of the bright morning sun were reflected from the surface of water in the bucket and projected on the ceiling. We paused for some time to marvel at how even the small drops of water dripping from our fingers created dramatic patterns of waves on the water surface and ceiling. This allowed students time to notice these waves and enjoy their aesthetic aspects.

Box 2. Mapping a soundscape:

In the school context, we could think of mapping a soundscape as an observational exercise or activity in which students take time to patiently listen to the many different sounds in their surroundings at different times of the day.[1] They could also be encouraged to walk around the place a few times. They could record their observations on a piece of paper or on the blackboard, while also spatially depicting their approximate location (relative to themselves), possible source, loudness, duration, pitch, etc.

I followed this with the planned demonstration. While we discussed our observations, I sensed that something else had caught the fancy of one of my students. He seemed to want to explore how the water in the bucket splashed around due to the vibrating tuning fork. After observing this for some time, he called me, *"Anna, see this!".* I went up to where he was stooped over, standing in a small puddle. He made the tuning fork vibrate as he had seen me do for the demonstration, but poured water on it instead of touching it to the water surface as I had done. I watched, dumbstruck at the pattern of standing waves forming on the water on the vibrating tuning fork (see **Fig. 1**).[2] He said something along the lines of: *"Are these waves too?"* Since I had not anticipated this, it took me some time to recognise these as gravity-capillary waves, in which both gravity and surface tension play a role. I appreciated his exciting 'discovery' and helped him share it with the other students.

A few days later, I wondered out loud if we could somehow see sound. We had been talking about how sound waves may not be visible because of air being transparent. After some tentative responses, one of my students had a Eureka moment and shouted out "Powder! Powder!" We sprinkled some talcum powder on an upturned steel plate and touched a vibrating tuning fork to its sides (see **Fig. 2**). This gave rise to a pattern of mounds of powder that led another student to remark with

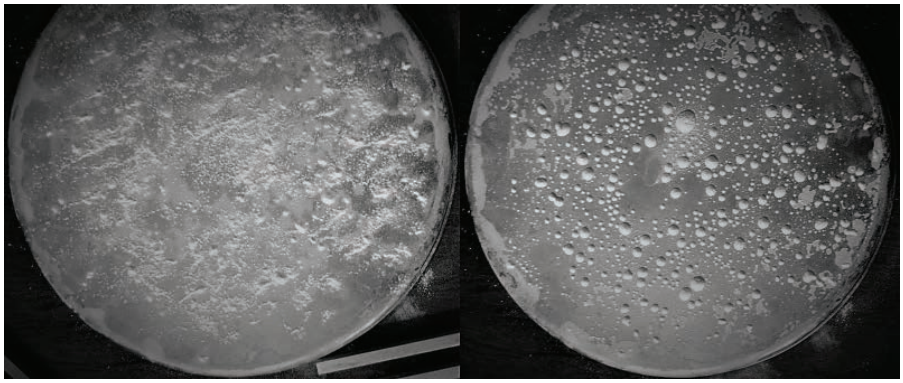


Fig. 2. Mounds of powder making a pattern on a steel plate after touching a tuning fork to it.
Credits: Anish Mokashi. License: CC-BY-NC.

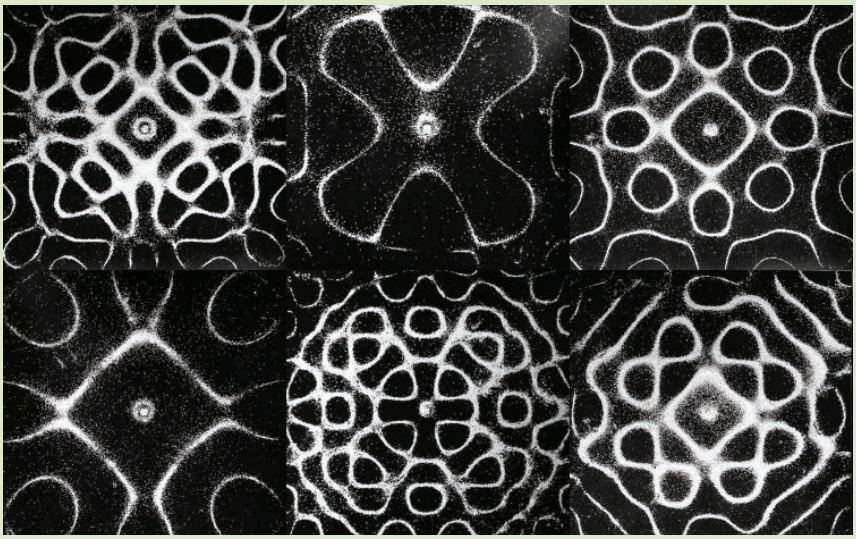
delight: *"It looks like a butterfly!"*. I was reminded of Chladni figures (see **Box 3**).

In a few days, a student extended the idea of visualising vibrations by sprinkling some powder on the flat surface of a vibrating tuning fork. The powder collected in a straight line of mounds, and seemed to circulate within each mound (see **Fig. 3**). A few years after this incident, I found the same phenomenon mentioned in Michael Faraday's book 'Experimental Researches in Chemistry and Physics' from 1859. Faraday describes it as, *"If a tuning-fork be vibrated, then held horizontally with the broad surface of one leg uppermost, and a little lycopodium be sprinkled upon it, the collection of the powder in a cloud along the middle, and the formation of the involving heaps also in a line along the middle of the vibrating steel bar, may be beautifully observed"*. This phenomenon is related to Chladni figures as well as to the flow of induced air currents near the surface of a vibrating tuning fork. It also happens to be an active field of research within acoustic streaming and interfacial science. Going further, the student also found out that if we tilt the tuning fork slightly downwards, the mounds of powder start moving up the incline, against gravity.[4] Since I have not found any mention of this phenomenon in scientific literature yet, it could be a novel observation.

Box 3. What are Chladni figures?

Named after the 18th century German scientist Ernst Chladni, these figures are patterns formed by a powder-like or grainy substance on the surface of a vibrating plate, membrane or sheet. Standing waves are formed on vibrating parts of the plate, and the powder collects in regions where the plate does not vibrate (called nodes or nodal regions).

The vibration frequency at which this occurs is one of the resonant or natural frequencies of the plate, which depends on its shape (say, circular, rectangular, etc.), its thickness, and the material with which it is made.[3]



Chladni patterns formed by powder or sand on a plate vibrating at different resonant frequencies.

Credits: Chris Smith. URL: https://www.flickr.com/photos/cjsmithphotography/8800645088/. License: CC-BY-NC-SA 2.0.

Exploring sound at home too

Do such explorations of sound occur only during activities planned by an adult? In response to this question, I would also like to share some instances of spontaneous or unplanned explorations of sound by my daughter that I was able to observe quite easily.

On one occasion, my daughter (who was a little over three years old at the time) was loudly humming a tune while holding a balloon. Suddenly, she thrust the balloon into my hand, brought her face close to it, and with much excitement started humming again. I could feel the balloon in my hands vibrate. To test the possibility that this vibration was caused by an air draft, I asked her to hold a sheet of paper between her mouth and the balloon. I could still feel the balloon vibrate, which meant that it was caused by the sound of her humming. Later that year, I used this experience to design an activity for high school students in a blended learning module for the Connected Learning Initiative (CLIx) at the Tata Institute of Social Science (TISS), Mumbai. This activity can be used to encourage students to explore sound and its propagation using a balloon (see **Activity Sheet: Vibrating Balloon**).[5]

My daughter shared another such observation more recently, when she was playing with a drum made of a rubber balloon stretched over a cup.

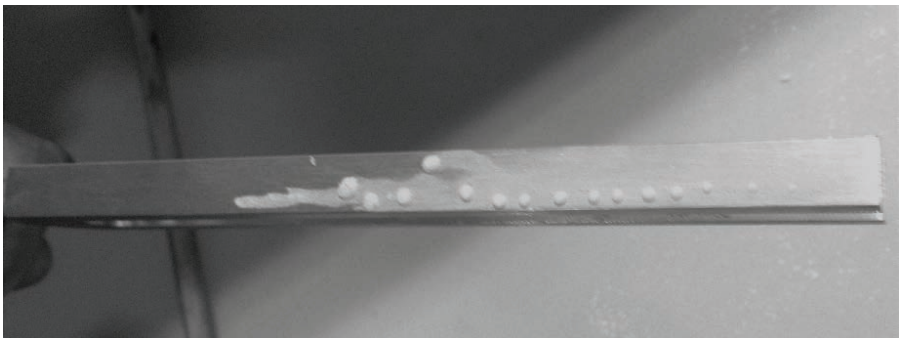


Fig. 3. Mounds of powder forming in a line on a vibrating tuning fork.

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Box 4. What do we mean by protoscience?

The term 'protoscience' is used to refer to science in its formative stages. This involved explorations of natural phenomena by processes that did not begin as but gradually evolved into the formal processes that we associate with science today. These included making careful observations of phenomena, performing experiments, making measurements, or using mathematics to describe things. Why is this relevant in science education? Many of the naive conceptions that children and adults have about phenomena were at some time, in the history of science, widely accepted explanations. Recognising such connections between children's efforts and the work and ideas of early thinkers from the history of science could help bring a flavour of the process of science into the act of learning science in the classroom.

She showed me how the drum made a resonating sound when she blew air over the rubber diaphragm in a certain way.[6] This may have been because the frequency of the diaphragm's oscillations matched one of the resonant or natural frequencies of the drum cavity/cup.

Paying close attention to what children do

Having witnessed these instances of children seeming to stumble upon non-trivial phenomena, I started observing children's explorations of phenomena more carefully. I also wondered if I may have been underestimating children's capabilities and overlooking other such explorations that may have happened right before me. This is not to suggest that we, as teachers, romanticise children and their abilities, but merely to emphasize the need to recognise them for what they are. While children may not be able to grasp mathematically abstract and complex theoretical aspects of phenomena, exploring and noticing finer details of the same certainly seems to come easily to them.

What we teach as science at school is the result of a social process — people being curious about physical and natural phenomena; exploring them in creative ways; borrowing, exchanging and debating ideas with others; thinking and rethinking hypotheses, concepts, and theories in the light of new experiments. As teachers and educators, acknowledging the seeds of a similar process within children too may provide us with opportunities to help students deepen their engagement with phenomena and concepts. We may be able to leverage children's capabilities in creatively exploring and interpreting physical phenomena to link the **learning of science** to the **doing of a kind of protoscience** (see **Box 4**). This may allow students to develop a personal connection with science and make its process their own. Just as one appreciates a good poem, one may also feel an affective connection with phenomena that one has experienced aesthetically. Besides, come to think of it, wouldn't fascination with phenomena be a good enough reason to want to keep studying science?

In addition, it may offer an approach to work on two important recommendations of the National Curricular Framework (2005) Focus Group on the Teaching of Science. One of these recommendations is to 'stimulate creativity and inventiveness in science'. The other is to help children build familiarity with phenomena till the middle school level (and to work on abstract concepts and theories related to these phenomena in high school). Recognising how different children engage with phenomena may help us to think of many possible ways to reach these goals. We may also discover that children are already quite good at some of these things, and all we need to do is to facilitate such processes further to 'make learning visible' (see **Box 5**).

Lastly, being aware of and open to such possibilities when children work with the physical-natural world may have value in setting the foundations to accord dignity to students and to their efforts within school and outside it. It may provide us with the opportunity to introduce science as a creative and social endeavour, and invite children to participate in this endeavour, to whatever extent possible. It may also allow us to move towards a more democratic discourse around science in the classroom. Thus, paying close attention to these aspects might help us design better teaching and learning experiences around school science (see **Box 6**).

Box 5. What do we mean by 'making learning visible'?

Drawing from the educational practices and perspectives from the municipal preschools of Reggio Emilia in northern Italy, this involves documenting and displaying children's work to 'make learning visible' for them, their parents, and teachers. This documentation is used to anchor a collaborative dialogic process of pedagogical reflection for improving teaching-learning, for building on children's work, and for facilitating continuous teacher professional development in small groups at school. It is accompanied by some other philosophical positions and pedagogical practices that may be suitable to adapt for the teaching-learning of science at the middle school level — the 'hundred languages of children', 'the pedagogy of listening', as well as the practice of observing children.[7]

Box 6. Did you know?

Finland has adopted a phenomenon-based learning approach to ensure that learning does not remain at a hypothetical level; students are able to apply it to their real-world contexts too. This approach also helps students appreciate internal consistency in any domain of knowledge and interconnections between different domains that are otherwise demarcated into separate subjects at school.

Parting thoughts

In an article written in 2005, Prof. Yash Pal had called for working towards a child-inspired education system.[8] Perhaps this excerpt from his foreword to the National Curricular Framework (2005) is a good place to conclude: *"Since children usually perceive and observe more than grown-ups, their potential role as knowledge creators needs to be appreciated. From personal experience I can say with assurance that a lot of my limited understanding is due to my interaction with children."*

Key takeaways

- Children notice minute details and nuances of physical-natural phenomena; they sometimes stumble upon novel phenomena that teachers and educators may not have seen before.
- Paying close attention to what children do (and say) while exploring phenomena reveal interesting aspects of their engagement with the world around them and of how they make sense of things.
- Being cognizant of children's facility in exploring phenomena and documenting their work could help us think of creative ways of teaching science at the middle school level.
- Such efforts could also help to personalise a subject like physics that many students find daunting.

Acknowledgements: I thank Srimurugan V, my former colleague at IISc, for his help in capturing the images in Figures 1 and 3. I would also like to acknowledge contributions by Honey Singh and Dinesh Kumar Verma, my teammates at CLIx, with whom I worked to develop the TISS module on Sound. Lastly, I thank the reviewers for their detailed feedback and suggestions to improve an earlier draft of this article.

Notes:

1. An article describing some of these experiences of witnessing children exploring phenomena has previously appeared in Sandarbh in Nov-Dec 2014. URL: https://www.eklavya.in/pdfs/Sandarbh/Sandarbh_95/23-36_Science_With_Children.pdf.
2. Source of the image used in the background of the article title: Child playing drums. Credits: Junuka Deshpande. License: CC-BY-NC.

Additional references:

1. Read more about how to design an activity to encourage children to create soundscapes here: https://www.nationalgeographic.org/activity/soundscape/.
2. Watch a short video clip of standing waves forming on water on the surface of a vibrating tuning fork here: https://www.youtube.com/watch?v=0UbH9nhjhR8.
3. Read more about Chladni figures in this post from the Scientific American: https://blogs.scientificamerican.com/but-seriously/chladni-figures-amazing-resonance-experiment/.
4. Watch a short video of the mounds of powder moving up the incline against gravity here: https://www.youtube.com/watch?v=nOLmc0pUesY.
5. Find an activity to explore sound and its propagation using a balloon here: https://clixplatform.tiss.edu/sound/course/activity_player/59b7e5272c4796015b350c69/59b7e5312c4796015b350d0c/. You could browse the entire module for other ways of teaching concepts related to sound. Links to download a student workbook and a teacher handbook can also be found on this online platform.
6. Watch a short video clip of how blowing air on the drum produces a resonating sound here: https://www.youtube.com/watch?v=cWd3SpSubUc.
7. Read more about the philosophical approach, pedagogical ideas, and educational practices from Reggio Emilia here: The Hundred Languages of Children: the Reggio Emilia experience in transformation. Carolyn Edwards, Lella Gandini and George Forman (editors), Praeger, Santa Barbara, California, 2012.
8. Read the complete article by Prof. Yash Pal here: For a child-inspired education system, The Hindu, September 6, 2005. URL: https://www.thehindu.com/todays-paper/tp-national/for-a-child-inspired-education-system/article27462698.ece.

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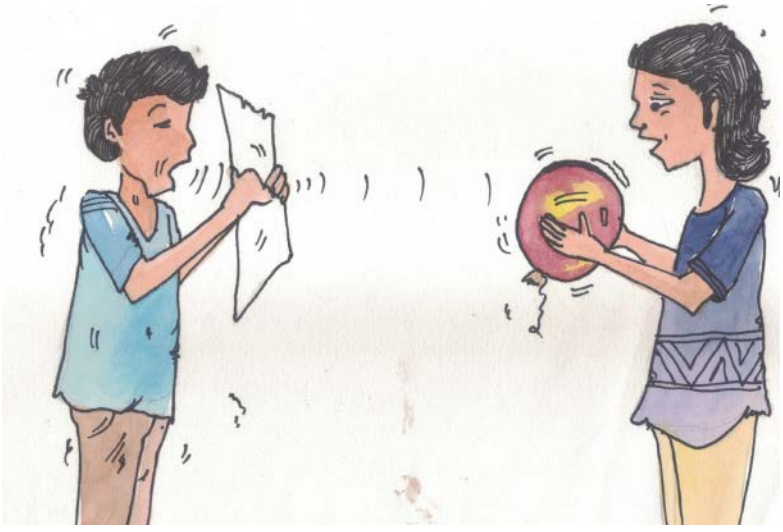
The Science Educator at Work

ACTIVITY SHEET : VIBRATING BALLOON

Hold a balloon in front of your friend's face and ask your friend to shout "ouuu" in a loud voice.



Q. What happens?

Q. Why do you think it happens?

Q. Is it due to the air that comes from your friend's mouth?

Hold a paper or a notebook between the balloon and your friend's mouth to block the air. Now ask your friend to shout again.

Q. Do you still feel the vibrations?

Take two steps away from your friend. Ask them to shout.

Q. Does the balloon still vibrate?

Q. Do you want to do something else with the balloon that is related to this activity/to sound?

Note: This activity was first published here: https://clixplatform.tiss.edu/sound/course/activity_player/59b7e5272c4796015b350c69/59b7e5312c4796015b350d0c/. This copy is shared here with the permission of the author.

i wonder... Rediscovering school science

Contributed by:
Anish Mokashi, who works with the Physics and Teacher Education groups at Azim Premji University.

Azim Premji University

ACTIVITY SHEET: VIBRATING BALLOON

1. This activity was originally designed for high school students.
2. The time requirement for the activity is one block period.
3. Since this activity involves shouting at a high pitch, it might be advisable to perform it outdoors or in a place where other classes are not disturbed.
4. The various discussions following the activity would need to be guided to some extent. Hence, it may help to have a co-facilitator.
5. Pair up the students, and give a balloon and a sheet of paper to each pair.
6. Preferably, give out the instructions and questions one at a time; moving on as and when they finish a given task. These could be written on a blackboard or passed on as chits of paper.
7. Encourage each pair of students to record their responses to the questions on a sheet of paper. Clarify that this exercise is not about getting 'the right answer'; rather it is an invitation to think, discuss, and record their ideas.
8. After each group of two has finished the entire activity, many such groups could be merged into a larger group, so that there are around 6 to 8 groups in all. Each such large group could be given 15 minutes for discussion. They could read out their responses as well as any observations and ideas that they may not have written down. Encourage students to ask each other to clarify the meaning of their responses. At the end of 15 minutes, invite the larger groups to share a summary of their discussion.
9. Record interesting or unique points and questions from each group presentation on the blackboard. These could be taken up for further discussion with the whole class.
10. Some groups may have performed variations of the activity (you would have to be on the lookout during the discussions) or might have ideas for an experiment to extend some ideas. Invite them to share these too at this point.
11. Invite a few students to emphasize the main points that emerged from the activity and the discussions. It is possible that the answers to some questions or extensions of experiments may not be obvious at this point. These can be taken up later to connect this activity with other concepts related to sound, or/and as project work.

i wonder... Rediscovering school science

Contributed by:
Anish Mokashi, who works with the Physics and Teacher Education groups at Azim Premji University.

Azim Premji University

WHEN IS NOON?

Can you tell when noon is? Maybe you've heard that noon is when the sun is at its highest point in the sky. Is the sun highest at 12 PM IST (see **Box 1**) for you?

Box 1. Indian Standard Time (IST):

This is calculated at a central place in India, 82.5°E, close to Prayagraj (Uttar Pradesh). This is the time we set all your clocks and watches and phones to. Generally, the closer you are to 82.5°E, the closer your local noon will be to 12 PM IST.

Generally, the sun is highest at your location before 12 PM IST if you are in the eastern part of India, and after 12 PM IST if you are in the western part of India. So 12 PM IST may not be your local noon.

But how do you know how high the sun is? You can't just look at it and tell, because you should NEVER EVER look at the sun directly!! But you can always look at your shadow to know how high the sun is. The higher the sun is, the shorter your shadow will be. In other words, local noon at your location on a particular date is the time of the day when the sun is highest in the sky and your shadow is the shortest. How do you find out when is local noon for you?

(A) Measure your shadow

Measure your shadow regularly between 10:30 AM IST and 1:30 PM IST. Your local noon is when your shadow is the shortest. (Note: the length of your shortest shadow may not be zero!) Your shortest shadow may be before or after 12 PM IST!

Shadows are the shortest first in Aizawl (Mizoram), then in Jabalpur (Madhya Pradesh), and then in Bhuj (Gujarat). But shadows are shortest around the same time for Nainital (Uttarakhand), Jabalpur (Madhya Pradesh), and Puducherry (see **Fig. 1**)! Can you tell how local noon changes from East to West and North to South?

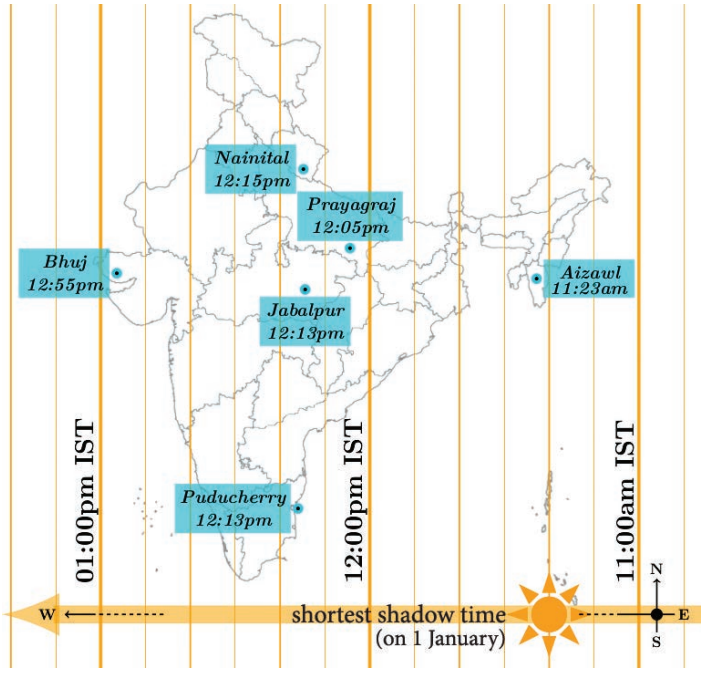


Fig. 1. You can find your location on this map (*approximate map/locations) showing the time of shortest shadow in different places in India.

Since the sun rises towards the East, places towards the East (like Aizawl) will see the sun rise before places towards the West (like Bhuj). Similarly, places on Eastern longitudes will also have the sun highest in the sky before places on Western longitudes (see **Box 2**). So local noon is earlier in eastern parts of India and later in western parts of India. For places on the same longitude (like Nainital, Jabalpur, and Puducherry), the sun will be highest in the sky at around the same time. So these places will have local noon at around the same time.

Box 2. Longitude:

This is how far East or West a location is from the Prime Meridian (at Greenwich, England). India starts at 68°E in Gujarat and goes to 97°E in Arunachal Pradesh.

(B) Local noon is midday

Every day begins at sunrise and ends at sunset. After sunrise, the sun goes higher and higher in the sky and then comes back lower and lower to sunset. So another way to think about local noon is the middle of the day. That is, exactly between sunrise and sunset.

Find today's sunset and sunrise time at your location (in your newspaper or online). The time between these is the length of your day. And the time exactly in the middle of your day is midday. This is when the sun is highest in the sky, so this is your local noon.

Was this the same time at which your shadow was shortest?

(C) When *exactly* is local noon?

You can also use an app to look up the exact time for local noon on any day and for any location: alokm.com/zsdapp (see **Box 3**).

Box 3. 'Zero Shadow Day' app:

This is an Android smartphone app that contains a number of interactive visualisations to understand how shadows cast by the sun change over the course of a year at different places. It also provides data for users to examine. The app was commissioned by the Astronomical Society of India — Public Outreach and Education Committee (ASI-POEC). You can find the app here: https://play.google.com/store/apps/details?id=com.alokm.zsd.

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TEACHING
FOOD RELATIONSHIPS

SAURAV SHOME

Children are introduced to food relationships at the elementary level through food chains and food webs. Research suggests that both models can leave students with misconceptions. What are some of the most common misconceptions? What are some pedagogical strategies to address them?

Understanding the idea of food relationships in ecosystems involves an introduction to food dependence among different organisms. This includes the role of producers, consumers and decomposers; the process of photosynthetically building complex matter from simpler molecules and decomposing complex matter to simpler matter; the transformation of energy during each process; and the role of humans in these relationships. It is often difficult to highlight all these aspects without oversimplification.

A common pedagogical approach is to begin with a simpler model of food relationships, and build an understanding of more advanced concepts around it. This means that the teaching of food relationships at the elementary level is traditionally limited to introducing food chains or at most food webs. Teachers report that students generally find both these models easy to understand. However, research suggests that both models leave students with many misconceptions about food relationships.

Common student misconceptions

Here are some common student ideas around a simple food chain (see **Fig. 1**) that many elementary-level students are familiar with:

1. A change in the population of a first-order consumer will not affect one or more producer populations. Students may, for example, believe that a change in the grasshopper population will not affect the grass population. The assumption that producers are independent of consumers can extend itself into the narrow view that the resources available to us are infinite or too abundant for us to be concerned about their depletion.

2. A change in one population in this chain will only affect another population if the two are in a predator-prey relationship. Students may assume, for example, that a change in the frog population will affect only the grasshopper and snake populations, but not that of the grass or eagle populations. While this

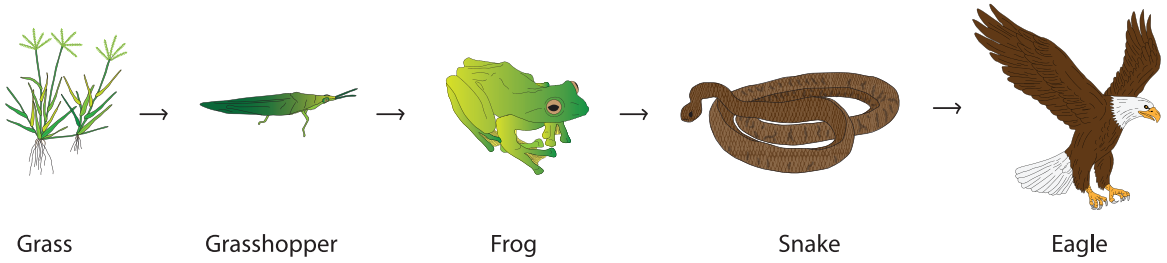

Fig. 1. A simple food chain that is commonly used to introduce food relationships at the elementary-school level.

means that students can identify the effect of a change in both directions, their understanding is limited to the immediate linear connections seen in the chain. They may often assume the existence of some strong self-adjusting mechanism in the ecosystem that compensates for any disturbance beyond these immediate connections.

3. A change in one population will not be passed along several different pathways of a food web. Students may assume, for example, that a change in the grasshopper population will not cause any change in the population of grazing animals or the carnivores preying on them.

4. A change in the size of a prey population has no influence on the population size of its predator. Students may assume, for example, that a change in the size of the frog population will not affect the size of the snake population in the same ecosystem. This misconception may be particularly common if food relationships are seen as isolated events rather than being connected with other biological processes (like reproductive advantage or disadvantage in the context of food availability).

5. A population located higher in a given food chain within a food web preys on all populations located below it in the chain. This can arise due to the simplistic presentation of food chains, the absence of discussion on the many species-specific relationships within a trophic level, and erroneous generalizations based on limited examples (like the fact that tigers eat many herbivores). In some cases, students can misinterpret the diagram of a food pyramid to mean that the species placed at its apex consumes all the species that appear at levels below it.

6. When the size of one population in a food web is altered, all other populations will be altered in the same way. While a student's ability to see interconnections may be heartening for teachers, seeing all the relationships in a web as being linear is a simplistic and incorrect understanding of food relationships.

7. Decomposers are not part of food chains or food webs. Since examples of food chains and food webs used in elementary-school textbooks do not explicitly mention decomposers and other microscopic organisms, many students may assume that these organisms have no role in the food relationships of other organisms.

8. Food chains and food webs involve a flow of matter, not energy. Since food chains and food webs are traditionally presented only in terms of one organism feeding on another, most students do not understand that each such relationship also involves the transfer of energy.

Addressing student misconceptions

How do we introduce food chains and food webs to elementary-level students in ways that address these misconceptions? Here are some strategies:

1. Introduce students to food relationships of specific organisms within a larger, more general category. For example, introduce general food relationships of insects, then highlight differences between the feeding habits of specific categories of insects like butterflies, ants, and cockroaches. Use this to discuss differences between the host plants of two or three different species of butterflies. Apart from offering a less simplistic perspective to food relationships, this exercise can help students expand their species vocabulary, and appreciate the importance of biological diversity in ecosystem health.

2. Widen the scope of food relationships discussed in class. Share examples where a predator or its prey are in other kinds of food relationships, like that of sun bears feeding on fruit and honey. In addition to predator-prey relationships, introduce and explore examples of saprophytes and parasites from the real-world contexts of your students. This could include observations of bracket fungi on decaying logs of wood, or of mosquitoes sucking blood from humans, cattle, and dogs.

3. Reduce emphasis on hierarchy. Traditionally, food relationships are represented as a pyramid with different trophic levels. Such representations suggest a linearity that causes students to mistakenly believe that most organisms fit a single trophic level, or that organisms at a higher trophic level consume organisms at all the lower tropic levels etc. Challenge this by using a networked web structure to discuss trophic levels.

4. Highlight the recycling of matter through food relationships. Describe, for example, how producers make food, decomposers act upon dead organisms breaking them down to simpler compounds, and how the carbon dioxide released through respiration becomes the raw material for photosynthesis.

5. Bring energy into the picture. Discuss the connection of food dependence to the transformation of one form of energy into another. Share, for example, how solar energy is converted to chemical energy in plants during photosynthesis, or how digestion in animals involves the transformation of chemical energy in food to thermal energy (used to regulate our body temperature) and mechanical energy (used in muscle movement).

6. Introduce activities and case studies to illustrate the dynamic and non-linear nature of relationships in food chains and food webs. Encouraging students to observe interactions between even a small number of species over time in local natural or artificial ecosystems can give them a sense of nonlinearity. One approach is to begin with examples of food relationships involving animals (including humans) familiar to students in their own contexts. For example, encourage children to think about what domesticated animals eat; and to watch and record the feeding habits of commonly observed birds, insects, rodents, etc. Use these observations to build class discussion. Another approach is through activities. For example, help students learn to take care of ants, earthworms, and butterflies in a terrarium that they have designed and built themselves. A third approach could be to use computer-based animations. For example, get students to build animations around case studies to show changes in the many food relationships that exist in particular ecosystems.

Parting thoughts

Introducing students to food chains and webs within a wider context of interconnected relationships that are nonlinear, include humans, change over time, involve the cycling of both matter and energy, and are observable in our real world can leave students with fewer misconceptions. While we offer some broad pedagogical strategies towards this goal, these are meant to be suggestive rather than sacrosanct. They are also likely to be most effective if used or adapted in a context-sensitive manner.

Key takeaways

- While many teachers report that elementary-level students find food chains and food webs easy to understand, research shows that both models leave students with many misconceptions about food relationships.
- Most common misconceptions arise from seeing food relationships as distant, linear, isolated events in the cycling of matter, which do not involve humans.
- These misconceptions can be addressed by presenting both models within a wider context of nonlinear interconnected relationships that change over time, involve the cycling of both matter and energy, include humans, and are observable in the real-world.

Notes: Source of the image used in the background of the article title: Some of the food we grow and consume. Credits: Marco Verch Professional Photographer. URL: https://www.flickr.com/photos/30478819@N08/48788305713. License: CC-BY.

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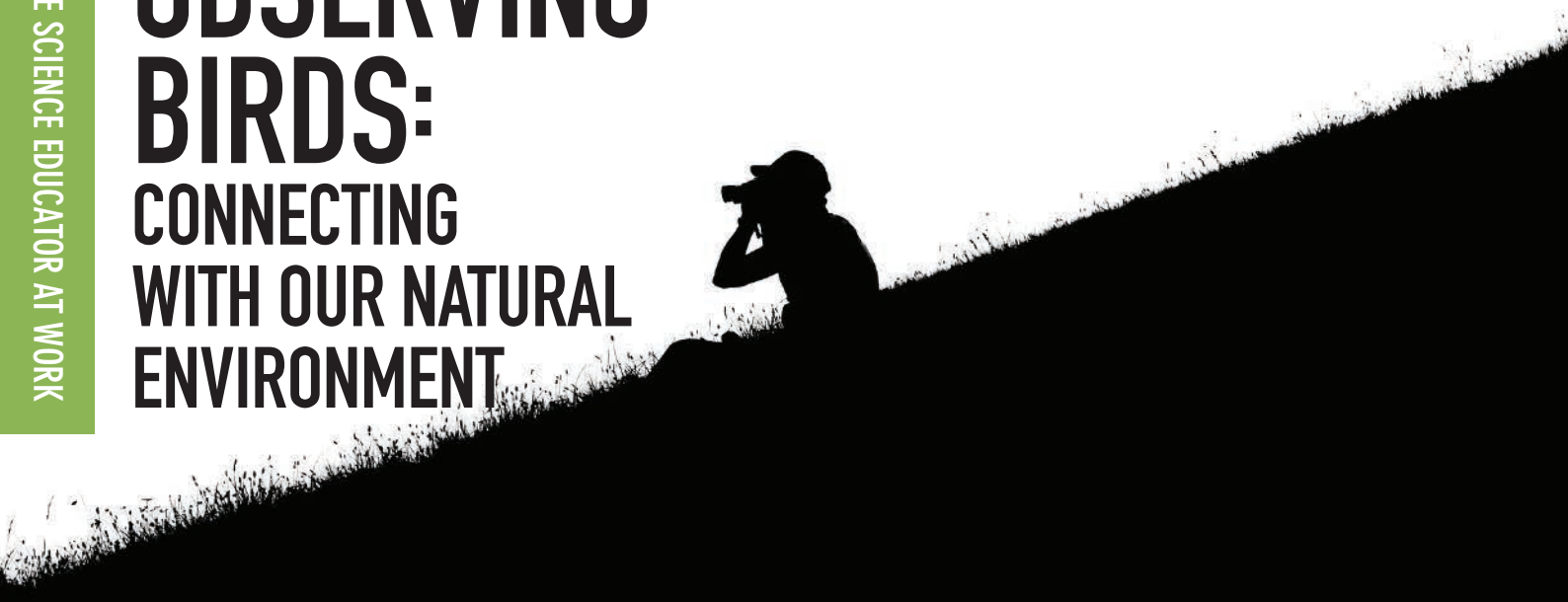
OBSERVING BIRDS: CONNECTING WITH OUR NATURAL ENVIRONMENT



GOWTHAMA RAJAVELU & SOUNDARAJAN R

Exploring birds in one's own neighbourhood provides an opportunity to help children and adults develop the skill of observation. Can it also provoke curiosity towards their own immediate surroundings? Can it build greater awareness of and sensitivity towards the natural world at large? We share our experience.

Observing the natural world engages, nurtures, empowers, and enlightens us. Bird watching offers a widely appealing, fun-filled, and aesthetically pleasing way of encouraging the cultivation of this skill in both children and adults. This activity is also believed to increase an individual's awareness and sensitivity towards the natural world — both of which are believed to shape how people respond to environmental challenges (see **Box 1**). They are also considered key competencies in enabling children to contribute towards the vision of sustainable development (see **Box 2**).

Before the pandemic, we were engaged in bird watching through regular group visits to the water bodies (lakes, rivers, wetlands and seashores) and forests in Puducherry. When this routine was disrupted by pandemic-related restrictions in movement and gathering in groups, we were faced with two questions — is it possible to encourage children and adults to explore birds in their own neighbourhoods? What kind of resources and support would be needed to equip beginners to engage in this activity individually rather than as a group?

Box 1. Responding to environmental challenges:

- According to The Tbilisi Declaration (1987), environmental education must aim to sensitize people with knowledge, attitudes, and skills to identify, understand and solve environmental problems, and participate in environmental dialogues (Tbilisi Declaration, UNESCO-UNEP, 1987).
- Hungerford and Volk's environmental behaviour model (1990) suggests that environmental sensitivity (defined as an empathetic perspective toward the environment) can be an important starting point in developing environmentally responsible behaviour.
- According to Bulkeley (2000), an individual's knowledge about their surroundings, combined with environmental sensitivity, is believed to influence how they respond to environmental challenges.

Box 2. Key competencies for sustainable development:

According to the NCERT learning outcomes at the elementary stage (2017), three key competencies need to be cultivated to enable individuals to act towards the vision of sustainable development:

- **Awareness** about immediate surroundings.
- **Sensitivity** towards our natural environment.
- **Skills** that enable us to think and act towards sustainable development.

A study on neighbourhood birds

We explored these questions through a pilot study on neighbourhood birds. Recognising the key role that adults can play in introducing children to the natural world with awareness and sensitivity, we invited a group of resource persons from the Azim Premji Foundation to participate in this study. To keep things simple, participation in this study involved three steps:

- Select a location near your house or immediate neighbourhood.
- Visit this location for at least 15 minutes twice a week to look for birds. Use the photos in the Google form provided by us **(Birds in your Neighbourhood — Data collection sheet)** to identify any birds that you spot and learn their (common English and local) names. Record your observations (location, type of ecosystem, weather conditions, name of the bird, its behaviour, etc.) as accurately as possible and share with us through the form.
- Continue making these visits for at least a month. Observe and make note of any physical changes (tree logging, clearing of bushes, etc.) you notice at the location. Would these changes have any impact on the kinds and numbers of birds that you see there? Again, share your thoughts with us through the Google form.

Overall, eleven people participated in this study and reported 43 bird species in fifteen habitats including roadside trees, vacant plots, canals, ponds, lakes, and the seacoast (see **Fig. 1**). The study lasted two months in the most exciting time of the year for birdwatchers (November and December) — allowing participants to observe both resident and migratory bird species. This led to more active involvement, although some participants did not stick to the schedule of two weekly observations as diligently as the others.

Reflections on the study

This study was designed to appreciate bird diversity, map bird habitats in the city, and improve people's knowledge of birds. Engaging in this study helped participants identify different bird species, hone their observation skills, and motivate them to share their

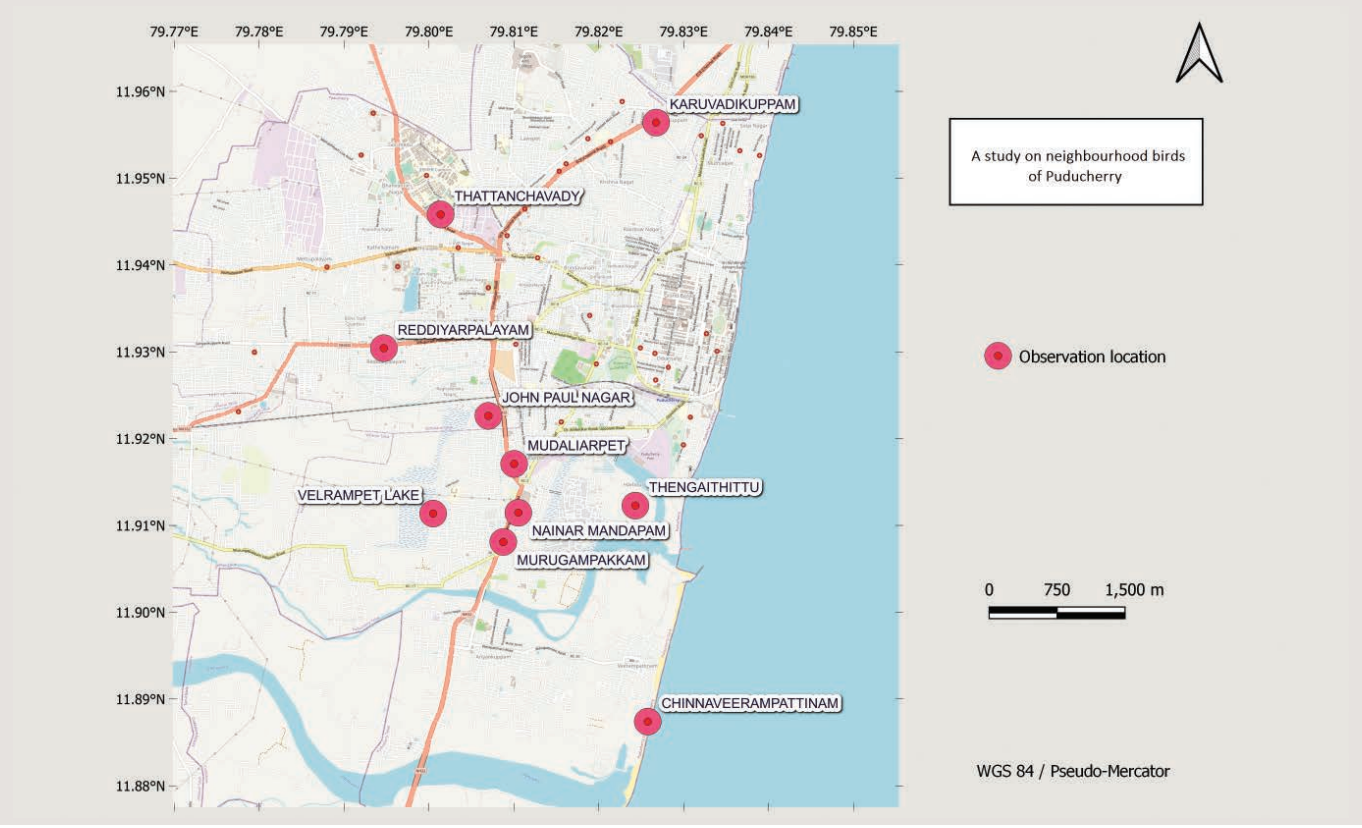


Fig. 1. Observation location map.

Credits: Gowthama Rajavelu & Soundarajan R. License: CC-BY-NC.

Table I. Habitat-specific observations of bird species from a bird diversity study in Puducherry.

Habitat selected	Birds observed (common names)
Building	Blue Rock Pigeon Common Myna House Crow House Sparrow Jungle Crow
Agricultural field	Oriental Magpie Robin Common Myna House Crow House Sparrow Purple Sunbird Red-vented Bulbul Rose-ringed Parakeet
Canal	Oriental Magpie Robin Common Myna House Crow House Sparrow Purple Sunbird Red-vented Bulbul Jungle Crow Pond Heron Purple-rumped Sunbird Asian Palm Swift Common Tailorbird White-breasted Waterhen
Wetlands	Asian Palm Swift Common Myna Rose-ringed Parakeet Pond Heron House Crow White-breasted Waterhen Barn Swallow Black Drongo Black Kite Blue-tailed Bee Eater Black-rumped Flameback Common Kingfisher Lesser Cormorant Little Egret Pied Cuckoo Red-wattled Lapwing Jungle Crow
Vacant Plot	Oriental Magpie Robin Common Myna House Crow House Sparrow Purple Sunbird Red-vented Bulbul Rose-ringed Parakeet Jungle Crow Purple-rumped Sunbird Asian Palm Swift Blue Rock Pigeon Black-rumped Flameback Common Kingfisher Lesser Cormorant Little Egret White-breasted Waterhen Common Tailorbird Pied Cuckoo Red-wattled Lapwing Black Drongo Pond Heron Ashy Prinia Asian Koel (male & female) Black Kite Barn Owl Brahminy Kite Common Babbler Golden Oriole Greater Coucal Indian Robin Rufous Treepie Scaly-breasted Munia Spotted Dove Tri-coloured Munia White-breasted Kingfisher
Pond	Asian Palm Swift Pond Heron Black Drongo Common Myna Grey Heron Gray-headed Swamphen Little Grebe Spotted Owlet Black-rumped Flameback Whistling Duck River Tern Little Egret Tri-coloured Munia Red-wattled Lapwing
Lake	Ashy Woodswallow Common Myna House Crow Blue-tailed Bee Eater Asian Palm Swift Pond Heron Rose-ringed Parakeet Grey Heron Lesser Cormorant Little Egret Greater Caucal Black-rumped Flameback Lesser Whistling Duck Red-wattled Lapwing Black Drongo Spotted Dove White-throated Kingfisher Grey-headed Swamphen Little Grebe Greater Egret
Shrubs	Spotted Dove White-throated Kingfisher Asian Koel Jungle Crow Little Egret Blue Rock Pigeon Common Myna Golden Oriole Indian Robin Rose-ringed Parakeet Oriental Magpie Robin Spotted Owlet Black Drongo
Street Avenues	Jungle Crow Common Tailorbird House Crow Common Myna House Sparrow Purple Sunbird Red-vented Bulbul White-browed Wagtail

enthusiasm and skills with others (see **Box 3**). It also seems to have helped participants connect birds to popular culture in the form of songs, movies, etc. This is reflected in some of the feedback we received from the participants (see **Box 4**).

In addition, observing birds in their habitats led some participants to look deeper into their relationship with their surroundings, asking questions such as — what brings birds to these places? How do we decide the richness of a location as a bird habitat? What does the habitat provide to us? What if these kinds of habitats disappear from our localities? For example, one participant (Swetha A, an Education Resource Person) observed white-breasted waterhens, house crows, and magpie robins at one of the locations she had selected for the study. On one visit, she noticed that the plants at this location had been cleared-up. This led her to ponder over questions like, *"What will happen to the birds residing there? Where will they go?"* Such experiences and concerns led to discussions on the diversity and behaviour of birds, the importance of a particular location as a bird habitat, and factors that influence the continued habitability of the location for birds (see **Table I**).

On the other hand, since the aim of the study was to observe birds and participation was voluntary, participants did not feel strongly obligated to follow the process we had suggested. This was our most important challenge. Although the activity aroused curiosity in birds and their habitats, we feel that a sense of obligation may be necessary to ensure that participants develop a more long-term and committed learning engagement with the natural world.

Parting thoughts

The pilot study offered participants the opportunity to explore their relationship with the natural world by selecting a location in their own neighbourhood that they could visit on a regular basis. The process of looking for birds and observing them keenly for identifying features and behaviours helped many participants strengthen their observation skills and ability to recognise common bird species. Sharing systematic records of not just the birds but their habitats provoked some reflection on our interactions with and influence on the natural world. We believe that a longer duration study with more opportunities for observation, reflection, and discussion on birds and bird habitats as a whole, may help build on this early interest and awareness. Lastly, this study offered some participants the opportunity to draw out a personal hobby from an exercise in environmental education.

Based on our experiences from this study, we would now like to extend it to students (especially at the secondary level) and teachers. Our hope is that this study will not only help strengthen their observation skills but also help students and teachers develop curiosity, awareness, and sensitivity for their natural environment. These are first steps towards developing the attitude, knowledge, and skills to address environmental problems and contributing to a sustainable future.

Box 3. Some highlights of participant observations:

- House crows and common mynas were the most spotted birds in all the different habitats selected by the participants.
- House crows and house sparrows were the most spotted birds in the street avenues.
- Red-wattled lapwings were spotted only by participants who chose lakes for their study.
- Asian palm swifts were spotted only near Velrampet lake, which may be related to the palm trees planted along its banks.
- Rose-ringed parakeets were the single most observed bird species in Murungapakkam — an urban space in Puducherry.
- A pond heron (a water bird) was observed perching on a neem tree at a location (Mudaliarpet) that did not have any water body in its vicinity.

Box 4. Feedback from participants:

"I am not a great observer at all. I thought participating in this study will help me to cultivate the habit of observing my surroundings on a regular basis. After the study, observation has become a common trait in me. I also learned the commonly seen birds in our surroundings through my peers."
— Puviarasan Sivarajan, Education Resource Person, Azim Premji Foundation.

"The first time, when I saw the format of the data collection sheet, I was wonderstruck. Because it had so many birds, their names, along with their pictures. In fact, the Maanguil bird (Indian Golden Oriole) name is known very well due to the popular Tamil movie song. I first saw them as a pair at Kandamangalam. In an interaction with my friends, I was able to name a few birds that were flying around, which made them look up to me as a knowledgeable person in Ornithology."
— Benedict Henry, People Functions, Azim Premji Foundation.

"Before coming to Pondy, I never observed birds or bothered to know their names. But now, I have a curiosity when I see birds, and I try to identify them by their names. I think I can make my family and friends build such an interest in birds by asking them to name birds or by sharing interesting facts about them. For example, the Drongo is a very cunning bird that imitates the sounds of other birds, animals, and even things such as camera click. Finding out the local names of birds and the reason behind those names, names of birds occurring in movie songs etc. are also ways to initiate conversations on birds and build an interest in birdwatching."
— Vimal P Thomas, Education Resource Person, Azim Premji Foundation.

Key takeaways

- Bird watching can help strengthen observation skills, and build awareness and sensitivity towards the natural world in both adults and children.
- Developing a bird-watching routine that beginners can undertake by themselves can help them identify birds in their own neighbourhoods, notice bird habits and habitats, and appreciate bird diversity.
- Over time, bird watching can encourage participants to share their enthusiasm with others as well as reflect upon our influence and impact on the natural world.
- Observation skills, awareness, and sensitivity towards our natural environment are among the key competencies needed to address environmental problems and contribute to sustainable development.

Acknowledgments: This study would not have been possible without the support of our voluntary participants — Puviarasan, Swetha, Vimal, Pugalenthi, Aathiganesan, Narendran, Benedict Henry, Dhivya, and Naveen. It was they who brought life to this activity. We thank Pugalenthi for his support in creating beautiful illustrations.

Note:

1. The 'Birds in your Neighbourhood — Data collection sheet' can be accessed here: https://docs.google.com/forms/d/e/1FAIpQLSeWBVd1O2LMO8xzrmthZKzCmNcfS4ElVykVcApFCcTZKSgVXw/viewform.
2. Source of the image used in the background of the article title: Bird watching. Credits: Skitterphoto, Pixabay. URL: https://pixabay.com/photos/bird-watching-binoculars-mountain-3635268/. License: CC0.

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Gowthama Rajavelu is an educator who believes in bringing about an active environmental spirit among kids and youth through strategically curated projects. He is currently working as a resource person at the Azim Premji Foundation, Puducherry.

Soundarajan R is interested in building a nature-friendly sustainable future, and believes education can steer this. He likes to explore nature in human settlements and travel. He is currently working as a Resource person with the Azim Premji Foundation in Puducherry.

EXPLORE YOUR SURROUNDINGS WITH THE FOLDSCOPE

In middle school, we introduce children to the microscopic world — to organisms, cells, and structures that exist at such small scales that they are simply invisible to the naked eye. Microscopes play a vital role in this introduction. It is through microscopes that children begin to observe this world for themselves.

Many schools may have only one or a few microscopes that are bulky and expensive. Thus, much of a child's explorations of this tiny world is limited to classroom experiences that may be directed or facilitated by a teacher. Now, contrast this with a small, easy-to-use, and affordable microscope that children could carry around. What things would they observe? What questions would they ask? What would they learn?

The Foldscope

The Foldscope is a really simple, inexpensive, but powerful microscope. It was designed by Manu Prakash (a professor at Stanford University, USA) and Jim Cybulski (his PhD student at the time). Unlike conventional microscopes, the Foldscope:

- Is constructed with paper, magnets, and glass. This makes it small enough to fit into a pocket, sturdy enough for easy and rough use by school and college students, and handy enough to not need electricity or any additional resource. This makes it ideal for observations on the go.
- Is inexpensive, costing around Rs 350/piece in the Indian market.
- Has a magnification of 140x (which means that the size of the image we see is 140 times the actual size of the object we are looking at) and a resolution of 2 microns (which means that we can use it to discern features as small as 0.002 mm).
- Can be attached to a smartphone to take photos and videos of magnified objects, and can be used to project magnified images on a surface with just a bright light.

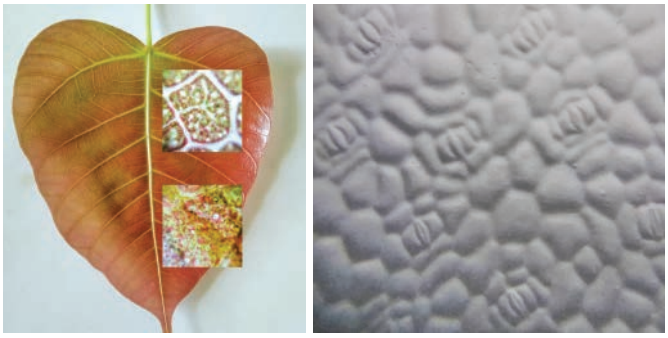
These features make the Foldscope particularly well-suited for exercises aimed at encouraging children to explore their immediate surroundings. For example, children could use it to observe changes in the colour and appearance of a leaf over time or monitor the opening and closing of its stomata — all without pulling the leaf off the tree. Preparing samples for observation of cross-sections also becomes much easier and faster. For example, a thin layer of nail paint can be applied to the back of a leaf. When this dries, it can be pulled off and observed under a Foldscope. Similarly, the sticky side of a piece of transparent tape can be used to touch the anther of any flower. This can be put on a paper slide and observed under a Foldscope (see **Fig. 1**). None of these preparations take more than a few minutes.

Uses in teaching and learning

Many students and teachers use the Foldscope to observe the natural world and document these observations as images. These images can be shared and discussed with many others on the online Foldscope community site. They can also provide data for experiments designed to answer a wide range of questions.

In one example, a high school student called Sameer (from Parbhani, a district in interior Maharashtra) who was documenting observations of pollen from various flowers in his neighbourhood, observed some powdery white spots on the leaves of a guava tree. This looked very much like pollen under a Foldscope. But based on his previous observations, Sameer knew that they were unlike the pollen of guava trees. This led him to ask — if these are pollen grains from a different plant, how did they reach these guava leaves? When he posted his observation on the Foldscope community site, some members suggested that Sameer observe a section of these leaves to check for infection. Some other members looked for and observed sections of

Fig. 1. Observations with a Foldscope.



(a) Leaf of a peepal tree *(Ficus religiosa)* with certain sections magnified.

(b) Stomata of a money plant (*Epipremnum aureum*).

Credits: Rafikh Rashid Shaikh. Licence: CC-BY-SA.

leaves with similar white spots under a Foldscope. They found thread-like structures that seemed to emerge from the deeper layers of the leaf. The pollen-like structures that Sameer had initially observed were at the outer ends of these threads. Discussions between Sameer and other Foldscope users led to the identification of the white spots as powdery mildew. In another example, MO Pandiarajan, a teacher from Tamil Nadu, and his students regularly use the Foldscope to explore jungles, ponds, rivers, etc. Pandiarajan also displays prints of microscopic photographs of everyday objects in exhibitions on roads, market places, bus stops, etc., where people can come and witness the beauty of nature at the microscopic level. In yet another example, students and teachers across India have been contributing images of pollen grains of plants native to their locations to a database on pollen on the Foldscope community site (see **Fig. 2**). Many of the photographs of pollen on Wikipedia have also been uploaded by Foldscope users.

Parting thoughts

My experience of working with children has taught me that their mind is full of questions about their immediate surroundings and the larger universe. Imagine a world where children can explore their microscopic worlds not only when they are in school, but anywhere and at any time. Access to sturdy, inexpensive, and easy-to-carry tools, like the Foldscope, can help children not only learn but also become producers of knowledge.

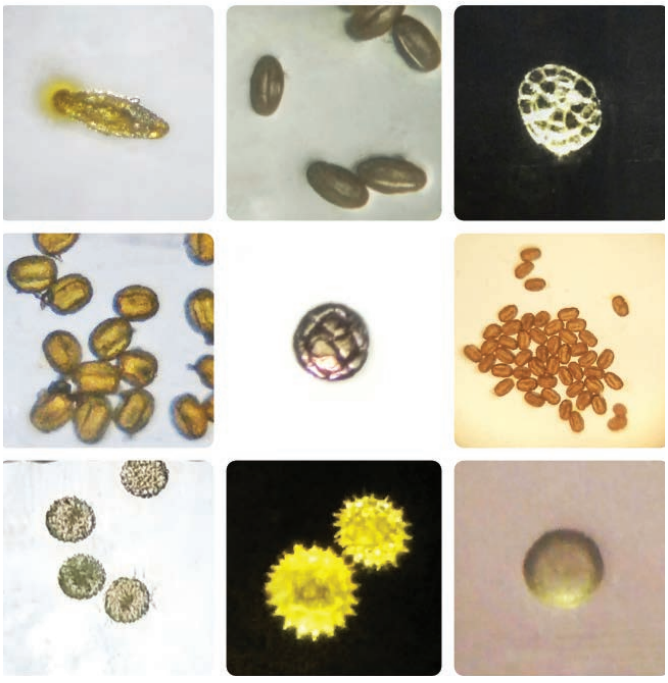


Fig. 2. Foldscope images of pollen grains of various plants.

Credits: Rafikh Rashid Shaikh. Licence: CC-BY-SA.

Rafikh Rashid Shaikh is passionate about understanding how children learn. He is a senior research coordinator at the Tata Institute of Social Sciences (TISS), Mumbai and a doctoral student at the Homi Bhabha Centre for Science Education (HBCSE), Mumbai, India. He is also a recipient of the Foldscope Fellowship for his science popularisation work. Rafikh can be contacted at: rafikh.sk@gmail.com.

Write for us

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

We welcome articles that offer:

- critical perspectives on science & science education,
- a deeper exploration of the foundational concepts & 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 & stories in science that engage the curiosity & imagination of your young learners, &
- examples of practice that encourage the learning of science in more meaningful & 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 & weight; Density; Force & pressure; Momentum; Energy; Work; Power; Light; Sound; Heat; Electricity & circuits; Gravitation; Stars & the solar system; & Magnetism.
- **Chemistry:** Atomic structure; The periodic table; The particulate nature of matter; Structure & bonding; Chemical reactions; Acids, bases & salts; Air & water; Materials – metals & non-metals; & Fuels.
- **Biology:** Living & non-living; Cell structure & organisation; Biological molecules; Movement in & out of cells; Plant nutrition & transport; Human nutrition & transport in animals; Diseases & immunity; Respiration; Excretion; Coordination & response; Inheritance; Variation & selection; Organisms & their environment; & 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 & times through the prism of their contributions to science.
- **Teaching as if the Earth Matters:** Perspectives & teaching-learning approaches to sustainability, earth sciences, climate-sciences, & systems thinking.
- **The Science Educator at Work:** Perspectives & 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 & 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, & what you wish you'd learnt in school.
- **Hot off the Press:** Why recent headlines are of interest to students & teachers alike.
- **Book Review:** Why & how a book you've read could contribute to the teaching & learning of school science.

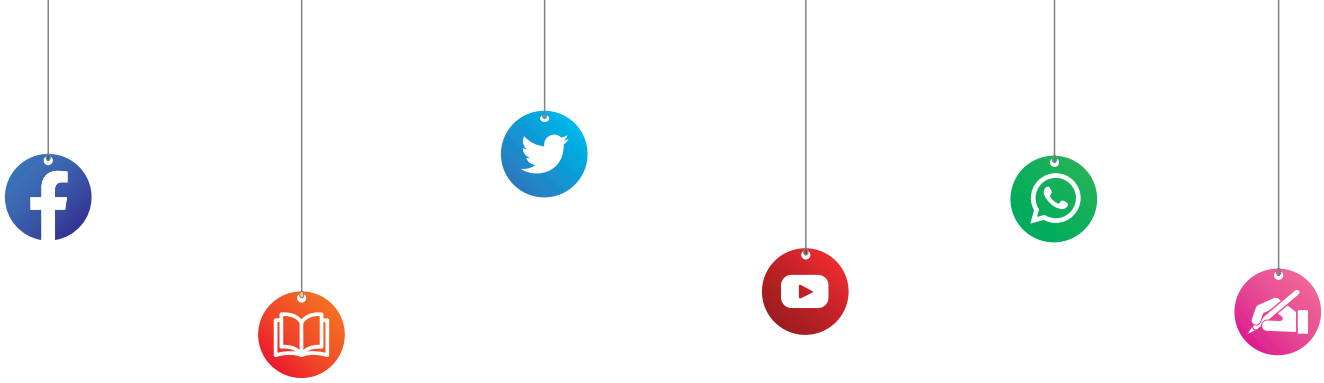
Themes for short pieces (200-600 words):

- **Myth or Fact:** Commonly held incorrect beliefs versus corresponding objective & verifiable observations.
- **10 Things You Didn't Know Anything About:** Ten interesting things 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, &
   - Areas of interest in school science

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



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Read

We publish **two issues a year**, in **English, Hindi & Kannada**. Each issue has one theme section & many non-theme sections. Themes from our latest issues include: Ask A Question, Teaching as if the Earth Matters & The Pandemic. 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 & 10 Things You Didn't Know About. Each issue also features short snippets, posters, activity sheets, and school-level field guides.

Ask & discuss

We invite authors & readers for **live, online discussions on the 2nd Wednesday of every month**. Some of the themes we have covered in the last year include:

- **Experiences with a Potometer** with Kishore Panwar & Shiv Pandey
- **Material Interactions** with Yasmin Jayathirtha & Vinay Suram
- **Seeing the invisible: Imaging a Black Hole** with Rajaram Nityananda & Murthy OVSN
- **Mental Health and the Pandemic** with Avantika Bhatia & Vijeta Raghuram
- **Students as Teachers** with Saurav Shome & Shiv Pandey
- **Observing the Microbial World** with Meena Kharatmal & Radha Gopalan

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To **receive notifications** about our latest issues & online discussions, please register at: https://bit.do/IWRegister. Or, **follow us on Facebook**: https://bit.ly/2UcVMaE.

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To **subscribe to our mailing list** & receive free hard copies of every issue, mail your postal address to iwonder@apu.edu.in. Please note that the mailing of hard copies is restricted to India.

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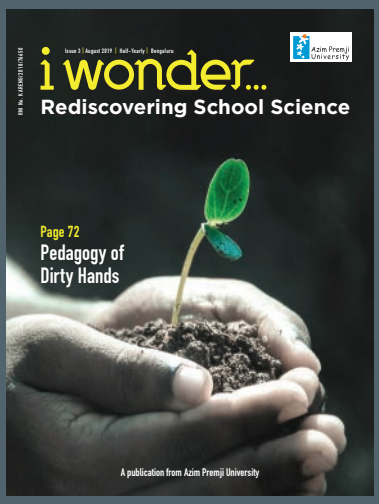
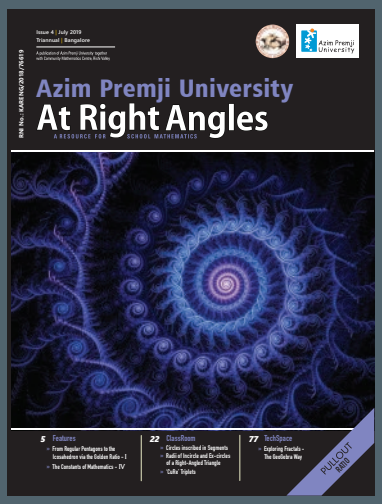
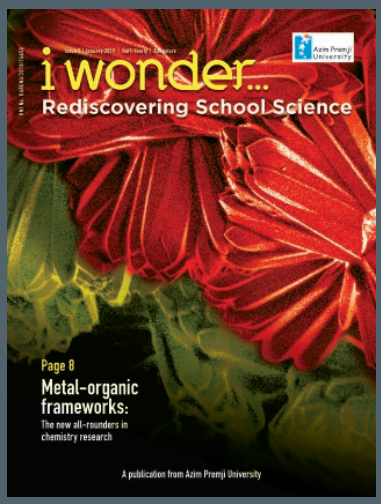
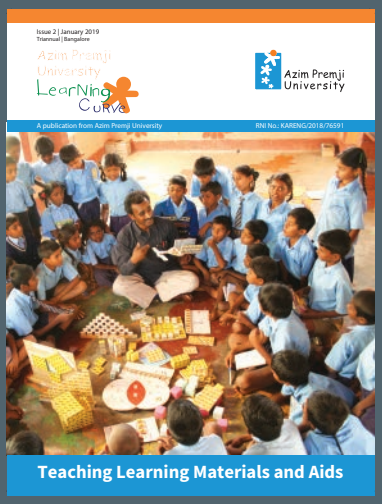


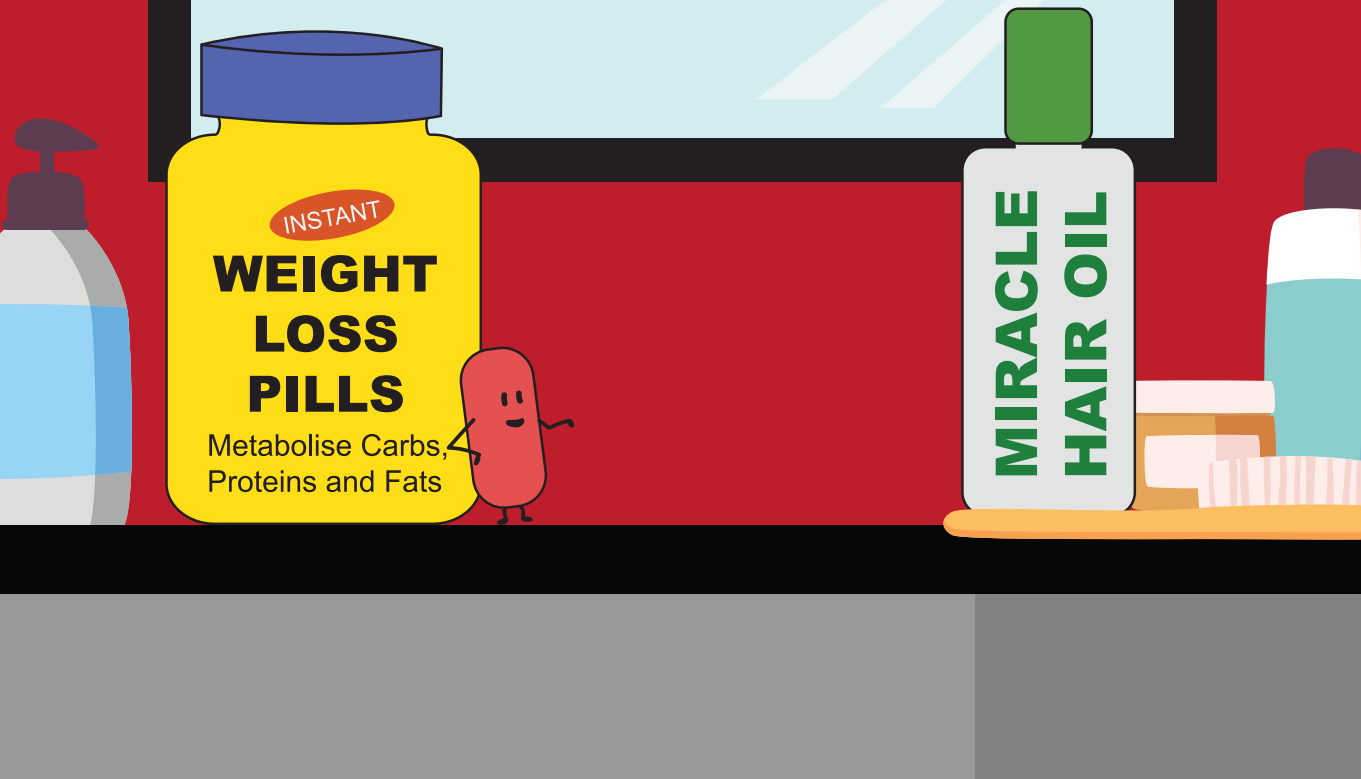






11 CHARACTERISTICS OF PSEUDOSCIENCE

AUTHOR: MELANIE TRECEK-KING



1. Is UNFALSIFIABLE

It can't be proven wrong. It makes vague or unobservable claims.

There's a viral infection that we must be careful of.

That is a broad claim. What makes you sure that the amulet will protect you against this infection?

But... you were coughing & sneezing just last week.

Ah! What kind of weather change triggers that?

But it rained only on one day. You were coughing & sneezing on two very hot & dry days before that. I remember we were all burning up in the heat, but didn't want to switch on the fan because you were unwell.

Looks like there's nothing that would make you doubt your belief in the amulet's power?

I am not worried — my amulet boosts immunity & fights all infections.

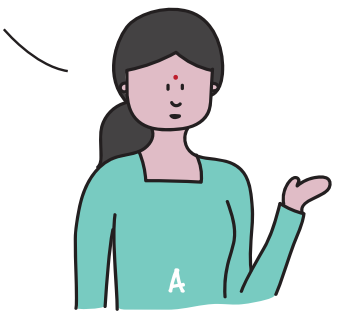
I have proof — I have observed that as long as I keep wearing it, I don't catch infection.

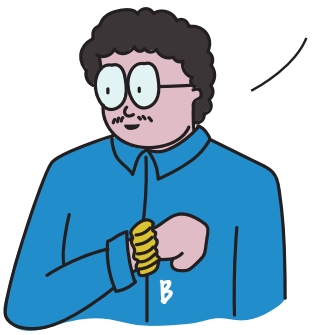
That was an allergy to the change in weather.

Sudden rains.

My body could sense that it was going to rain — it triggered my allergy.

That's right. I have complete confidence in it.





2. Professes CERTAINTY

Talks of "proof" and presents ideas with complete confidence.

THINK ABOUT

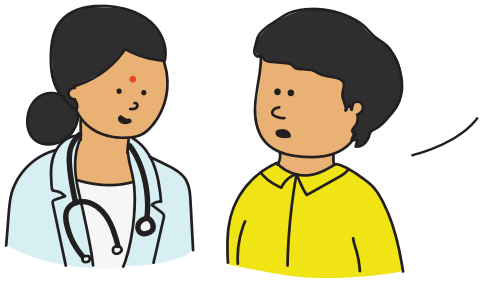
Say A brings this magical amulet to you (at great risk to B's health):

Q. How would you test if the amulet boosts immunity? What kind of evidence would you look for?

Q. How would you test if the amulet protects against every single (all) infection in the world? When would you be completely certain of this property?

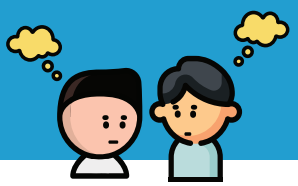
3. Relies heavily on ANECDOTES

The evidence largely comes from personal experiences and testimonials.



My friend's grandmother's sister would walk up this hill and circle this tree on the hilltop three times every morning. She did this every day for a year. By the end of the year her cancer had disappeared. All the doctors treating her were amazed — they called it a miracle.

THINK ABOUT



Q. How would you test if this walking routine really cured the man's friend's grandmother of cancer? What kind of evidence would you look for?

Q. How certain do you feel that this cure would work on other people suffering from cancer? What would you need to know to arrive at this conclusion?

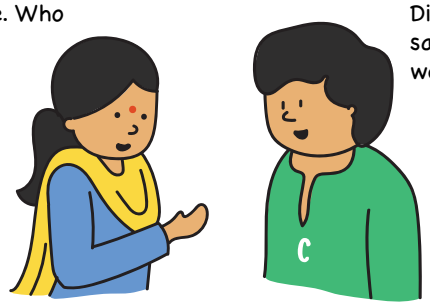
4. Uses TECHNO BABBLE

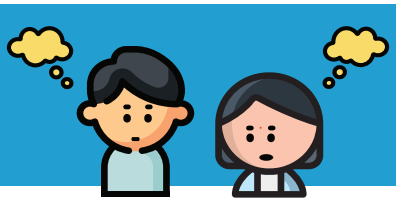
The words sound scientific but are used incorrectly or don't make sense.

This gemstone, when worn correctly, attracts alpha waves from the universe that get transmitted to the limbic system of the brain through the nerves in your finger, thereby enhancing positive emotions and mental peace.

You are as depressed as ever! You need professional help, not a gemstone. Who knows if it even works!

Didn't you hear what the shopkeeper said? I just have to figure out how to wear it correctly.





THINK ABOUT

Your friend C comes to you for advice. What part of the jeweller's claims about the gemstone's effects on mental peace are used incorrectly or don't make sense? Why do you think so?

5. CHERRY PICKS evidence

Uses favourable evidence while ignoring or minimizing disconfirming evidence.

Weight Loss Pills Tests on Humans:

21%

of people taking it show weight loss.

14% of people taking it show excessive hair growth all over the body.

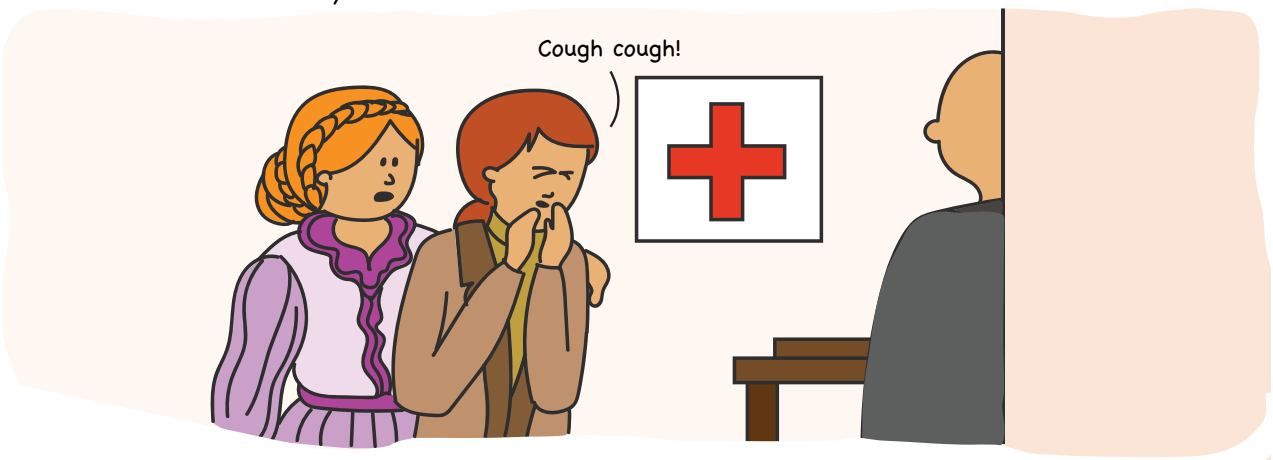
THINK ABOUT

Look at the chart showing the results of a test study. What kind of evidence has been ignored?

6. Lacks PLAUSIBLE MECHANISM

There's no way to explain how the claim might work based on existing knowledge.

Somewhere in 19th century Britain....



Doctor, how does bloodletting cure pneumonia?

That Austrian scientist — Joseph Dietl? His study shows that the mortality rates of pneumonia patients who received bloodletting treatment are three times higher than those of pneumonia patients who do not receive it.

I don't think we know for sure yet.

We have been using this treatment for centuries. I don't see any reason to change it now.

7. Is UNCHANGING

Doesn't self-correct or progress.

THINK ABOUT

If you were the doctor and had just heard of Dietl's study:

Q. Under what conditions would you continue using bloodletting to treat pneumonia patients?

Q. Would you question or change anything about the procedure (like its length, frequency)?

Q. Would you question or change anything based on the patients' health (their age, stamina, the severity of their symptoms)?

Q. Would knowing how bloodletting was believed to cure pneumonia patients help you decide whether you wanted to use it in this particular case? In what way?

8. Makes EXTRAORDINARY/ EXAGGERATED CLAIMS

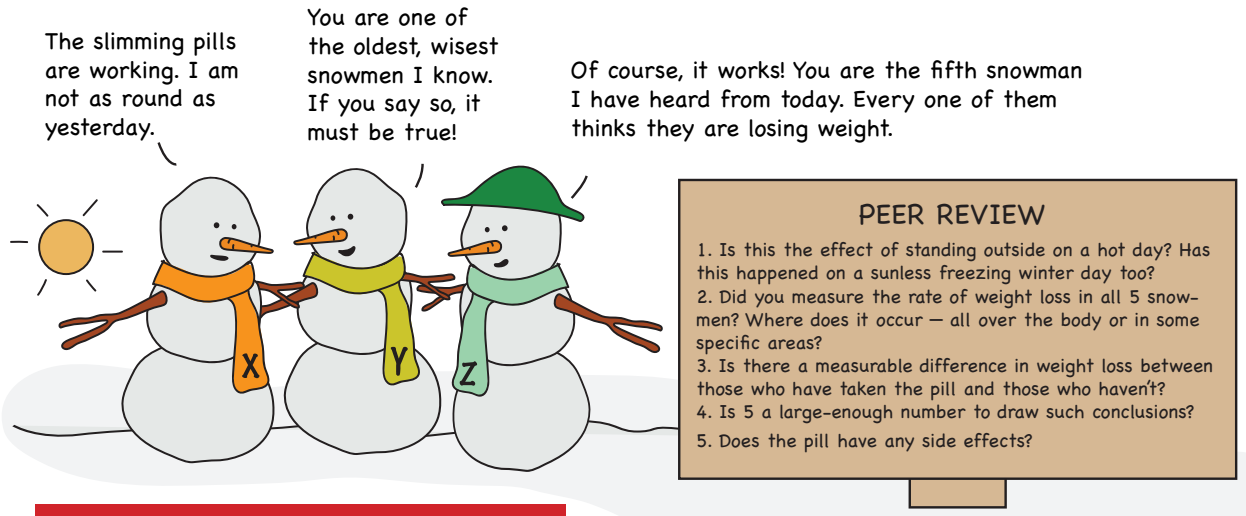
Promises extraordinary benefits with insufficient evidence.

THINK ABOUT

Your friend comes to you for advice. What part of the claims in the advertisement for the all-natural compressor technology seems exaggerated to you? Why do you think so?

9. Commits LOGICAL FALLACIES

Arguments contain errors in reasoning.



10. Lacks adequate PEER REVIEW

Avoids critical scrutiny by the scientific community.

THINK ABOUT

Your friend comes to you for advice.

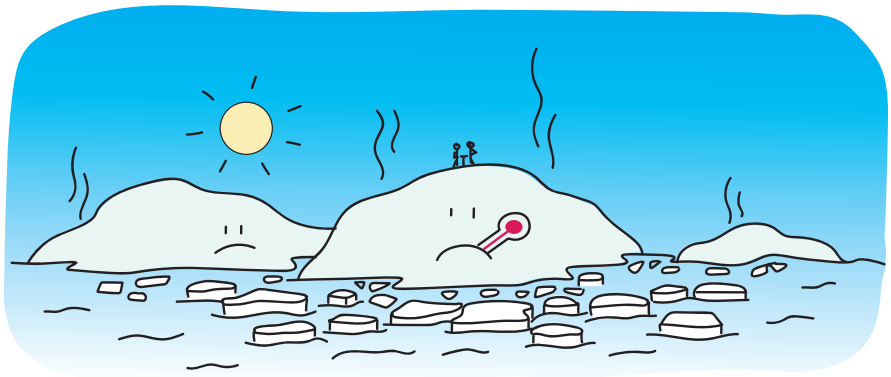
Q. Is there an error in reasoning in
   a) Snowman X's conclusion?
   b) Snowman Y's reason for believing in Snowman X's conclusion?
   c) Snowman Z's statement?

Q. If Snowman Z shared their findings with you for peer review, what questions would you ask? Is there something that the other reviewers haven't asked yet?

11. Claims there's a CONSPIRACY to suppress their ideas

Criticism by the scientific community is a conspiracy.

Did you hear about the climate change 'conspiracy'? Apparently environmental organisations are conspiring with scientists to fudge climate data because they want fossil fuel companies to go bankrupt and the world economy to crash!



THINK ABOUT

The dictionary uses the word 'bias' to describe a tendency to feel or show inclination or prejudice for or against someone or something. The two men drilling for oil seem to be suggesting that climate scientists may be biased against fossil fuel companies. Bias can influence what questions scientists ask, what methods they use to collect evidence, how they interpret evidence, and what they present for review and publication.

Q. Have you felt biased towards something or someone? How has this influenced your ability to ask questions, look for evidence, and arrive at conclusions?

Q. If you were a climate scientist, what would you do to reduce the likelihood that a bias against oil drilling in the arctics may affect your study?

- Do you think this list is exhaustive? Are there other characteristics that you would add to it? If yes, also share why you think they deserve a place here.
- Can you find examples (from the newspaper, your textbook, or any other source) for each of these characteristics? Do any of your examples show only one of these characteristics?

ABOUT THE AUTHOR:

Melanie Trecek-King is an Associate Professor of Biology at Massasoit Community College in Massachusetts. With over twenty years' experience in college and high school classrooms, she especially enjoys teaching students who don't want to be scientists when they "grow up." Her passion for science education led her to create 'Thinking Is Power' to provide accessible and engaging critical thinking information to the general public and to other educators interested in incorporating more critical thinking content in their courses. The content for this poster has been taken, with her permission, from a post titled '11 Characteristics of Pseudoscience' (URL: https://thinkingispower.com/11-characteristics-of-pseudoscience/) from 'Thinking Is Power'. To read the entire post & access other related material, visit: https://thinkingispower.com/.

OTHER CONTRIBUTORS:

Ideas and visuals for examples; & the text for Think About sections were contributed by Vidya Kamalesh (Artist, i wonder...), Vijeta Raghuram (Associate Editor, i wonder...) & Chitra Ravi (Editor, i wonder...).

11 CHARACTERISTICS OF PSEUDOSCIENCE

A publication by:

i wonder...
Rediscovering school science

Azim Premji University

GIANT MILKWEED

The Giant Milkweed is a plant that grows next to roads and in open fields and scrublands.
It gets its name from the milky-white juice or sap found in the leaves and stem.
The milkweed plant is visited by many insects, small animals and birds.

This plant is known by many names; in English it is the Giant Milkweed, Yakka Gida in Kannada and Aak in Hindi.
What name is this plant known by where you live?

The white sap can be unsafe for you and other animals if eaten in large quantities.This is one way the plant protects itself from insects and animals that like to eat its leaves. The sap can also irritate your skin and eyes. Always wash your hands well with soap and water after touching the leaves or bark of this plant.

Can you think of other ways in which plants protect themselves from people and animals?

LEAVES

The leaves are soft, oval and pale green. You might find a striped caterpillar munching on the leaves. This is the caterpillar of a Plain Tiger Butterfly. Milkweed is a 'host plant' for these butterflies. This means that the butterflies lay their eggs on these leaves. Once the caterpillars emerge from the eggs they eat the leaves.

Look at the butterfly closely, what colours do you observe? Why do you think it shares a part of its name with the Tiger?

FLOWERS

Milkweed flowers are light purple in colour. Many people think the flowers look like a crown - which is why the milkweed plant is also called the Crown Flower.

The large blue-black noisy carpenter bee, butterflies, beetles, fruit flies and wasps are just some of the insects that visit the flower.

FRUIT AND SEEDS

Inside the fruit or seed pod of the milkweed plant you can find small, flat seeds. Each seed has a white tail of hair-like fibres. Some birds use these white, fluffy hairs to make their nests soft and comfortable for their chicks. When the seed pod opens, these little seeds float away to grow wherever the wind carries them.

If you find a milkweed seed, place it on your palm and gently blow.
Does it float in the air?

STEM AND BARK

The strong, sap-filled stems of this plant spread out close to the base of the plant. Look closely at a broken stem or leaf - do you see the sap oozing out?

You might see shiny blue milkweed beetles, or a colourful painted grasshopper hiding among the stems. The painted grasshopper eats the sap-filled leaves of this plant which makes it harmful to other animals that may want to eat it.
Its bright colours warn other animals that it is unsafe to eat!

You may also spot aphids - tiny white or yellow insects that live on the leaves and stems. Near them, you are sure to see some ants. Ants and aphids have an interesting friendship - the aphids suck the sap of the plant and put out sweet waste called 'honeydew' which the ants love to drink.To say thank you, the ants protect the aphids from other insects that like to eat them.

Observe a milkweed plant nearby - you will see many other creatures, small and big!
Make a list or draw the visitors you see.

"Chlorine is a deadly poison gas employed on European battlefields in World War I. Sodium is a corrosive metal which burns upon contact with water. Together they make a placid and unpoisonous material, table salt. Why each of these substances has the properties it does is a subject called chemistry."

— Carl Sagan

Catch the next issue of **i wonder...** to explore **'Our Chemical World'.**

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