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i wonder...

Rediscovering School Science

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An Artistic Exploration

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

Imagination is in all aspects of our life—music, art, literature, scientific inventions and discoveries, and how we understand our place in the natural world. Our powers of imagination allow us to think about what the world was like, what it is, and what it could be. And when we ask the questions 'what if?' and 'what might be', they open much greater possibilities. They take us beyond what we know and where we are, pushing us to think and create in novel ways, a process that the psychologist and cognitive scientist Alison Gopnik describes as *"just what our human minds do best—take the imaginary and make it real."* It requires us to go beyond reproducing what we see and know; to evaluate or combine existing knowledge in new ways. In the context of science, cognitive scientist Nigel J. T. Thomas explains that *"scientific **understanding** involves coming to see some aspect of reality in a particular way, and creativity depends on coming to see things in a **new** way."* The practice of science—particular ways of observing, reasoning, using imagination to devise hypothesis, experiment, and construct explanations to make sense of evidence—is a creative process.

Often creativity is perceived as a unique trait of geniuses or talented individuals. The Russian psychologist Leo Vygotsky argues that it is present *"whenever a person imagines and creates something new, no matter how small."* He reminds us that a large part of humanity's creations has emerged from collective creativity—a combination of these *"small"* individual creations. Here, Vygotsky emphasizes the importance of cultivating creativity in school children since *"the entire future of humanity will be attained, through the creative imagination."* And if we see the purpose of education as preparing children for the future, *"development and exercise of the imagination should be one of the main forces enlisted for the attainment of this goal."* Providing rich and diverse sensory experiences, says Vygotsky, is critical in supporting the *"operation"* of a child's imagination. Nurturing creativity requires an environment where children can express themselves freely and without fear of being judged. Psychologist Mark Runco calls this *"a tolerant environment"*, adding that *"as a parent or a teacher, you can model that creativity is valued and be open-minded when your child gives an answer you didn't expect."*

In this issue, many of our authors share their explorations and experiences of various dimensions of creativity in science teaching and learning. In the theme section 'Our Chemical World', Ranjit presents the possibilities that a collaborative artistic exploration of chemical reactions can open up for students to strengthen their chemistry understanding and build scientific skills. In reflecting on the role of the teacher in this approach, Ranjit shares his experience of how being attentive and tolerant of childrens' questions and ideas can nurture creative inquiry and empower them to take ownership of their learning. In their respective articles on teaching the nature of matter and tracing the evolution of the definition of elements, Uma and Srinivasan touch upon how a historical approach can help students understand abstract notions in chemistry. Both articles may also be helpful for students to appreciate the importance of collective creativity in scientific inquiry and practice. The act of writing a poem is a unique expression of imagination and communicating emotion in words. But what is its place in the science classroom? In our 'I am a Scientist' section, scientist-poet Mala explains how she combines her passion for poetry and chemistry to explore the chemical world with her students. She suggests that encouraging students to write poems can be one way of helping them engage more with the subject and give teachers insights into student understanding. An inclusive, judgment-free, safe classroom environment allows students to be imaginative in their thinking, questioning, and explorations. Our 'Science Educator at Work' section features Dhanya's article, where she shares her approach to creating such an environment and the possibilities it opened up for students to engage in a deeper inquiry and reflection of the various dimensions of human reproduction.

What are some of your own experiences in cultivating and nurturing creativity in your classrooms? Do share your experiences and feedback on this issue with us at iwonder@apu.edu.in.

Radha Gopalan
Editor

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NATURE OF MATTER

UMA SUDHIR

What are some of the most common alternate conceptions students hold about the nature of matter? How do they arise? What level-appropriate approaches can teachers use to build a more scientifically accurate understanding?

The physicist Richard Feynman once said that if only one bit of all the scientific knowledge we have is to be passed on to future generations, then it should simply be this that matter is particulate. Since the atomic theory lies at the heart of modern chemistry, it is usually introduced to children at the beginning of middle school, even before they have engaged with formal chemistry courses.

However, this theory and related concepts are often taught in a superficial manner, and children are not given sufficient time to assimilate ideas about the nature of matter. Neither do we share the evidence for the particulate nature of matter with them, nor do children learn of the implications of the atomic theory in describing chemical changes or changes in the state of matter. This is further complicated by the fact that chemical symbols are also introduced at an early stage and are used to convey different things at different times without adequate clarification. Consequently, children tend to see the atom as a mysterious entity and fail to connect the abstract symbols used to represent them with observed phenomena in the real world.

Prior and alternate conceptions

This lack of understanding is evident in several studies which show that children exhibit a range of prior or alternate conceptions about the particulate nature of matter, which tend to be difficult to unlearn. Children see the properties of these particles as being continuous with their observations of the bulk properties

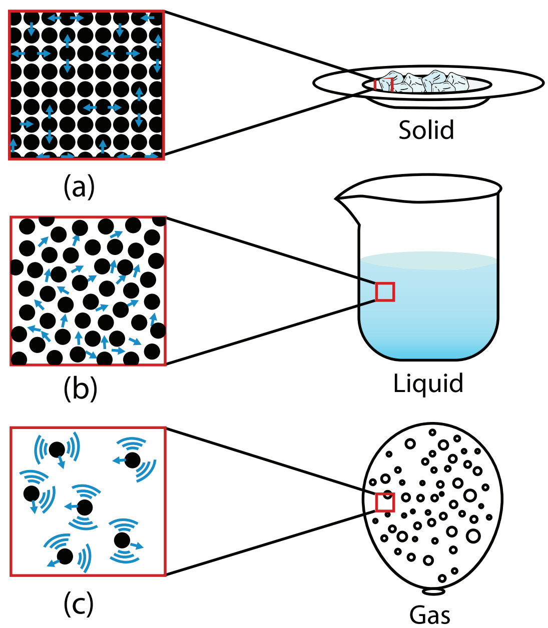

Fig. 1. Misleading illustrations in textbooks can influence student misconceptions about the nature of matter. For example, this is an illustration from the first chapter 'Matter in our surroundings' from the current NCERT science textbook for Grade IX. If students were to believe this depiction to be accurate, then they would believe that the density of the solid would be at least twice that of the liquid form of the same substance, and the density of the liquid would be around four times that of the same substance in the gaseous state. This is obviously not true of any known substance.

of a substance, and do not develop an appreciation for the relationship between bulk phenomenon and the atomic nature of matter. For example, they assume that because chlorine gas is yellow-green in colour, its atoms will be yellow-green in colour too. Similarly, children tend to attribute changes in macroscopic behaviour to changes in the particles. For example, they may believe that a solid expands because its atoms expand, or that a solid melts into a liquid when its atoms 'melt'. Other studies show that even when children associate the correct technical term with an event or phenomenon, they may not be able to give a coherent account of the process involved in it. Like when shown a cube of ice kept at room temperature, children may correctly identify the ice to be 'melting', but have no idea of what melting means at the molecular level.

One factor that contributes to these misconceptions is the inclusion of misleading illustrations and models in textbooks. For example, the decrease in density when (most) solids melt and the extent of their expansion when they are heated are both greatly exaggerated (see **Fig. 1**). Liquids are represented in a way that suggests that they are readily compressible. The decrease in density when a liquid changes to a gas is underrepresented. The number of molecules shown in most diagrams does not convey any idea of how many particles are being talked about. So an appreciation of 'bulk' properties arising out of the combined action of very large numbers of particles is absent. Illustrations often relate the colour of particles to the colour of the bulk material; an atom of carbon is shown to be black. Diagrams also often show 'molecules of water' floating in a blue background (see **Fig. 2**). This gives students the impression that water and its molecules are two independent things.

Some misconceptions may arise from inaccurate statements that we, as teachers, share in class, perhaps as short-cuts. For example, we may say that water consists of hydrogen and oxygen. This is imprecise—the water **molecule** is made up of two atoms of hydrogen and one atom of oxygen. Water consists of water molecules and no trace of any property of hydrogen and oxygen atoms can be seen in it.

Other misconceptions may arise from the ease with which teachers and textbooks shift between different levels when talking about matter. For example, they may both move between descriptions of the macroscopic properties of the reacting substances, their submicroscopic properties (the atoms and molecules taking part in the reaction), and the symbol system (formulae and equations) used to denote a reaction. Neither may make explicit to the learner what shifts have taken place, what aspect is being discussed, and how these are interrelated. As children do not get enough experience in conducting chemical reactions and seeing mass relationships between reactants and products, they find it difficult to connect events occurring at these three levels. Thus, for example, children often say things like N_2O_5 cannot be prepared from N_2 and O_2 because three more atoms of oxygen would be needed. This suggests that they don't understand the relationship between the element and its depiction in the form of a symbol or a formula. Since they have no appreciation of how these formulae have been arrived at, they also tend to change the numbers of various atoms in the formulae in order to balance equations (an activity that they see as a mathematical exercise instead of one that reflects the exact quantitative nature of the reaction).

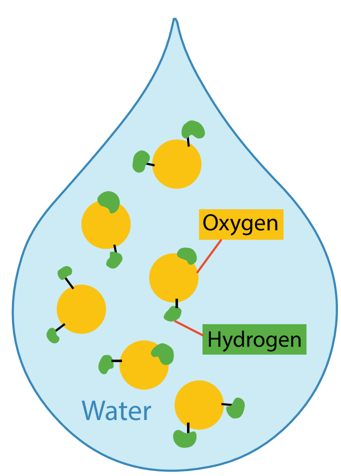

Fig. 2. Each water molecule is made up of two atoms of hydrogen and one atom of oxygen. What is the blue background in which these molecules of water float?

Due to the casual nature of instruction, children often do not know which concepts are useful or relevant in describing or explaining a certain phenomenon. For example, children who see the electrolysis of water molecules produce hydrogen and oxygen molecules are likely to say that boiling also causes water to split into hydrogen and oxygen (both gases). This may be due to the fact that they give undue importance to the observation that both boiling and electrolysis seem to need energy.

Children may also have difficulties in recognising gases as matter. If so, they may not take into account the possibility that gases may be used up or produced in a reaction. This leads to confusion about what exactly a chemical reaction is. For example, if children do not recognise the role of oxygen and atmospheric moisture in the rusting of iron, they tend to believe that it is a property of iron to turn red and crumbly after some time. They may also believe that the iron remains unchanged in spite of rusting. It is as if they are drawing parallels with aging—as an infant named Nirjuli grows up, her height, weight, shape, and almost everything else changes, but she is still Nirjuli!! They also have difficulty comprehending the idea that a large amount of empty space exists between the particles in a gas.

Where children have prior concepts about substances, they do not easily substitute them with more 'scientific' ideas. For example, studies suggest that children may use the particulate nature of matter to describe gases because they do not have any prior ideas about the nature of gases. Since this is not the case with solids and liquids, children resist the idea that these forms of matter are also made up of particles. This is also why they tend to think of the properties of atoms in solids and liquids as being continuous with their bulk properties. Such alternate ideas are discovered only on probing because children quickly learn to give, and we tend to accept, expected answers without having any concrete understanding of what these answers signify.

Introducing properties of substances

How do we convey such complicated theories to children? We believe that students do not need to learn an overarching theory about the nature of matter till they are familiar with the properties of various substances and how they react with one another. Thus, at Eklavya, we introduce children to the physical and chemical properties of various substances in middle school (in Grades VI, VII, and VIII) and strongly recommend that abstract theories be taught only in high school (Grades IX and X). This means that our focus in middle school is to offer children some exposure to the following ideas or concrete experiences before they move on to theoretical issues:

1. Specific properties of substances: Children need to be familiar with simple experiments which show that different chemical substances have different properties that can be tested and observed. Also, they need to have some experience in distinguishing between substances on the basis of their chemical properties. For example, many metals may look similar but differ markedly in their reaction with acids, and this can be easily studied.

2. Physical versus chemical changes: Often, teachers share seemingly straightforward indicators to help students recognise that a chemical change has taken place and a new substance has been formed. But students are only able to appreciate this when they perform experiments where they have to distinguish between a chemical and a physical change, and the conditions under which these changes take place. Thus, they must learn to perform simple tests to identify differences in the properties of the starting materials of a reaction and its final products.

3. Different states of matter: As discussed before, while students may learn how to use the correct terms for the processes involved in a change in states, they have no conception of the submicroscopic processes that occur during these changes or how these changes can be brought about. For example, the external source of energy that causes the boiling of water and its conversion to vapour may be more apparent to students than the energy involved in the melting of ice. Similarly, they may not understand that the reverse processes of condensation and freezing release the same amounts of energy, or that evaporation causes cooling. One way to help students understand these processes is to encourage them to closely observe seasonal changes in states of matter. For example, students living in cold areas could be encouraged to test the folk theory that the weather becomes warmer after it snows, and gets colder when the snow starts melting. Similarly, students living in warm areas could be asked to test if the evaporation of sweat from their skin feels cooling or heating. Since the rate of large-scale evaporation reduces with a resulting rise in humidity, it is possible that students may feel 'hotter' as their sweat takes longer to evaporate. In such cases, encouraging students to study the condensation of water vapour on a cold surface could help them appreciate the same process in reverse.

4. Elements, compounds, and mixtures: The usual route of teaching this starts with introducing the idea that atoms of different elements combine to form compounds. Due to the manner in which this is taught, students are often confused about the difference between compounds and mixtures, and why molecules of elements exist. At Eklavya, we start with the purification of mixtures instead. We also introduce students to the twin questions of separation and purity. This helps them appreciate how our classification of a substance as 'pure' depends on the techniques of separation available to us and the methods we use to test the purity of a sample.

Parting thoughts

How do we introduce students to the abstract concepts and theories related to the particulate nature of matter? We believe that the tradition of diving directly into Dalton's postulates does not work. Instead, it would be helpful if we were to introduce students in middle school to the bulk properties of substances and help them identify changes in their physical and chemical properties through simple experiments. In high school, students can be taken through all the convoluted paths and by-lanes that various theories about the nature of matter gave rise to, and how these debates were resolved. Rather than disguising history as chemistry, this approach would help them appreciate the cumulative work done by Berzelius, Guy-Lussac, Avogadro, and Cannizzaro. It would also help them assimilate the ultimately simple resolution given by Dalton's atomic theory, and become familiar with the contributions of Lavoisier and Boyle. In addition, an awareness of the historical sequence of the development of ideas in the field of chemistry will help students understand and appreciate the nature and process of science.

Key takeaways

- Various alternate conceptions about matter make it hard for students to grasp its particulate nature or use this idea to explain observed phenomena.
- Students often confuse the bulk properties of matter with the properties of its constituent atoms.
- Some of these confusions arise because of problematic illustrations in textbooks, while others arise because of the casual nature of instruction.
- Exposing students to different 'chemical' experiences in middle school may help lay the necessary foundations to introduce abstract theories in high school.

Notes:

1. This article was first published in Sandarbh, Issue 83, pg 13-21. This version is restructured and revised for conciseness. URL: https://www.eklavya.in/magazine-activity/sandarbh-magazines/192-sandarbh-from-issue-81-to-85/sandarbh-issue-83/560-children-s-misconceptions-about-the-nature-of-matter-by-uma-sudhir.
2. Source of the image used in the background of the article title: Rusting iron. Credits: Logan King, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Rusty_Barbed_Wire.jpg. License: CC-BY-SA.

Uma Sudhir is associated with Eklavya's science education programme.

AN ARTISTIC EXPLORATION

RANJIT KUMAR DASH

Can integrating the art and aesthetics of lithography in an inquiry-based approach to chemical reactions strengthen student understanding and help them develop important skills in science? What questions, discussions, and digressions emerge from such an approach? What role does the teacher play in facilitating such explorations?

An experiential inquiry-based approach to teaching science may not only strengthen conceptual understanding, but also go beyond topic-specific learning outcomes to help students develop important skills in the practice of science. These include observation, critical questioning, abstract thinking, verbalizing gaps in understanding (self-awareness), experimentation, and collaboration (practical skills). Can we deepen such learning experiences by offering space for students to work with a sense of mindfulness and beauty?

To explore this question, I introduced the fundamentals of chemical reactions to Grade VII students using the art of lithography (see **Box 1**). I knew that this kind of hands-on work was likely to capture their attention. My decision was also guided by the fact that the students in my class had been exposed to a variety of artwork, and enjoyed creating art themselves. And some of them had shown a capability for the practical skills needed for this kind of artwork.

Box 1. What is lithography?

The term lithography is derived from two Greek words—'lithos' meaning 'stone' and 'graphein' meaning 'to write'. Based on the immiscibility of oil and water, it uses simple chemical processes to create images on a flat surface. In its simplest form, an image (called the positive image) is drawn on a flat rocky surface (like, limestone or marble) with a hydrophobic (water-repelling) medium (like, wax crayons, oil paint, or nail polish). An aqueous acid solution is used to etch off the negative image (the unpainted parts of the surface) to impart 3-dimensional features to the surface. One could also attempt to combine the visual effects of both positive and negative images while choosing a pattern for etching.

Aims of the activity

One aim of this activity was to strengthen an understanding of important concepts in chemical reactions. Students in this age group had not yet been introduced to the atomic structure of matter, but showed a factual understanding of chemical reactions in terms of the properties of substances and some preliminary ideas about acid-base reactions. While some students seemed to appreciate topics involving the nomenclature and classification of matter, quite a few did not relate to the abstract nature of these topics. All the students were quite curious to observe some of the chemical changes that they had heard and read about.

The other, broader, aim was to help students develop a propensity to work and inquire together, and to explore concrete experiences as a scientist would. Such activities inevitably draw out interesting questions and comments from students. While the plethora of questions addressed to the teacher can sometimes be daunting, I feel that only some of these questions need answers. Some others may need some refinement by the teacher. But many questions could be left, perhaps with some pointers, with students for their own exploration. For the teacher, this last category of questions can be seen as an invitation to participate in the way students make sense of things. They reveal the nature of the student's mind that is simultaneously observing, questioning, trying to offer explanations, and connecting their thinking to everyday experience.

The activity

I started the activity by introducing students to the marble slabs and sea shells that we were to use as our base material (see **Activity Sheet I**). I also explained the overall process and the expectations involved (see **Fig. 1**).

During steps 1 and 2, I invited creativity by encouraging students to work in groups and use nail polish to paint any shapes they agreed upon on the surface of the base material. The teacher may need to ensure that there is good understanding and alignment within each group on what to draw.

Step 3 was a teacher-led phase. Each slab was immersed in an aqueous hydrochloric acid solution used as an etchant and kept in a shallow transparent plastic pan to allow us a clear view. The students were encouraged to observe the entire process and record their observations and any thoughts that occurred to them.

In steps 4 and 5, the etched sample was washed with plain water and the paint was wiped off with acetone. Students were then able to see, touch, and feel the etched surface. Each group was encouraged to observe and correlate the effects of their drawings on the etched marble surface. From a purely aesthetic point of view, they were also encouraged to repaint the figures as they wished, using watercolour, crayons, or ink to give finishing touches to their samples (see **Fig. 2**).

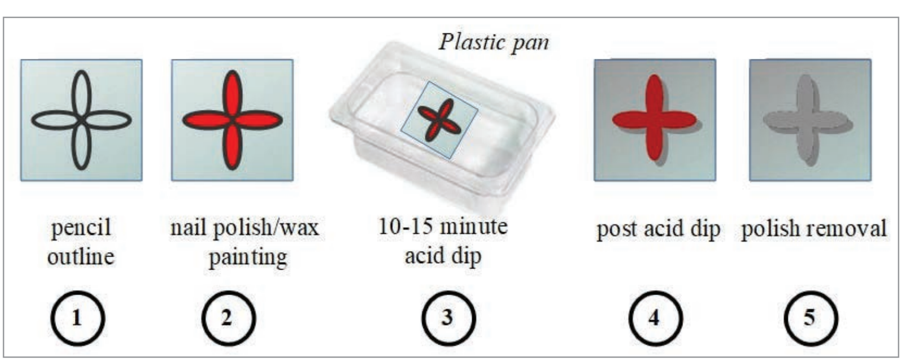

Fig. 1. Different steps involved in acid etching.

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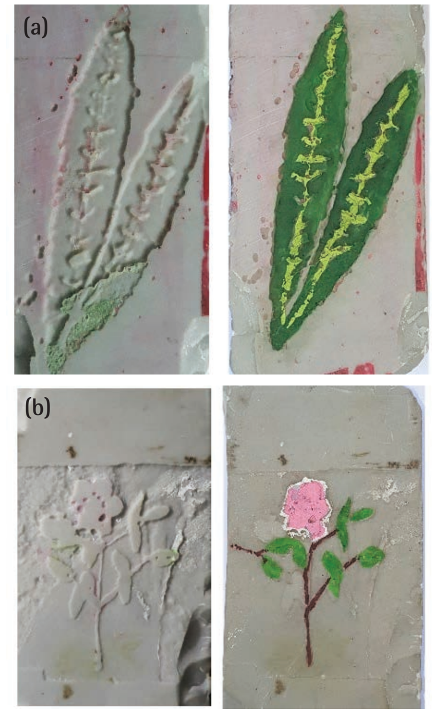

Fig. 2. Some examples of repainting. The twin leaves in (a) and the flower in (b) have been repainted.

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Trigger questions: connecting science processes to experiences

Throughout the activity, but particularly during its last stage, students came up with many questions, observations, and new ideas to implement in a second run. It was a joy to watch them discuss these with each other, and make new connections. Here are some of their questions and comments along with some notes on their background, and the kind of learning they may lead to:

Question: *"Can we use citric acid or vinegar to etch designs on any stone? Can I use this method to make stone jewellery in the holidays?"*

I pointed out that this method may not be appropriate for 'any stone or metal'. I also indicated that this was a great idea, provided students could use this method of etching at home in a safe manner. Towards this goal, I suggested that they could start by using kitchen vinegar with some citric acid on marble tiles or chalk stone surfaces.

Box 2. Would acid etching stop by itself?

We decided to explore this possibility by letting this experiment continue for the duration of an entire class. The students observed that the rate of appearance of bubbles (that appeared at the start of the reaction) showed a gradual slowing down and stopped completely after about 15-20 minutes. They also observed that by this time the marble slab looked porous and diminished. Student groups were invited to discuss this observation and offer some explanation for it. Two interesting responses emerged:

a) Just like the solubility of sugar in water, there may be some limit to how much marble gets dissolved by acid;

b) Since the acid and the marble are in the same solution, the marble may have mixed with the acid, making the acid more and more impure. This might explain the slowing down of the reaction.

One can see these very natural and logical connections the students had arrived at while trying to explain their observations (also see **Teacher's Demonstration: Is Acid Etching Self-limiting?**). One may pause here and wonder what brings about such reasoning in preadolescents. Is it exposure to scientific literature, discussions, or just a developmental outcome? Is this an outcome of early age involvement in observational activities? Are some social factors also involved? Perhaps multiple factors may contribute to the development of such intelligence. Such instances seem to suggest that it may be possible for young minds to discover the fundamental questions of science even within the constraints of today's classrooms and syllabi.

Question: *"How fine can the carvings be? Can I draw hair-like lines?"*

The student was trying to contrast this chemical etching technique with a stone carving process that she was familiar with. Having observed the effort (energy) it takes to use a chisel to carve a slab of stone, she was wondering if the removal of matter from a marble surface through chemical etching also needed some energy. My response was to convey that chemical processes also involve work at a microscopic level.

Question: *"What are those whitish powdery things? Is that marble powder? How small can we cut a piece of marble so that it still is marble?"*

Here the student was referring to a powdery white substance that was formed during the reaction. She was unsure if this powder came from inside the marble piece. This question brings to mind early scientific debates about the nature of matter at microscopic scales. Atomists like Democritus used pure reasoning to suggest that there was a lower limit to dividing a grain of sand while retaining the properties of sand.

Question: *"Where does the etched-out marble vanish? What would happen to the marble if we leave it inside the acid solution for a long time?"*

This student wondered if it were possible for the acid to "eat up" the whole slab if the reaction was allowed to continue long enough. In other words, she wanted to know if this process would ever stop by itself (see **Box 2**).

Comment: *"As long as the acid solution touches just the surface, etching should continue. The entire slab need not be inside the solution."*

This comment came from a student who was interested in using less acid for the activity (see **Box 3**).

Question: *Is it possible to 'anti-etch' or 'grow' something on the surface of the slab?*

One group explored the possibility of drawing their "story" by combining both negative (etch) and positive (anti-etch) images on the same slab. While a negative image adds depth to the figure, a positive image renders an upward projection (see **Fig. 3**). They described this as an interesting challenge since they had to shift their attention between the two drawing techniques (see **Fig. 4**). While most of them seemed to like experimenting in this way for the fun of it, a student questioned if it was possible to combine both the techniques in a

Box 3. Can we use less acid for etching?

We made some changes in the setup to explore this possibility (see **Activity Sheet II: Less Acid for Etching**). In the modified set-up, we decided to place the slab upside down to ensure that only the surface to be etched would be in contact with the acid solution. Since the slab would be only partially immersed in the solution, we would be able to use much less acid for etching. To achieve this, we used four plastic bottle caps of the same dimensions to support the marble slab.

In spite of making a couple of attempts to set this up, it did not seem to work. The students and I wondered what could be preventing the etching from taking place. On closer examination, we observed that the slab surface that was in contact with the acid solution was covered with bubbles (which meant that the reaction had started), but these bubbles weren't rising up to the surface as in the previous set-up. Many of the students suggested that the bubbles could somehow be preventing the reaction from proceeding further. While this wasn't a full explanation, it offered a significant insight—the film of carbon dioxide may be preventing contact between the acid and the marble surface. Once I drew what I thought could be happening on the blackboard, most of the students seemed to understand this possibility better.

Getting clarity about a phenomenon is definitely valuable, but what is more significant is the way in which the mind arrives at such clarity. I hoped that a significant takeaway from this experience, at least for some students, was about how performing science experiments can surprise us (and scientists) at times.

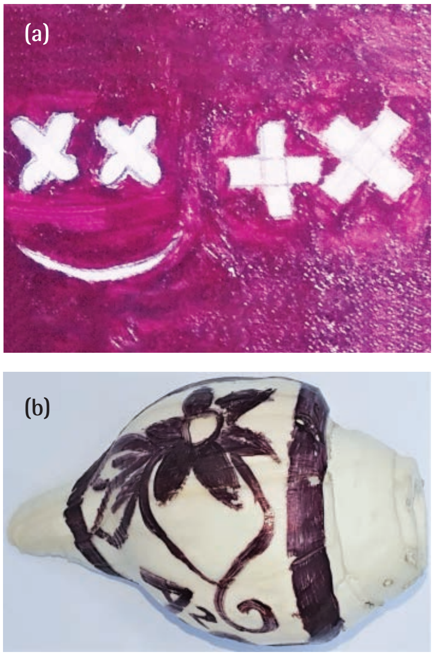

Fig. 3. The results of etching and anti-etching techniques. (a) A negative image of the crescent moon and stars. Here the background is painted with nail polish. Since this is hydrophobic, the acid solution reacts only with the exposed, unpainted surface. The moon and stars show depth. (b) A positive image of a flower. Since the flower areas are painted with nail polish, the acid solution will react only with the unpainted background. The flower will look elevated.

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Fig. 4. Combining etching and anti-etching techniques. A student group imagined a trip to an island. To the left of the image is a pair of coconut trees, and to the right is a boat anchor. This was created in such a way that the trees have gone down from the surface and the boat anchor has come up. Part of the student group was busy improvising the story. Clearly, a lot more was happening than just the learning of chemistry concepts!

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single figure. While this response was not directly related to a chemistry concept, the student's ability to sense this new possibility is an example of a creative act in the learning process—a trait to be encouraged.

Some reflections

(a) Discussion as a way of learning: Interesting discussions kept happening intermittently throughout the activity (see **Box 4**). The extent to which the students were interested in each other's questions, suggestions, and explorations was quite remarkable. These discussions were broadly about the nature of matter at microscopic levels, explaining an observation, sharing an insight by a student, and so on. It was as if the group had a mind of its own! Many students showed increasing self-awareness, in the sense that in attending to others' ideas and explanations, they became more aware of their own thinking. It was also interesting to see how some students were able to bring the class to a common understanding.

(b) Expanding and deepening connections: Such an integrated, inquiry-based teaching style allows many opportunities for deeper mental connections to be formed. For example, this activity allowed multiple possibilities of connecting various concepts while offering interesting digressions (see **Fig. 5**). Many potential digressions may be explored to break the monotony of the class. I feel that such contextual digressions bring about a reflective mood and may help in forming deeper mental connections.

Parting thoughts

Areas as diverse as arts, games, and cooking can offer many opportunities to teach science in a hands-on and fun-filled manner. The challenge for a science educator is to identify aspects of these areas that lend themselves to understanding specific concepts in the science curriculum, and to convert them into grade-appropriate activities in a creative manner. It is my submission that such science activities can help sustain the attention of a group without much coercion.

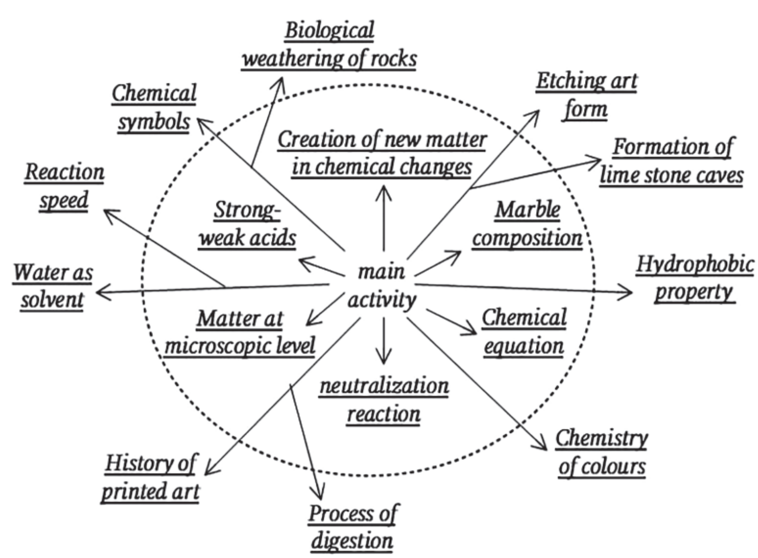

Fig. 5. A mind map that can be used by teachers for planning the activity. Such maps help link various concepts and ideas, and also in making directed and meaningful digressions in the classroom.

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Box 4. A sample of interesting discussions:

(a) On the nature of the acid:

Student A: *"Sir, the acid is in the water solution. But why does the smell hurt so much?"*

Student B: *"Perhaps the acid is evaporating from the water."*

My response: *"Yes, some acids evaporate from the solution. In general, the solution may contain substances that evaporate at different temperatures and at different rates. In this solution, hydrochloric acid evaporates more easily than water. That is what is hurting your sense of smell. It is the smell of hydrochloric acid in the air."*

Student C: *"You had mentioned that many acids are naturally found in gaseous form. Does this make it easier for such acids to escape from solutions?"*

This student was trying to apply the ideas of acids and bases introduced during earlier classes to a new question. This included the understanding that fire, which is a chemical reaction, tends to separate acids and bases—air takes up acids in the form of emanating smoke, and the earth (soil) takes up bases in the form of ashes. Thus, many acids (like CO_2 and HCl) are found in gaseous form, and many alkalis (like $CaCO_3$) are found in soil. It also drew from the understanding that water dissolves both acids and bases, and the reaction of these two solutions is called a neutralization reaction.

(b) On the reaction products:

My question: *"What do you think about the white powdery substance that is created when the reaction is going on? What could that be?"*

Student D: *"It must be marble powder."*

Student E: *"But when we break a regular marble slab, the powder does not come out like this. It must be something else."*

Student F: *"Is it something like rust in the iron bar experiment? Rust is different from iron, and did not exist before rusting...."*

Recognizing the formation of new substances is key to understanding any chemical process.

(c) On the hydrophobic nature of substances:

Student G: *"Sir, why is it that only the unpainted area reacts to the acid? Why does the painted area* ***not*** *react to it?"*

My response: *"Observe the surfaces in the painted and unpainted areas that are in contact with the acid. In the painted areas, the acid solution is in contact with the nail polish. So what do you think the nail polish does to the painted area?"*

Student H: *"Oh okay... So, the nail polish makes the reaction slower? That may be why the unpainted area gets etched faster."*

My response: *"Some substances like to 'stay away' from water even if they are dropped in water. Substances with this property are called 'hydrophobic'. Some examples of such substances are oil, nail polish, oil paint, fat, grease, and wax."*

Student H: *"So if the water in the acid solution has to touch the marble surface, it has to go through the paint, which it cannot do because of the nail polish. Right?"*

My response: *"Yes, that's right."*

Student G: *"But it is the acid which etches, and not water."*

Student H: *"Buddy, the acid is contained in the water. If the water cannot touch the surface, how can the acid touch it?"*

Box 5. Some suggestions for the teacher:

- Encourage students to observe things that they may have overlooked, and to probe some of their observations more deeply.
- Be open to co-approach ideas and concepts, and be tentative about them. This involves a capacity to be attentive and tolerant about how ideas take shape in students' minds, and then come to a common understanding.
- Pay close attention to the exchanges that take place within each group since it can give insights into the way students think on their own and in a group. Several ideas for experiments to extend the activity may emerge during these exchanges.
- Use the blackboard to draw mind maps to show the connections that students identify between the activity and chemistry concepts in their curriculum. These may include chemical reactions such as neutralisation (identifying the reaction and reaction products), the chemical composition of marble and chalks, weak and strong acids, etc.
- Through this activity try and bring about a 'fun, but still relevant' element in learning.

By increasing avenues for individual exploration, this approach can also be more effective in getting students with diverse interests, abilities, aesthetic sensibilities, and skill levels involved in the learning process. In addition, it empowers students with the 'art of exploration' and imparts a 'sense of ownership', both of which bring vitality to the learning process (see **Box 5**). Students not only learn the required concepts in chemistry, they tend to cherish such experiences till long after.

Our Chemical World

ACTIVITY SHEET I : ACID-ETCHING

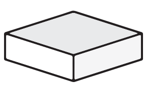
Aim:

To explore if:

1) Drawings can be etched on a marble slab or shell surface using chemicals.
2) This activity can be used to understand various introductory topics in chemistry.

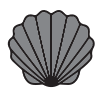
What you need:

Surface to etch on (1 per group of students)



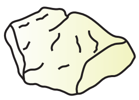
Marble slab of any shape with at least one plane surface to paint on

or



Sea-shell of any dark shade (medium size so that you can hold it and paint on it)

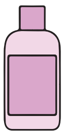
or



Any "fizzy rock" (a rock that is reactive to acid, like limestone, chalk stone) that is easily available locally with at least one plane surface to paint on

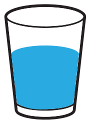
10% to 20% by volume of aqueous hydrochloric acid solution (add acid to water rather than water to acid)

Any quick-drying water-resistant acrylic liquid paint (like nail polish) of any colour (1 bottle per group of students)

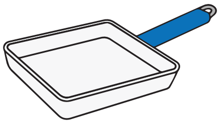


Acetone or nail polish remover (about 50 ml) to clean any left-over paint or drawing mistakes on the surface

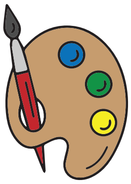
Some cotton or a piece of cloth to rub acetone against the surface if needed



Some tap water to wash the stones or shells after acid etching



A shallow transparent plastic pan



A variety of watercolours and crayons to repaint/decorate the surface after etching is over

What to do:

(a) Painting

- Discuss within your group and agree on what you would like to draw on the base surfaces (marble slab or shell) provided. Start by drawing the selected design on paper before you paint it on the base surface.
- Identify two people from your group to do the drawing. Use coloured nail polish to slowly and carefully paint the agreed-upon shape on the base surfaces. You can use nail polish brushes or painting brushes for this purpose.
- Clean the base surface with acetone if you would like to re-draw or modify the shape. This can be done multiple times to ensure that everyone in the group is satisfied with the final artwork. (Hint: starting with a paper-pencil drawing can help minimize the number of such iterations).

(b) Acid etching

- Give your group's painted sample to your teacher, who will carry out the acid etching step, one sample at a time.
- Observe the acid etching demonstration carefully. Record any observations, questions and ideas that your group comes up with. Particularly look for signs to suggest the starting and ending of any change in your sample.

(c) Cleaning

- Observe how your sample is cleaned to remove any acid residue before it is handed back to you.
- See, touch, and feel the texture of the etched surfaces. Compare the etching with your original drawing. Record your observations. Also, make note of any differences you notice between the kind of finish you expected and the actual surface finish.

(d) Finishing (Optional)

- Wipe off the nail polish colours by rubbing it with cotton or a piece of cloth dipped in acetone.
- Use watercolours or crayons to give finishing touches to your drawings.

Think about:

- Why is nail polish used to draw shapes for etching?
- Why is acetone used to wipe away the nail polish?
- What changes do you observe when the base surface is: (a) placed in the tray? (b) left in the acid solution? (c) removed from the tray? (d) washed with water? (e) cleaned with acetone to remove the nail polish? How would you explain these changes?
- What changes do you observe in the colour, texture, and appearance of: (a) the 'drawn' and 'not drawn' surfaces of the base material, and (b) the hydrochloric acid solution in the tray? How would you explain these changes?
- Why do you think bubbles were formed when the base surface was placed in the acid solution? Why do the bubbles come up to the surface of the solution? Have you seen something similar elsewhere?

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ACTIVITY SHEET I: ACID-ETCHING

TEACHER'S GUIDE

1. Two consecutive classes can be used on different days. In the first class, students can understand the process and finish the artwork. The second class can be used for the teacher-led demonstration of acid etching.
2. This is designed as a group activity. Break the class into groups of 2-4 students each to ensure maximum participation by all the students.
3. Explain the activity step-by-step, the time required, and the precautions to be taken in each step.
4. Introduce the students to the materials they will be using as the base for their etching. Give each group one piece of marble slab or shell and tell them that they are going to paint on the surface which will be etched eventually.
5. Use the blackboard to explain hydrophobic and hydrophilic properties. Explain clearly which areas of the surface will get etched by acid due to the acid-base reaction.
6. Clearly explain which tasks will be performed by the student groups and which ones will be demonstrated by the teacher. Also, instruct the students to observe and take notes during the demonstration.
7. Some groups might need help deciding what to draw on their base surface. Also, the students who are chosen to paint images on the base material may require support and guidance to do this with care. Nail polish brushes are not as firm as a paintbrush, and using these may require dexterity and careful manipulation.
8. Make students aware of specific precautions that must be taken in handling acetone and acids in general:
   - Acetone is volatile and flammable and can irritate the skin, nose, and eyes. Ensure that the activity is done in a well-ventilated area. Students should avoid contact with acetone. In the event of contact, ensure that they wash the contact area thoroughly.
   - Use acid-alkali gloves when handling hydrochloric acid, and explain to students the importance of using protective gear when handling corrosive acids, solvents, and alkalis.
   - Explain the safety aspects of mixing acid and water to students. Specify why it is safer to add acid to water rather than the other way around.
9. For the demonstration of the etching step:
   - Prepare etchant (diluted acid solution) by adding concentrated hydrochloric acid (37% standard solution) to distilled water in the shallow pan. Ensure that you slowly add the concentrated acid to the water in the ratio of 10% to 20% by volume. If the acid is too dilute, the reaction may take longer. Decide the final volume of the solution depending on the size of the base materials.
   - Using acid-alkali gloves, immerse each sample carefully in the etchant for about 10-15 minutes. Make sure that the surfaces which need to be etched are facing upwards.

- Draw your students' attention to the appearance of bubbles as it signals the start of the reaction. Ask students to note when the reaction slows down (typically after 10 to 20 minutes of immersing the samples depending on the initial strength of the acid solution) and stops.
- Remove the pieces 5 minutes or so after the bubbles have disappeared. You may continue with the next fresh piece with the same solution. If the reaction does not happen or the solution has become cloudy, prepare a new solution for each new set of etchings.
- One or more samples can be etched together depending on the volume of etchant. However, the etching tends to get shallower as the number of samples increases. One can try this out with 1 or 2 samples at first and then decide. This can be a point of observation and discussion.
- Wash the etched samples with tap water to remove any residual acid.

10. Encourage the students to make their observations and record them as a group. Clarify that this activity is an invitation to think and discuss as a group.

TEACHER'S GUIDE

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Our Chemical World

TEACHER DEMO : IS ACID ETCHING SELF-LIMITING?

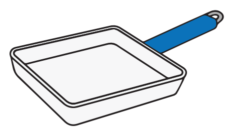
Aim:

To explore if:

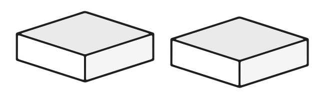
1) The reaction between the marble and the dilute acid solution stops by itself.
2) The concentration of the acid affects the reaction time.

What you need:

100 mL each of 10% by volume of aqueous hydrochloric acid solution.



A shallow transparent plastic or glass container to hold the acid solution.



Two small pieces of marble that are as close as possible to each other in shape, size, and weight; and can be easily placed in the plastic tray. The weight of each piece should be between 20–30 g.

What to do:

1. Clean both marble pieces with tap water. Ask the students to weigh the two pieces of marble and make note of their weights. Use this step to confirm that the two pieces have identical weights.
2. Gently place the first piece of marble in the 10% acid solution. Ask students to record the time when bubbles start appearing (indicating the start of the reaction). Also, ask the students to record the time when the bubbles stop appearing (end of the reaction).
3. Use a pair of tongs to pull the marble piece out of the acid solution and wash with tap water. Ask the students to weigh the washed marble piece and make note of the weight.
4. Put the marble piece back in the same batch of 10% acid solution. Leave it for 10-15 minutes. Take it out again, wash it, and ask students to weigh the piece again.
5. Repeat steps 2-3 of the experiment with the second piece of marble.
6. Put the second marble piece in a fresh batch of 10% acid solution. Leave it for 10-15 minutes. Take it out again, wash it, and ask students to weigh the piece again.

Ask students to record:

	Piece 1:	**Piece 2:**
Initial weight (grams)		
Weight after the 1st round of etching (grams)		
Weight after the 2nd round of etching (grams)		
% weight change		
Duration of appearance of bubbles in 1st round of acid etching (minutes)		
Duration of appearance of bubbles in 2nd round of acid etching (minutes)		

Ask students to think about:

- With each marble piece, was there any difference in the duration of appearance of bubbles between the first and second rounds of etching?
- What was the % weight change in each of the two marble pieces after the first and second rounds of etching?

Invite students to discuss:

- Why do bubbles form during acid etching? Can you think of any reasons for this observation?
- Compare the % of weight change in each of the two marble pieces after the first round of etching. Was there a difference? Can you think of any reasons for this difference?
- Compare the % of weight change in each of the two marble pieces after the second round of etching. Was there a difference? Can you think of any reasons for this difference?
- Compare the duration for which bubbles appeared in the first round of etching. Was this different for the two marble pieces? Can you think of any reasons for this difference?
- Compare the duration for which bubbles appeared in the second round of etching. Was this different for the two marble pieces? Can you think of any reasons for this difference?
- Do you think that acid etching is self-limiting or ends by itself? What factors help end this reaction?

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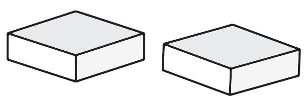
Our Chemical World

ACTIVITY SHEET II : LESS ACID FOR ETCHING

Aim:

To explore if etching an upside-down (inverted) marble surface will involve less HCl solution.

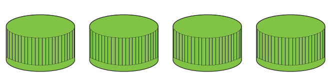
What you need:



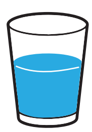
Two marble slabs that are identical in size, shape, and weight; and have at least one plane surface (preferably with an area of 2-3 square inches) of identical dimensions on each

20% by volume of aqueous hydrochloric acid solution

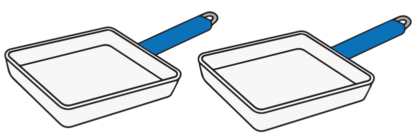
One bottle of nail polish of any colour



Four identical plastic bottle caps to support one of the slabs



Tap water to wash the slab after acid etching



Two shallow transparent plastic pans

What to do:

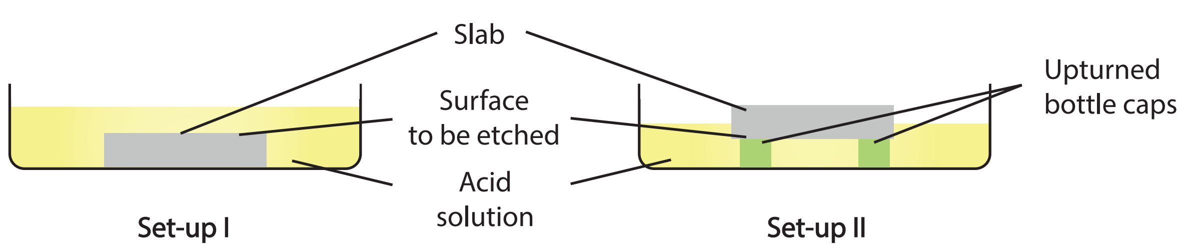
(a) Painting on the marble slabs

- Paint all the surfaces of both the slabs with nail polish except the flat surfaces where etching is supposed to happen.
- Leave aside for 5-10 minutes to let the paint dry.

(b) Setting up acid etching:

Assemble the following acid etching set-ups (see Figures A and B).

- Set-up 1 (see Figure A): Take one of the plastic pans and place the 1st slab inside it with its flat surface facing upwards.
- Set-up 2 (see Figure B): In the second plastic pan, place the 2nd slab with its flat surface facing downwards and supported by the four bottle caps.



(c) Acid etching (this step is a teacher demonstration)

- Observe how your teacher slowly pours acid solution into both the set-ups. This volume must be enough to cover the upward-facing surface (which is to be etched) of the slab in Set-up I, and the lower-facing surface of the slab in Set-up II. The volume of acid needed in Set-up II will be much less than that needed in Set-up I.
- After bubbles stop appearing, observe how your teacher uses a pair of tongs to pull out each of the slabs and then washes it under tap water to remove any residue of the acid.
- Observe the extent and quality of etching on both slabs.

Observe and think about:

- How long does it take for bubbles to appear in Set-up I? Where do they appear? How long does it take for the bubbles to stop appearing?
- How long does it take for bubbles to appear in Set-up II? Where do they appear? How long does it take for the bubbles to stop appearing?

Discuss:

- Compare the two set-ups for the number of bubbles and the rate at which they appear. Do you see any differences? If yes, can you suggest any reasons for the difference?
- Compare the extent and quality of etching on both slabs. Do you see any differences? If yes, can you suggest any reasons for the difference?

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Key takeaways

- It is useful to plan classroom activities that encourage an understanding of science concepts through art and aesthetic work.
- Activity-oriented classes allow a multi-sensorial and 'fun' approach to learning. Students get an opportunity to relate to concepts through their own observations, feelings, and experiences. This may aid better attention and deeper learning.
- It is important for the teacher to lead the class, but not at all times. If student groups can be encouraged to work together, they listen and learn from each other; examine, extend and trim down each other's reasoning; and, sometimes, bring the majority of the class to a common understanding.
- Such an approach may allow the teacher to facilitate the development of some psycho-emotional skills that are crucial to the practice of science. These include observation–listening–thinking, working together, intelligent guesswork, as well as the ability to make sense of information and make connections.

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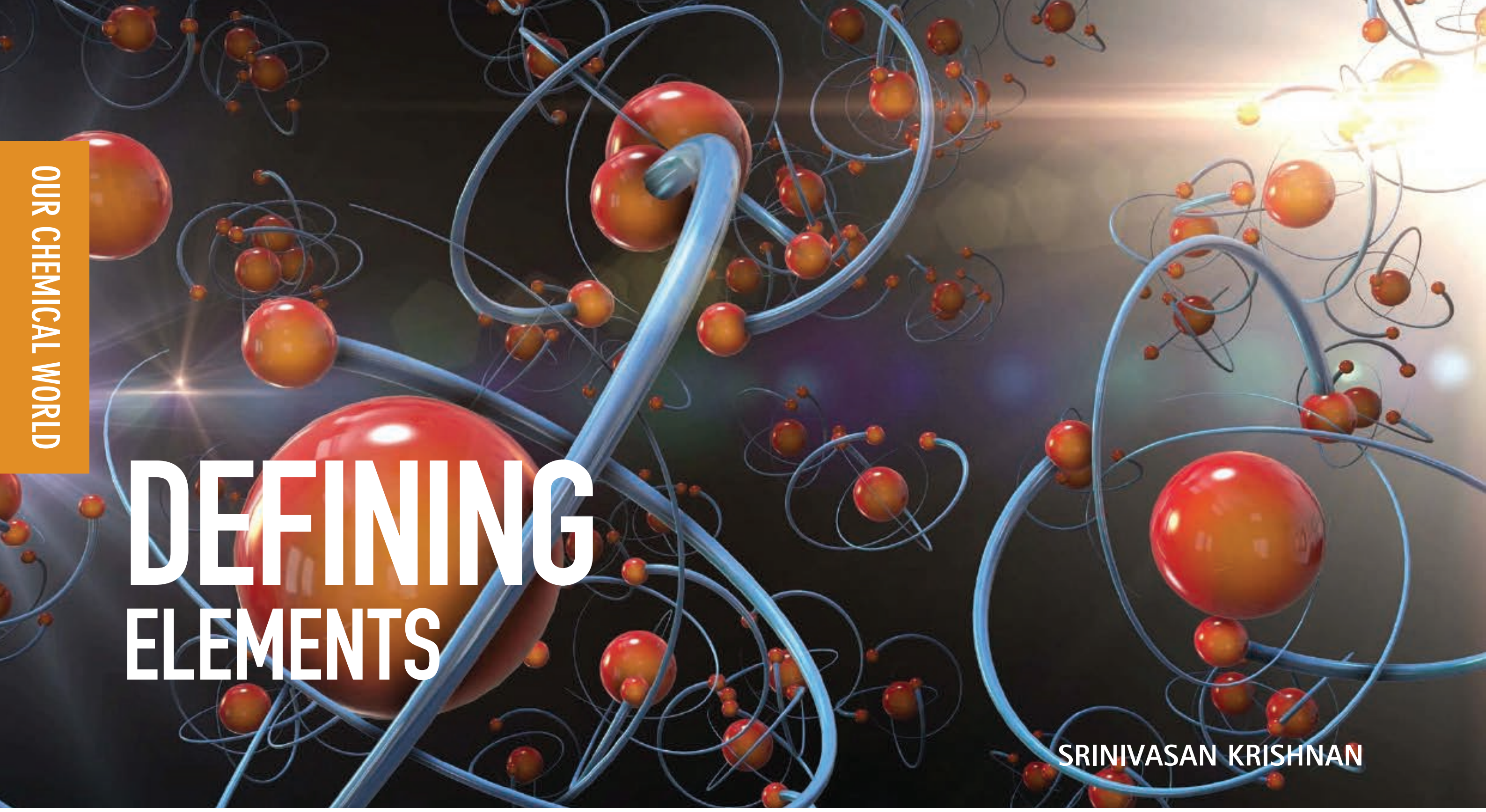


DEFINING ELEMENTS

SRINIVASAN KRISHNAN

When do we call a substance an element? How is the concept of an element linked to that of an atom? Are atoms real? Why are our definitions of elements prone to ambiguity and change?

We use our senses to observe the different substances that make up our world. And we use our powers of deduction and inference (dependent largely on existing technology and the robustness of intellectual structures) to discover new substances and categorize known ones in ever more suitable ways.

This inquiry into the world of matter also aids in the synthesis of new substances. From antiquity, humans have displayed the ability to make new kinds of substances by a combination or distillation of existing ones. Everyday examples of this ability include cooking a dish, mixing medicines and beverages, constructing buildings and tools, and so on. Our quest to make ever more complex substances and systems with 'desired' properties is based on our ability to answer the question—what are the basic substances out of which all other substances are made?

The idea that all substances on earth may be made up of the same unique and fundamental building blocks is not new. Many ancient civilisations have imagined the existence of these element-like substances (see **Box 1**). Some of them have also defined these 'elements' in terms of 'atom-like' indivisible particles (see **Box 2**). This suggests that the concepts of elements and atoms were inextricably linked in the ancient world. This understanding has evolved over time. Today, we classify 92 naturally occurring substances as elements and are artificially synthesizing many more (with atomic numbers greater than 92). This is possible only because our understanding of the relationship between atoms and elements is now robust enough to allow such creation. However, chemists still recognise a certain lack of certainty and precision with both these concepts that is rarely communicated in textbooks and other educational resources for teachers and students.

Box 1. Elements in ancient civilizations:

While many ancient civilizations believed in the existence of elements, there were differences in what each civilization classified as elements. For example, the ancient Greeks believed that there were just four elements—earth, air, fire, and water. The ancient Indians suggested an additional element—ether. The Chinese had a slightly different list of elements—earth, fire, water, wood, and metal.

Box 2. Atoms in ancient civilizations:

Many ancient civilizations believed that elements were made up of indivisible particles, similar to the concept of atoms. For example, Kanada, the founder of the Vaisheshika school of philosophy in the 6th century BC, suggested that all matter was composed of 'atoms' of four basic kinds, each corresponding to one of four elements—earth, water, fire, and air. He assigned different properties to the different kinds of atoms, and described complex rules to determine how they combined to produce all known substances. The Buddhist, Jain, Islamic, and Greek schools of thought also constructed the concept of atom-like particles as being the smallest units of elements, and the origin of all matter. While each school described these particles and their properties differently, all of them believed that these particles were eternal, indestructible, indivisible; and that particles of one kind were identical.[1]

Are atoms real?

The idea that elements are made up of atoms has had immense importance in the development of modern science. As the physicist Richard Feynman once wrote, *"If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generations of creatures, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis (or the atomic fact, or whatever you wish to call it) that all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another. In that one sentence, you will see, there is an enormous amount of information about the world if just a little imagination and thinking are applied."* However, one could argue that atoms may not be real. After all, they are too fast and too small for us to 'see' them even under regular microscopes. Then why have we continued to believe in their existence? And how do we know that elements are really made up of such particles?

In 1905, Albert Einstein, then an unknown physicist working at the Bern patent office, was studying the second law of thermodynamics. At this point in time, the 'material existence' of atoms and molecules was the subject of a heated scientific debate. While some scientists, like the physicists J. Willard Gibbs and Ludwig Boltzmann, argued that heat was the effect of the non-stop agitated motion of atoms; other scientists, like the physicist Ernst Mach and the physical chemist Wilhelm Ostwald, denied the existence of such particles. It was in this year that Einstein published a path-breaking paper that offered unequivocal evidence for the existence of atoms and molecules. He recognised that any particle that was immersed in a bath of atoms/molecules would model the behaviour and kinetics of a large atom/molecule. Thus, using a microscope to observe pollen grains in water, Einstein showed that their Brownian motion would only be possible if the drop of water was made up of molecules. In the absence of such molecules, the suspended pollen grains would either bob in the water or move smoothly in different directions as the water jiggled and moved about. This was not the case—the pollen grains moved as if they were being randomly hit by other particles.[2] These other particles could only be molecules of water (see **Box 3**). That Einstein received the Nobel Prize in Physics in 1921 for this explanation reflects its significance for the scientific community.

But it is only since the 1980s that we have come close to seeing individual atoms.[3] The invention of scanning tunneling microscopes (STM) in 1981 has allowed us to map atomic positions on any surface through changes in current caused when its tip or probe encounters an atom.[4] In 2018, David Nadlinger, from the University of Oxford, photographed a single strontium atom that was illuminated by a laser beam.[5] In 2021, David Muller at Cornell University in Ithaca, New York, used an electron microscope to capture the highest-resolution image of an atom that we have so far.[6]

When do we call a substance an element?

Textbooks offer a variety of 'precise' definitions of elements. Surprisingly,

Box 3. 'Seeing' atoms indirectly through Brownian motion:

Put some pollen from a grass flower into a drop of water, and observe using a microscope. If the size of the pollen is right (neither too heavy nor too light), you will see it move or jiggle in a random manner as opposed to showing a continuous smooth motion. This random movement is called 'Brownian Motion', after the botanist Robert Brown who first described it (in 1827).

A harder experiment to conduct is to shine a bright light through some smoke particles captured in a glass cell and observe this through a microscope. Amidst swirling masses of smoke, one may occasionally spot smoke particles (that look like bright spots of light) showing Brownian motion.

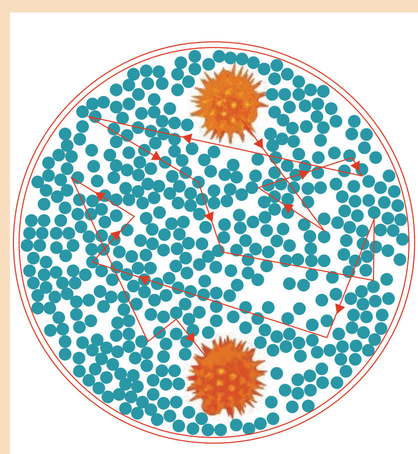


Fig. 1. The random motion of pollen in water is a result of the Brownian motion of the molecules of water.

Box 4. Dalton's atomic theory:

Dalton combined ideas proposed by many other scientists, including Cavendish and Proust, into a theory that could be measured and tested. This theory included five propositions:

1. All matter is comprised of tiny, definite particles called atoms.
2. Atoms are indivisible and indestructible.
3. Atoms of the same element have similar properties (like shape and mass) but are different from atoms of other elements.
4. The atom is the smallest unit of matter that can take part in a chemical reaction.
5. Atoms of different elements combine in fixed whole-number ratios to form compounds.

however, chemists are yet to arrive at an unambiguous, concise, and comprehensive definition for elements. Some of their challenges are related to nomenclature. For example, all of us may agree that oxygen is an element. But what do we really mean by that? Are we referring to an isolated oxygen atom or molecular oxygen gas or triatomic ozone? Or does the term 'element' refer to all of them?

More important challenges are related to our lack of certainty about whether what we call an element today will be broken down into more 'basic' substances in the future. For example, one common definition is that an element is 'a substance that cannot be decomposed into simpler substances'. This means that if a substance X can be broken down into two or more different substances, which when recombined produced substance X, then X is definitely not an element. This was one of the first useful definitions because it allowed scientists to identify what was **not** an element. It is, however, impossible to use this definition to conclusively prove that a substance is **really** an element since our ability to decompose a substance depends largely upon the technology and methods currently available to us. Thus, there is always a possibility that a substance that is not decomposable now may become decomposable when more advanced technologies and methods become available. Another, more useful, definition suggests that an element is 'a substance composed of identical atoms'. This definition was one of the cornerstones of John Dalton's atomic theory, published in 1808 (see **Box 4**). The observation that 'elements' always combined in whole number ratios to form new substances convinced Dalton that they were made up of singular building blocks. He reasoned that if atoms did not really exist, the ratios in which elements combined would be random.

Both these definitions were made obsolete by the discovery of isotopes. This discovery showed that some substances that had been previously classified as 'elements' (because they were believed to be non-decomposable) could decompose (naturally or on bombardment with charged particles in a nuclear reactor) into isotopes. The isotopes of an element differ from each other in their physical properties and can be recombined to produce the original sample. If we were to accept the first definition, such elements would be classified as compounds. Again, contrary to Dalton's definition, the atoms of isotopes are not identical—they differ in their mass (due to differences in the number of neutrons) and often in the physical properties of the substances they form (see **Box 5**). Thus, if we were to accept Dalton's definition, each isotope of an element would be classified as a separate element.

The modern era of chemistry started around 1789, when the 'father of chemistry', Antoine-Laurent de Lavoisier (1743-1794), attempted to classify elements. Lavoisier defined an element as a substance that could not be further divided by any known method of chemical analysis (see **Box 6**). This very precise definition is remarkable because by restricting it to substances that were indivisible by 'known methods of chemical analysis', it seems as if Lavoisier was acknowledging the possibility that other methods (which would come to be known only about 150 years later!) could succeed in further decomposition. It may also be interesting (and amusing) to note that Lavoisier included all those entities that he could not split using chemical means in his list of elements. This included light, heat, and metal oxides. It was only with the widespread use of the electric current in the 19th century that metal oxides were found to be decomposable. Since light and heat are not substances, they are no longer classified as elements.

Advances in many fields of science, including nuclear physics and astrophysics, in the 19th and 20th centuries, have provided clear evidence that all known elements are made up of atoms. We also know that atoms are made up of three stable particles—positively charged protons, neutrons with no net charge, and negatively charged electrons. And that protons and neutrons are bound together in

Box 5. Ordinary water and heavy water:

Ordinary water has the common isotope of hydrogen, with one proton in its nucleus; while heavy water has Deuterium, an isotope of hydrogen with one extra neutron. A mole of heavy water is significantly heavier (2 g) than ordinary water, its freezing point changes to 3.8°C, and it is about 11% denser than ordinary water. Isn't it amazing that the presence of a single extra neutron causes such a difference in properties? Due to its unusual properties, heavy water is extensively used in nuclear reactors to absorb neutrons (or as a neutron moderator).

the dense inner core (or nucleus) of the atom, which is surrounded by orbiting electrons that fill most of the volume of an atom. With this knowledge in mind, we arrive at what may be a more accurate definition of an element: 'An element is composed of atoms of one kind, all of which have the same number of protons (called its atomic number)'.

Box 6. How do we know if a substance is likely to be an element, a compound or a mixture?

If you were to put two graphite rods or thick pencil leads into a glass of tap water and connect these rods to an 18V battery, you would see bubbles (of gas) arising at both electrodes. The two gases can be easily collected in separate test tubes. We know from textbooks and other reference materials that these gases are the elements hydrogen and oxygen, but how do we prove this experimentally?

Take oxygen for example. Let us start with the hypothesis that it is a mixture of two or more gases. Assuming that we can use all known gas separation techniques, there is a high chance that we would be able to separate it into these gaseous components by at least one of these techniques. This would provide experimental evidence that oxygen is not really an element but a mixture of gases. In reality, however, we would have only managed to separate the different isotopes of oxygen, all of which are very similar to each other in their physical and chemical properties. This does not eliminate the possibility that our inability to separate oxygen into other gaseous components may be due to the absence of sufficiently advanced technology.

Our inability to separate oxygen into other gaseous components by current separation techniques may also be because these gaseous components may have similar physical properties, like weight. This leads us to the possibility that they may differ in their chemical properties. If so, one way to separate the oxygen mixture would be to set up reactions between oxygen and specific quantities of pure alkali metals, like sodium and potassium. If even one of these reactions yields two or more compounds that we can clearly distinguish by their physical (like sight, smell, or touch) or chemical properties, it would prove our hypothesis. It would be best to avoid using transition metals for such reactions—due to their different oxidation states, even if oxygen were an element, such reactions would result in the formation of more than one compound.

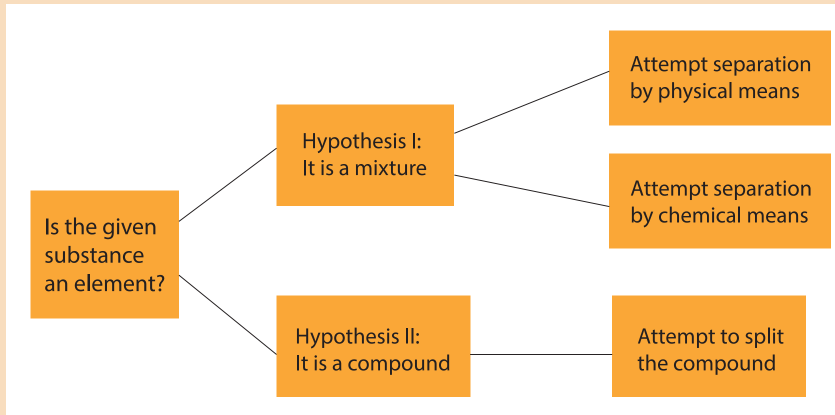


Fig. 3. A flow chart showing a possible scheme of investigation when you encounter a substance that is new to you.

Another way to test this hypothesis would be to obtain oxygen from other sources, like by heating mercury oxide or some nitrates. If this reacted with the hydrogen obtained from our initial experiment (with the graphite rods) to produce water (and this is what really happens), then the simplest explanation would be that oxygen is not a mixture of gases. Whew! That is a lot of work just to show that a given substance is not a mixture!

This does not, however, eliminate the possibility that oxygen is a compound. Testing this possibility is a lot more complicated because we do not, at present, have the tools to split this compound chemically. Till such tools are developed and oxygen is decomposed, the possibility that oxygen is a compound cannot be eliminated. Also, once oxygen is decomposed, its components will be regarded as elements till we find an appropriate method to split them further. Since neither of these has occurred yet, we continue to believe that oxygen is an element.

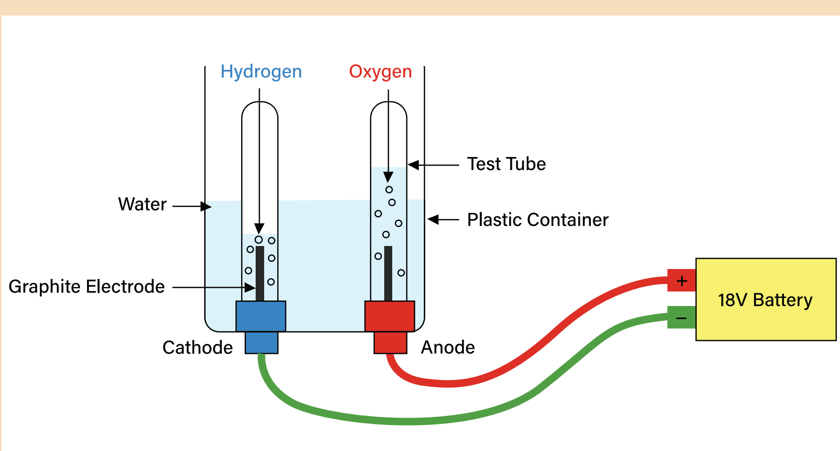
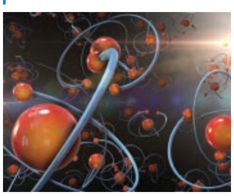


Fig. 2. The electrolysis of water: oxygen and hydrogen gases collect in the test tubes.

Parting thoughts

While the concepts of atoms and elements are fundamental to our understanding of chemistry, they do not have clear unambiguous definitions. Instead, many textbook definitions represent stages in our understanding of each of these concepts and their relation to each other. Teachers often assume that students are familiar with the limitations and uncertainty of these definitions or will figure these out by themselves with time. However, what is likely to be less confusing is for teachers to trace the history of these evolving definitions, communicate the conditional nature of their validity, and encourage an exploration of the kind of developments that could make our best definitions in the present seem inadequate or flawed in the future.

Key takeaways



- Our ability to make more complex substances and systems with 'desired' properties depends on our understanding of elements and atoms.
- Our evidence for the material reality of atoms and our understanding of their subatomic structure has evolved with new advancements in technology.
- Our definitions of elements evolve with the techniques of separation available to us and the methods we use to test the purity of a sample.
- Teachers and textbooks rarely communicate the uncertain nature of common definitions of elements.
- Tracing the history of evolving definitions of elements could be useful in communicating the conditional nature of their validity to students.

Notes:

1. This article is derived from a longer article first published in i wonder..., Feb 2017, pg. 84-94.
URL: https://publications.azimpremjiuniversity.edu.in/1267/1/16_THE%20ORIGINS%20OF%20ELEMENTS.pdf.
This version has some additions (by the editors) to update it and to make its connections to middle school science more explicit.
2. Source of the image used in the background of the article title: Chemistry. Credits: tommyvideo, Pixabay.
URL: https://pixabay.com/illustrations/atoms-molecule-chemistry-science-5064796/. License: CC0.

References:

1. See 'The Atom in the History of Human Thought' authored by Bernard Pulman and published by Oxford University Press (1998) for a more comprehensive account.
2. See an accurate motion picture of Brownian motion here: https://en.wikipedia.org/wiki/Brownian_motion.
3. Watch Sam Kean take us through the nearly 2,400-year quest to see the atom in this episode of Reactions' "Legends of Chemistry" series: https://www.youtube.com/watch?v=ipzFnGRfsfE.
4. Watch Olivia Gordon, from SciShow, explain how the Scanning Tunnelling Microscope allows us to see individual atoms in a sheet of metal: https://www.youtube.com/watch?v=S-M7JjYCITY.
5. See David Nadlinger's award-winning photo of a strontium atom and read about how he took it: https://www.ox.ac.uk/news/science-blog/image-strontium-atom-wins-national-science-photography-prize.
6. See David Muller's image of an atom and read more about it here: https://dug.com/behold-the-highest-resolution-image-of-atoms-ever-taken/.

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WHAT DOES YOUR SHADOW ON THE EQUINOX TELL YOU?

Equinoxes occur twice a year—20th March and 23rd September. On these days, the sun's rays falling on the earth are perpendicular to the earth's axis. Thus, the duration of day and night is nearly equal.

On these days, you can find out many things about the earth using observations and calculations, including the minimum shadow length, local noon, North (and other directions), latitude, and longitude at your location. These activities will show you how.

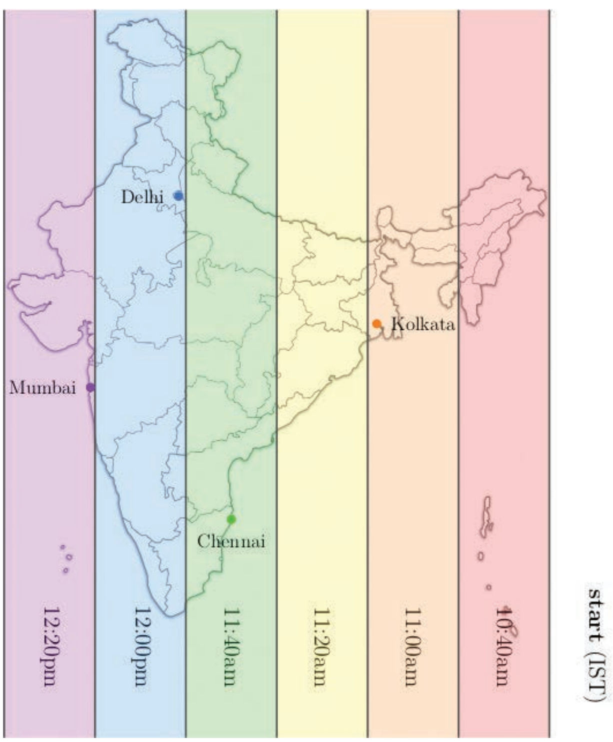

Fig. 1. When to start your experiment? Find your location on this map to decide when to start your experiment.

Credits: Alok Mandavgane & Varuni P. License: CC-BY-NC.

You will need

Flat ground (with direct sunlight), a vertical object, and measuring tape.

What to do

1. Set up the experiment:

- Start your experiment by marking a point on flat ground (see **Fig. 1**). At this point, place a vertical object (with a height > 20cm), like a pipe, a stump, or yourself. This is your Gnomon (or a vertical stick that shows the time by the length and position of its shadow). Measure the height of the Gnomon (see **Fig. 2**).

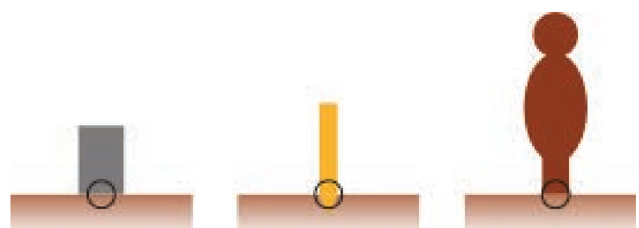

Fig. 2. Measuring the height of your Gnomon.

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2. Observe and measure:

- Mark the tip of the shadow of your Gnomon on the ground.
- Measure the shadow length after every 10 minutes for a duration of 80 minutes.
- Additionally, measure the shadow length at 12 PM IST.

What can you find out?

a) Local noon: The local noon on any day is the time at which the sun is at its highest point in the sky and the shadows are the shortest. So finding the time when your shadow is the shortest will give you your local noon (you can verify your observation of local noon on the ZSD app, which is described in **Box 1**).

b) Directions (N, S, E, W): To do this, join the base of the Gnomon to the marking you made on the ground at local noon. This is the North-South line (an imaginary line forming a great circle that passes through the earth's North and South geographic poles). Once you mark this line, you

Box 1. Other resources:

(a) 'Zero Shadow Day' (ZSD) 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). It can be accessed here: https://play.google.com/store/apps/details?id=com.alokm.zsd.

(b) ASI-POEC activities: These activities help explore and understand shadows:

- Zero Shadow Day: https://astron-soc.in/outreach/activities/zero-shadowday/.
- Equinox Shadows: https://astron-soc.in/outreach/activities/shadowsequinox/.
- December Solstice Shadows: https://astron-soc.in/outreach/activities/shadows-decemsolstice/.

(c) Classroom session about shadow lengths:

1. Where is My Shadow? Learning Unit, Vigyan Pratibha (HBCSE). URL: https://vigyanpratibha.in/index.php/where-is-my-shadow/.
2. A book of activities to explore the sun and shadows. Monteiro, V., Mahashabde, G., and Barbhai, P. (2008). Sun Earth Experiments: Activity Cards for Day-time Astronomy. Navnirmiti Learning Foundation. URL: https://navnirmitilearning.org/wp-content/uploads/2021/07/Sun-Earth-Experiments-Activity-Cards-for-Day-Time-Astronomy.pdf.

will observe that shadows will be to the west of it before local noon, and to the east of it after local noon. Remember: On the equinox, the sun rises exactly East and sets exactly West. So, if you observe the rising or setting point of the sun at the horizon, you can check if this agrees with the directions you found from your local noon shadow.

c) Latitude: Since the sun is overhead at the equator and its rays are perpendicular to the earth's axis, the angle made by these rays to any vertical object at local noon on equinox days is equal to its latitude. To find this out, draw a right triangle with the Gnomon's height and its minimum shadow length. Measure the angle at the top of this triangle (see **Fig. 3**). This angle is equal to your latitude!

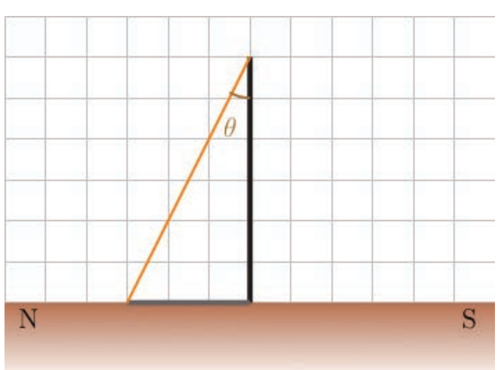

Fig. 3. Find out your latitude.

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d) Longitude: At any instant, different places on earth have different times of the day. The 24 hours of a day are evenly spaced around 360 degrees of longitude. So, 1 degree of longitude accounts for 4 minutes. The reference longitude at which IST is calculated is 82.5E (near Prayagraj). To find your longitude, calculate the time difference between local noon at IST and your local noon (see **Fig. 4**). This tells you how far you are from 82.5E. Then, use the following calculation:

Your longitude = 82.5E + (local noon at 82.5E - your local noon)*/4

Local noon at 82.5E on 20th March: 12:07**

Local noon at 82.5E on 23rd September: 11:52**

(* Taken in minutes

** This is not exactly 12 PM IST since there are some differences due to the "Equation of time". You can learn more about this on the ZSD app.)

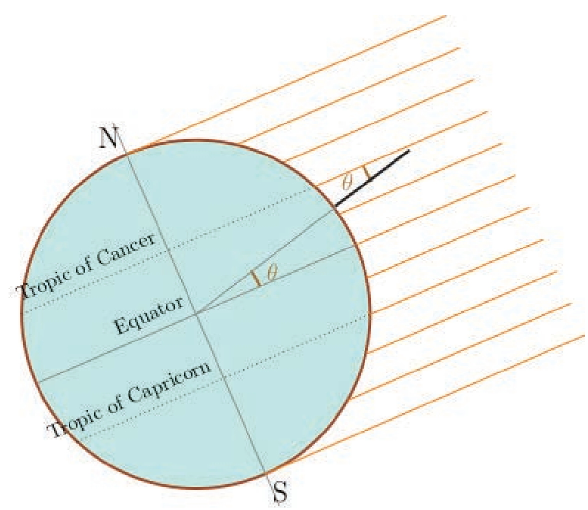

Fig. 4. Find out your longitude.

Credits: Alok Mandavgane & Varuni P. License: CC-BY-NC.

What else?

To share your information with others, fill out a google form linked on the webpage: https://astron-soc.in/outreach/activities/shadows-equinox/.

Do you think that the data you and others have collected can be used to calculate other things, like the circumference of the earth or the rate of rotation of the earth? How would you go about it?

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Notes:

1. This snippet is based on a poster that was developed along with AIPSN and ASI-POEC for observation and measurements of the equinox: https://astron-soc.in/outreach/activities/shadows-equinox/.
2. Source of the image used in the background of the article title: Jigsaw pieces. Credits: Wounds_and_Cracks, Pixabay. URL: https://pixabay.com/photos/puzzle-piece-tile-jig-jigsaw-game-3306859/. License: CC0.

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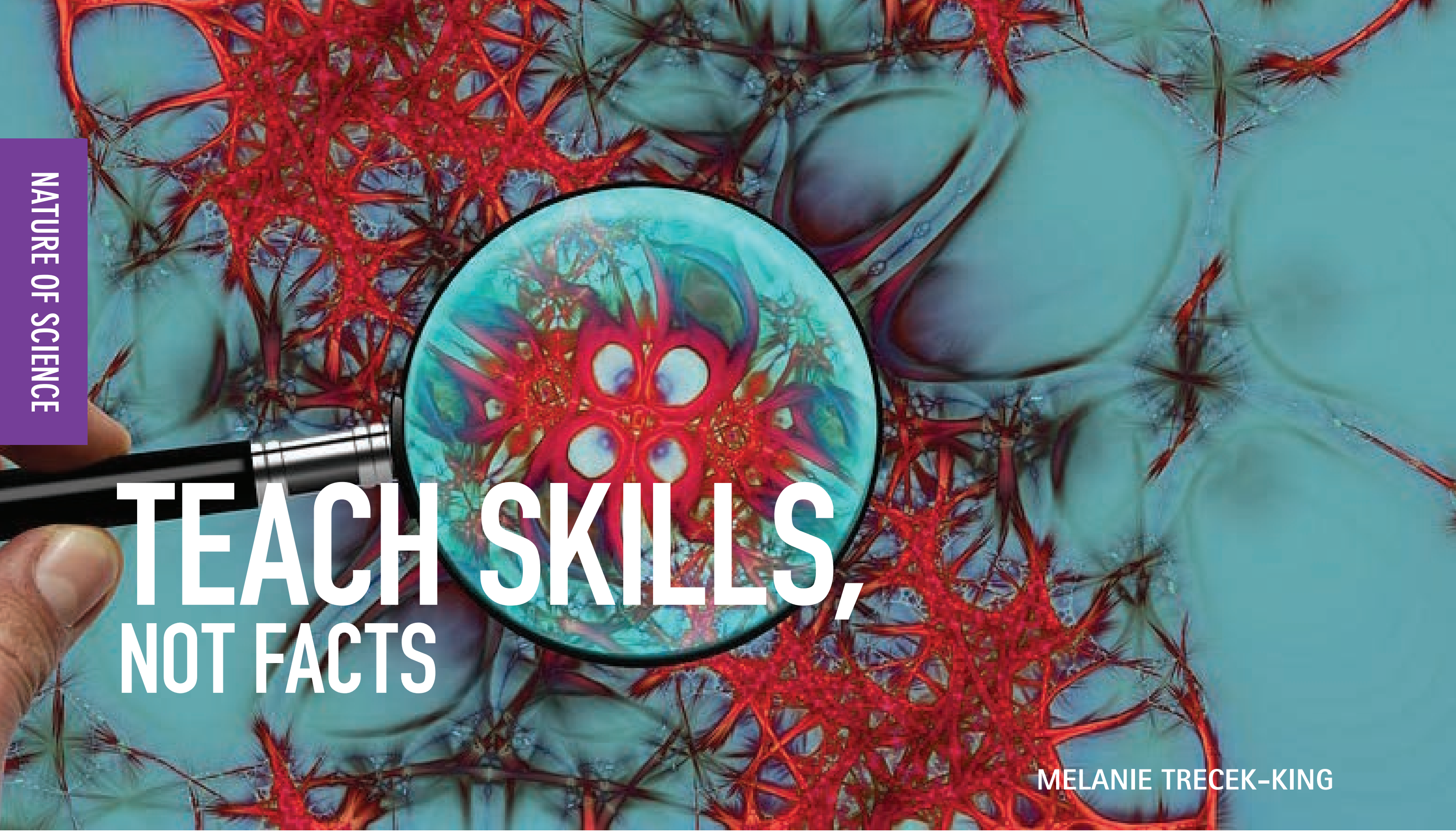


TEACH SKILLS, NOT FACTS

MELANIE TRECEK-KING

Why are all students required to take science? Is it to memorise science facts, or to foster critical thinking and science literacy skills? Why is it important for students to develop these skills? How do we help students learn them?

The moment is burned into my brain like a flashbulb memory—I was teaching 'Introduction to Biology', a course for students not majoring in science, and noticed that my students looked completely deflated. It was at this moment that I realised that my students were not going to remember, let alone use, what they were learning past the exam. Worse, any fears and anxieties they associated with science would continue to haunt them. I had squandered their one opportunity to gain the empowerment that comes with science literacy and critical thinking. This realisation hit me like a ton of bricks.

I had been teaching this course for over a decade, eager to convince my students that science is awesome, that it improves the quality of their lives, and that science literacy is essential in today's world. Biology is the study of life, after all, and science is one of the most reliable ways of knowing. I thought I had a solid case. Unfortunately, few of my students seemed to agree with me. I wouldn't (necessarily) say they hated science, but they were certainly science phobic. A common complaint I heard from them is that they shouldn't be required to take science classes when they intended to major in business, literature, or art. Why should they spend their time (and money) learning about the structure of cell membranes or evolution? And, honestly, I could see their point. As much as I find these topics fascinating and worthy of study, I knew what students were really learning was how to memorize information to regurgitate at exams. So I asked myself—why are nearly all students, regardless of the majors or career paths they are likely to choose, required to take science? The obvious answer seemed to be to foster critical thinking and science literacy. But what does that mean?

Critical thinking and science literacy

Thankfully, I stumbled upon a quote by Carl Sagan: *"If we teach only the findings and products of science—no matter how useful and even inspiring they may be—without communicating its critical method, how can the average person possibly distinguish science from pseudoscience?"* He was right. Science is so much more than a bunch of facts to memorize. It is a process. It is a way of learning about the world, of trying to get closer to the truth by subjecting explanations to testing, and critically scrutinizing the evidence. It is not just **what** we know; it is **how** we know. Basically, science is good thinking.

While nearly all educators say that teaching critical thinking skills and science literacy is important, many students graduate without showing an improvement in either. One very likely reason is that few instructors were formally taught either of these skills or can define them. So, what is critical thinking? There are many definitions, but essentially critical thinking is 'reasonable, reflective thinking that is focused on deciding what to believe and do'. And science literacy is more than just memorising facts. Scientifically literate people understand scientific reasoning and are able to draw reasonable conclusions from the available evidence. They are able to evaluate hypotheses, arguments, conclusions, and their own beliefs. And they're aware of the cognitive biases and logical fallacies that may impact our ability to evaluate evidence and draw fair conclusions. Both these skills are essential to help students navigate their world—today and tomorrow. They can empower students to make better decisions and inoculate minds against the misinformation and disinformation that is currently all too prevalent in our society.

The good news is that, in theory, science courses are the perfect vehicles to teach critical thinking and science literacy. The bad news is that most science courses focus on memorising facts rather than developing skills. But facts are forgettable and widely available. Plus, many of the facts we teach in class will most likely change. After all, science is a never-ending process of weeding out bad ideas and building on good ones.

I will fully admit to being part of the problem. Like many other science educators, I had assumed that, since critical thinking is at the heart of scientific inquiry, I was teaching it in my classes. And, of course, I believed that in teaching facts, I was teaching science literacy! I honestly didn't realize how wrong I was. The global pandemic has made clear the importance of understanding the nature of scientific inquiry and the value of science to society.[1] I wonder how students who took my 'introductory bio' course all those years ago made sense of the pandemic, and if the facts I taught them provided them with the tools to understand coronaviruses, mRNA vaccines, or hydroxychloroquine. The world changed. Knowledge changed. My students needed skills for the future, and I had failed them. If we don't teach students the process of science, how will they be able to differentiate between reliable and unreliable claims? And isn't **that** the point of science education?

Changing focus

I convinced my institution to replace the introductory level biology course that I had been teaching with a new one, called **Science for Life**, that focuses less on the findings of science and almost exclusively on critical thinking and science literacy.[2] One of the main goals of this course is to evaluate evidence for claims to determine how we know something. Another is to learn to recognize the characteristics of good science by evaluating bad science, pseudoscience, and science denial. The entire course is centred around empowering students to make better decisions to help them live better lives.

Unlike most science classes that start with the scientific method, I begin with witches. Centuries ago, being accused of witchcraft and "confessing" under torture were sufficient evidence to convict and sentence a person (usually a woman) to death. Because most students today don't believe that diseases and storms are caused by witches casting spells, they are able to more skeptically examine the supposed evidence and explore why people at the time had such strong beliefs. Through this, they recognise that while we like to think that our beliefs come by rationally following evidence, more often than not, we form beliefs (like of a woman being a witch) in irrational ways and look backward for justifications (see **Fig. 1**).

Our discussion naturally leads to epistemological questions, such as how we know what we know, and how knowing is different from believing. Richard Feynman famously said, *"The first principle is that you must not fool yourself, and you are the easiest person to fool."* Unfortunately, most of us think we're immune! To prove to students how easily they can be fooled, I give them astrology-based 'personality assessments', which nearly all of them

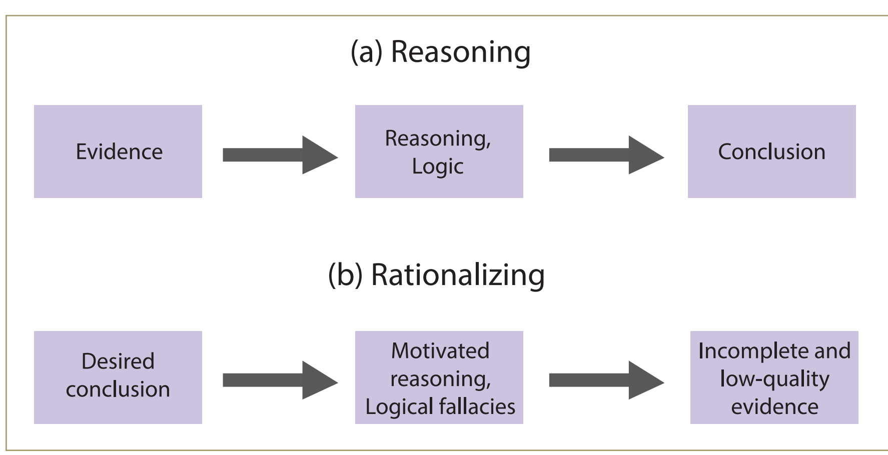


Fig. 1. The difference between reasoning and rationalizing. (a) Reasoning is following evidence to a logical conclusion. (b) Rationalising is selecting evidence to justify a conclusion.

report as being highly accurate. It is only when they learn that all of them have received the same results do they realize that they've been conned. After I apologize and explain why I lied to them, they're more open to learning skills, such as skepticism, that can protect them from being fooled. While many students confuse skepticism with cynicism or denialism, true skepticism is simply proportioning beliefs to the evidence and is, therefore, an essential characteristic of science.

To equip students with the skills necessary to evaluate claims, I provide them with a toolkit, summarized by the acronym FLOATER.[3] The principles in FLOATER (Falsifiability, Logic, Objectivity, Alternative explanations, Tentative conclusions, Evidence, and Replicability) encapsulate the essence of critical thinking and the process of science. Through repeated practice, students learn to use scientific reasoning to evaluate claims, because pseudoscientific and unreliable claims fail at least one of the rules in FLOATER.

The next lesson is one of the most important ones in the course—the limits of perception and memory. For many, personal experiences are the best way to "know" something. Whether it is believing in UFOs because they've "seen" one or that homeopathy is effective because it "worked" for them, we often fail to recognize that our perceptions are subjective and highly biased, and that our memories are flawed and unreliable. Understanding this is essential for us to know why anecdotes, including one's personal experiences, are unreliable evidence.

We then dive into metacognition, or thinking about thinking. Since our brains have to process a lot of information, and they're lazy, much of this is done on autopilot. This fast, intuitive thinking uses mental short-cuts (or heuristics) that can lead to errors (or cognitive biases). These errors cause our thinking to deviate from reality. Ultimately, the goal is to teach students how to think better by being aware of how they are thinking, and recognizing the limits of what they know.

After students have a better appreciation of how flawed their thinking can be, and the importance of skepticism, we turn to information literacy. Information affects how we think and the decisions we make, yet it can be difficult to distinguish reliable from unreliable information. In fact, we are most likely to fall for misinformation when it confirms what we already believe and/or triggers strong emotions. Thankfully, the concepts covered in the course thus far provide students with the background knowledge to skeptically evaluate sources and claims online. This also helps students to understand the importance of peer review in the process of science. While many science courses teach students how to read primary literature, I don't think that is helpful or necessary. It may even be unrealistic to expect anyone, especially someone who has only taken a few basic courses in science, to rely on jargon-rich articles published in professional journals for making decisions in their daily lives. Instead, it is important that students recognize the limits of their knowledge, and, more broadly, learn how to be good consumers of information.

By the time I introduce the process of science, students have an understanding of why science is reliable and necessary. To reiterate—science is good thinking. We are all biased and irrational; and at its core, science is a way of knowing—a way that recognizes and corrects for our biases. Consider the double-blind, randomized, controlled trials used to test new medications. Every aspect of these studies—such as the blinding, use of placebos, and random sampling—is designed to correct for the cognitive biases that can interfere with determining whether the drug actually works. By building up a justification for science, the logic of the scientific process falls into place.

Speaking of the scientific method, there isn't one, and we do our students a disservice when we teach it as such. While most textbooks start with a recipe-like formula, from observation to hypothesis to experiment, most science does not follow these steps. Science is a community of experts using diverse methods to gather evidence and scrutinize claims. There are endless ways to do science. For example, not all science uses controlled experiments. Observational science, such as discovery science, historical science, and epidemiology, collects data in the 'real world'. Importantly, different types of studies provide different types and qualities of evidence. A broader understanding of the nature of science, which is essentially evidence-based thinking, equips students to evaluate the evidence for any particular claim.

Throughout the course, I use lectures, quizzes, case studies, and assignments to explore real-world issues relevant to students, and provide opportunities to practice evaluating claims. Topics include ghosts, psychics, fake news, fad diets, crystal healing, conspiracy theories, Bigfoot, the MMR vaccine and the autism "controversy", homeopathy, astrology, and climate change denial. Since many students believe in various forms of pseudoscience, its inclusion in the course increases engagement and teaches them how to recognize pseudoscience in their daily lives. Importantly, these issues help students understand that it is important to think critically because being fooled can lead to real harm (see **Box 1**).

Finally, many activities are based on the inoculation theory (which is similar to how vaccines work) for misinformation. Basically, exposure to a bit of misinformation can help build up immunity to the real thing. In some activities, students use humour to create misinformation, such as an advertisement for a pseudoscientific, alternative medicine product and a discussion in which they use fallacies to argue why they should not fail the course.

Box 1. Some student testimonials:

Testimonial 1: *"Our memories and how they can be changed by simple suggestions that you didn't even pick up on. A memory was always a fact to me, like playing back a recording. Now I understand how wrong I was. This was even more important to know and use in my profession as a police officer."*

Testimonial 2: *"Over the duration of this course, I've come to realize that a lot of the issues with our society are simply because we are bombarded with information that exists at our fingertips, and that is pushed at us from numerous sources, all too willing to confirm our beliefs rather than impart facts. If people knew how to be properly skeptical, and how to do real research into the credibility of sources and how to find factual information, this would be a much different world."*

Testimonial 3: *"For most of my life, I assumed skepticism was having a negative outlook on life. Now I know it is actually a vital tool we should all use while taking in information in our daily lives. I think the most valuable thing I've learned is that evidence is vastly underrated and overlooked in most people's everyday lives."*

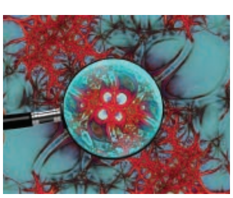
Testimonial 4: *"Everything in this course was outstanding! I already hold a BS in Space Studies from another university and thought I had a good handle on the scientific process. This class really showed how little I knew about the scientific process and how to critically think while being skeptical of the evidence provided. Would highly recommend this course be mandatory for all majors in the country."*

Parting thoughts

The ability to think critically and be scientifically literate has never been more important. We owe it to our students (and society) to teach them curiosity, skepticism, and humility. This is especially true for those students who are likely to take science courses only for a few years. These courses are often the last chance we have to teach students the critical thinking and science literacy skills necessary to be informed citizens.

It is possible to teach these skills, but they cannot just be a component of the curriculum; they have to **be** the curriculum. Instead of teaching students **what** to think, good science education teaches them **how** to think. By emphasizing process over content, students gain the skills necessary to think better and therefore make better decisions. The premise of this kind of education is intellectual empowerment. I tell students at the end of every class, *"Thinking is power. So demand evidence and think critically!"*

Key takeaways



- Science is good thinking. Good science education focusses on how to think rather than on what to think.
- Helping students develop critical thinking and science literacy skills enables them to evaluate hypotheses, arguments, conclusions, and their own beliefs.
- Both these skills are essential for students to navigate their worlds, and can empower them to make better decisions.
- A course dedicated to teaching these skills may help students distinguish scientific facts from misinformation and pseudoscience, even as knowledge and facts change, and new facts emerge.
- Teaching skills and not facts could make science more meaningful and useful even to those students who may not pursue science as a profession in the future.

Acknowledgments: Special thanks to Matthew P. Rowe for his feedback and guidance.

Notes:

1. This article was first published in Thinking is Power and is available here: https://thinkingispower.com/from-non-majors-biology-to-critical-thinking-an-educators-journey/. An updated version was published in Skeptical Inquirer and is available here: https://skepticalinquirer.org/2021/12/teach-skills-not-facts/.
2. Source of the image used in the background of the article title: Network. Credits: geralt, Pixabay. URL: https://pixabay.com/photos/annoy-network-magnifying-glass-3991596/. License: CC-BY-SA.

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1. Harrison, Guy. 2021. How to repair the American mind: Solving America's cognitive crisis. Skeptical Inquirer 45(3): 31–34. URL: https://skepticalinquirer.org/2021/04/how-to-repair-the-american-mind-solving-americas-cognitive-crisis/.
2. Rowe M. P. *et al.* 2015. Redesigning a general education science course to promote critical thinking. CBE Life Sciences Education 14: 1–11. URL: https://www.lifescied.org/doi/pdf/10.1187/cbe.15-02-0032.
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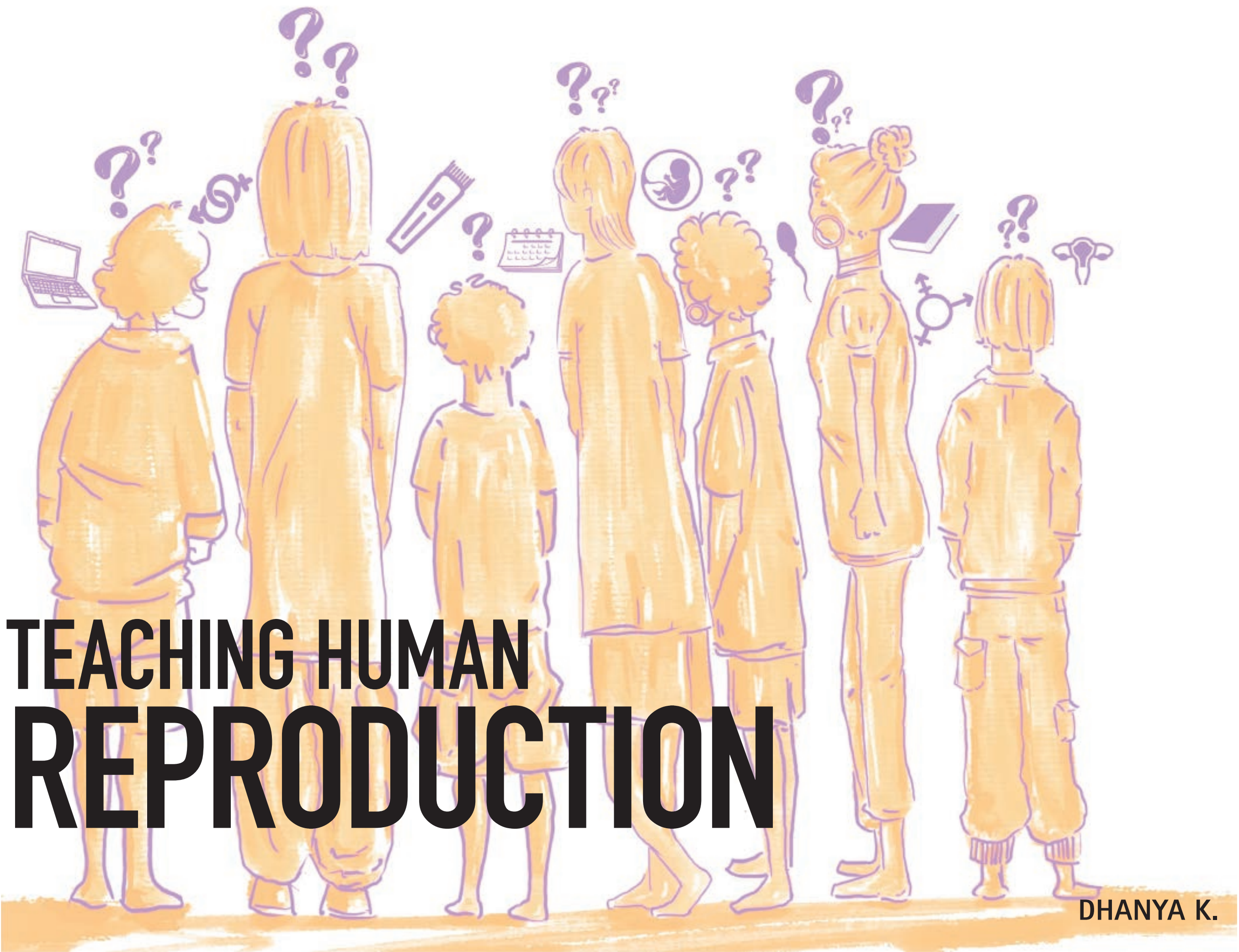

TEACHING HUMAN REPRODUCTION

DHANYA K.

Students and teachers meet the chapter on 'Human Reproduction' in the high school biology textbook with hesitation. How do we break this stigma? Is it possible to connect this chapter with realistic conversations? How do we do this in a manner that is open and helpful for students?

As high-school students make the transition into puberty, their interest in the body and sex is piqued. They become curious and eager to learn about their bodies, as well as the physical and emotional changes they experience during this transition. Most school curricula recognise the importance of equipping students with accurate information and empowering them with the ability to reflect, think critically, and fearlessly communicate thoughts or questions regarding their sexuality and sexual well-being. However, the basic information that most textbooks provide is neither up-to-date nor comprehensive in nature. They do not, for example, cover the biology of ejaculation, erection, premenstrual syndrome, etc. The internet is another easily accessible source of information for many students. Unfortunately, much of the information they access there may be fragmented, biased towards the male sexual experience, and may set unrealistic standards for beauty and intercourse. This may negatively impact their sexual growth and well-being. Lastly, teachers may find it difficult to find avenues for open conversations on this theme for a variety of reasons, including personal discomfort, ideological conflicts, and academic constraints.

The unit on 'Human Reproduction' in the high school science curriculum may offer an avenue not only to discuss the biology of this process but also to encourage reflection on the needs and values associated with sex and reproduction. This article describes a module that I designed to promote awareness of the human body, anatomical and behavioural changes during puberty, and the science of intercourse. In addition, it aimed to encourage students to articulate their understanding of body and sex comfortably—to normalize conversations and break the associated cycle of judgment, shame, and stereotypes. As a teacher-student group, we have questioned societal norms, our ideas of beauty and relationships, and the influence of media. We have also been open about our ignorance.

I tried this module with four consecutive academic batches of Grade IX students of a private residential English medium school. Each batch had 50 students of mixed genders, divided into two sections. About 12 hours were dedicated to the completion of the module for each batch. This article summarizes the common approaches and observations from students across all four batches.

The icebreaker

A simple approach I use to break the ice is to chalk out the words 'Human Reproduction' in bold on the blackboard and distribute blank sheets of paper to the students. I then say, *"Share any questions you have on the topic of human reproduction. The questions can be anonymous. I will read each of your questions. If I know the answer, I will share it with you. If I don't know the answer, we will try to find it together."*

After about 5-10 minutes, I further encourage them: *"You know this can be a wonderful opportunity to ask any kind of question, be it about growing up, sex, pornography, gender, pregnancy, masturbation, etc. You could get useful information instead of browsing aimlessly on the Internet and being led to possibly confusing answers or dead ends. Please do use this opportunity to ask any question you want."*

Usually, the students are hesitant at first; they make faces, laugh, and inevitably tell me that they don't have any questions. However, over the years, I have observed that when given sufficient time (I allot the entire class duration of 60 minutes to this exercise), several questions emerge from the students (see **Fig. 1**). In fact, I once received as many as 260 questions from a single batch! There have also been instances where students have submitted additional questions in person after the class (see **Box 1**).

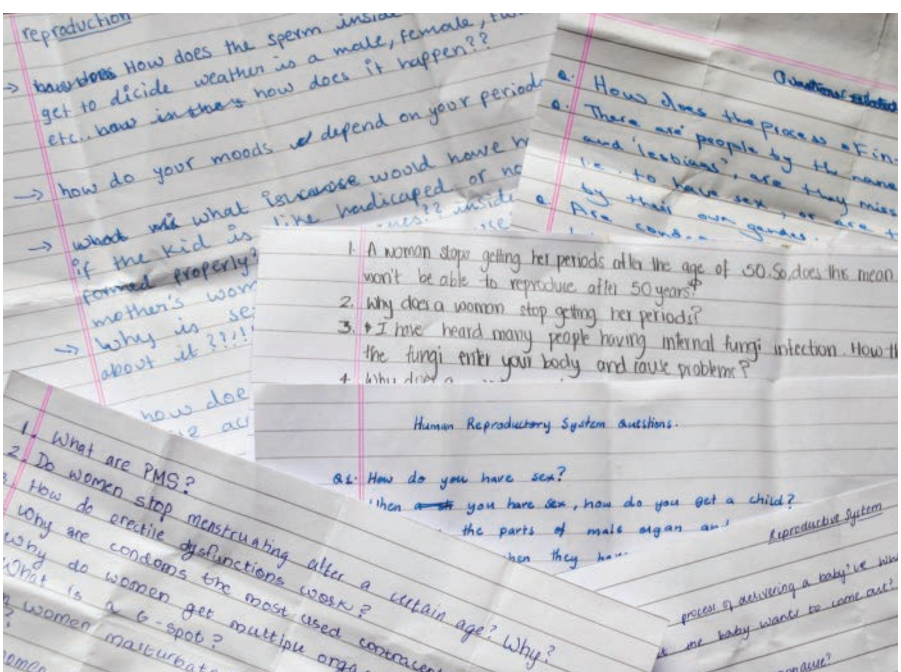

Fig. 1. A collage of responses from students to the icebreaker question.

Box 1. Sample questions from students:

This is a sample from a collation of students' questions from 2016-2020. Some of these questions, along with responses to them, are available on the Sawaliram website (https://sawaliram.org/search).

- Why is menstruation painful?
- Why are periods considered taboo? Why do shops wrap sanitary napkin packets in sheets of newspaper or pack them in black polythene?
- How did women manage menstruation before cloth pads or sanitary napkins?
- Are there reasons other than pregnancy for a woman to miss her periods?
- Why does the menstrual cycle start for some at 10 years of age, and at a later age for others?
- Why do women start having periods from when they are 10-12 years of age when they usually only give birth after they reach their 20s?
- Why are female body parts called derogatory terms?
- Are girls attracted to bigger penises?
- Why do boys, and not girls, grow taller during puberty?
- Do men also have menopause and lose the ability to reproduce?
- Why does Indian TV blur only female undergarments (like bras) and not male undergarments?
- Does it hurt when you have sex for the first time?
- Why do people get addicted to sex?
- How do you dispose of condoms?
- If a man and a woman have unprotected sex, is it necessary that it will result in fertilization?
- Are morning-after pills harmful?
- What happens during labour?
- What is a C-section?
- Why do people masturbate and why is it considered taboo?
- When people masturbate, what pleasure does it give them?
- Why do people watch pornography? What makes them want to watch it?
- Why do humans show sexual attractions or desires?
- How are emotions and mood swings controlled by the body?
- How do other organisms change their gender?

I start by separating questions, like those related to the exact mechanics or details of the act of sex itself, that I do not intend to address in class, either due to my own discomfort or their age-inappropriateness. To more effectively address the remaining questions, I arrange them into categories, like body/anatomy, pregnancy, intercourse, pornography, etc. I take a week or two to find accurate answers to these questions from books, the internet, peers (other teachers), or clinicians. I also use this time to mentally prepare for the next class. For example, I actively work towards using a non-judgemental tone and body language while answering questions. I also review the boundaries that I will set with the students.

Exploring the questions with students

(a) Chalk the talk

Typically, I start with questions related to the human anatomy. Rather than show a chart or a PowerPoint presentation, I draw the male and female reproductive systems on the blackboard and encourage the students to replicate these diagrams in their own notebooks. As they work on their drawings, I walk around the classroom to observe their behaviours and attitudes. Surprisingly, the initial sense of discomfort that students display when I begin drawing the diagrams on the board is quickly replaced with a sense of ease when they start drawing. It is possible that drawing diagrams by hand helps break some of the stigma associated with reproductive organs.

After the students finish their drawings, I name each part of the reproductive system, share the etymology of their names, and explain what they do. I use the same tone and manner that I use when I teach about the human heart or the anatomy of a leaf. This practice helps students to perceive the process of learning about reproductive organs as being similar to learning about any other organ. Several questions about the anatomy and physiology of the reproductive system get addressed through this method. At the end of the class, I also read out the student questions that were covered (see **Box 2**).

(b) Out in the open

After the chalkboard discussion, the next set of classes are typically conducted outside the classroom in open areas of the school, as open spaces are less constrictive and facilitate unhindered interactions among students. The students and I sit in a circle during these open space sessions, so that we can all see each other and feel our human connection. I give a short introductory talk to share the theme of the discussion, its purpose, and expectations from them during the discussion. I also encourage them to see the discussion as a collective learning experience, invite them to feel free to express themselves, and stress the

Box 2. Sample questions addressed in the blackboard sessions and the approaches followed:

Q. What are gonads?
I treated this as a question on the anatomy and physiology of the reproductive system and used blackboard drawings to answer it. I also clarified a common misconception that only the male body has gonads. On occasion, we would also listen to parts of this podcast: https://www.wnycstudios.org/series/radiolab-presents-gonads.

Q. Where is the sperm produced and how? Where does the sperm go during intercourse? How does the sperm cell know where to go?
In addition to the blackboard, I used some video resources to address these questions. These included:

- A video on the physics of movement of the human sperm: https://www.ted.com/talks/aatish_bhatia_the_physics_of_human_sperm_vs_the_physics_of_the_sperm_whale.
- A microscopic visualization of the human sperm: https://youtu.be/JQ5RvbjWFtQ.

Q. How does an erection occur?
Here, I explained the structure and functioning of the nervous system, muscles, and blood vessels. As these themes overlap with other chapters in the biology curriculum, I could make connections with what students had learned prior to this class and grade.

Q. How much time does it take for a female to get pregnant after sex? What is the probability of becoming pregnant when you have sex?
These types of questions were addressed to introduce the menstrual cycle. A video resource that can be used here is: https://youtu.be/ayzN5f3qN8g.

Q. What are condoms? How do they break?
I discuss this question after sharing this video on contraceptives: https://www.youtube.com/watch?v=Zx8zbTMTncs.

We also discuss female contraceptives at length. I share this video on why female condoms are so hard to find: https://youtu.be/6XxA-4Jp7AU.

Then, I share this educational video on how to use a condom: https://www.youtube.com/watch?v=06kT9yfj7QE. I also introduce the topic of sexual consent here through this video: https://www.youtube.com/watch?v=pZwvrxVavnQ.

Q. What do boys experience during puberty?
I discuss the many changes that occur during puberty. This can help normalise these changes and conversations around them. For example, speaking openly about nocturnal emissions or menstruation helps students not feel ashamed and accept these natural changes as normal processes. Here is a video resource that could be helpful: https://www.youtube.com/watch?v=-XQcnO4iX_U.

Here are a few other frequently asked questions that I discuss during these sessions:

Q. Why do we experience pain during periods?

Q. What is PMS?

Q. How does one know that a female has conceived?

Q. Why do women experience menopause? Why do they never get pregnant during menopause?

Q. Why is the male sexual organ sensitive?

Q. What is virginity, and how do you lose it?

Box 3. Sample questions addressed in the open discussions and the approaches followed:

Q. How come we all have similar ideas about what is beautiful?

We watch this video on the 'Science of attraction': https://www.youtube.com/watch?v=169N81xAffQ. We also discuss existing social norms of beauty, body shaming, etc. Discussion can also be initiated with questions, such as: What is meant by being beautiful? Does beauty mean—being thin, fair, muscular? Do we have to fit a certain definition to be beautiful? Who defines the criteria for beauty? Does media play a role in this definition? Do we unconsciously allow ourselves to be defined by what we see in media? What can we do to establish a positive relationship with our own bodies?

Q. How do you know when you are pregnant? What are the symptoms?

To prime our discussion, we watch videos on:

- Surprising effects of pregnancy: https://www.youtube.com/watch?v=F_ssj7-8rYg.
- Crash course video on pregnancy: https://www.youtube.com/watch?v=BtsSbZ85yiQ.
- How do pregnancy tests work: https://ed.ted.com/lessons/how-do-pregnancy-tests-work-tien-nguyen.

Q. What is a test-tube baby?

We watch this video on in-vitro fertilization (IVF): https://ed.ted.com/lessons/how-to-make-a-baby-in-a-lab-nassim-assefi-and-brian-a-levine.

Q. Are there reasons other than pregnancy for a woman to miss her periods?

We watch a SciShow video on 'Why did you skip a period': https://youtu.be/DT37UwFPF8c. We also discuss the role of nutrition, exercise, and hormones on periods.

Q. What is homosexuality? Is it normal to be homosexual?

Here I explain what LGBTIQA is, and share that it is perfectly normal to be any one of them. We also discuss societal prejudices around gender and related laws.

Here are some other frequently asked questions that I discuss during these sessions:

- What are HIV and AIDS?
- How does sex give pleasure?
- What is an orgasm?
- Is it right to want to have sex at the age of 14?
- Is sex painful?
- How are twins formed?
- What is pornography? Is it harmful?
- Which is a healthier option for a mother—operation or normal delivery?
- Is there a female equivalent for masturbation? What is it?
- Why are teenagers interested in sex?

need to refrain from making fun of or judging anyone.

I start the discussion by reading aloud any one of the collated questions (see **Box 3**). Usually, I choose an extension of the anatomy-based questions. This could be a question like, 'How many times is intercourse needed to fertilize an egg?', or 'Why is periods considered a taboo topic to discuss openly?' or 'Does it hurt when one has sex?'. Students tend to avoid eye contact or stare at the floor while I read this. After I have finished, I take a long pause to look at everyone in the circle. Then I encourage the students to take over, by asking questions like, *"What do you think of the question? Does anyone know what the question means?"* Slowly, the students start to open up. In the end, for each of the student questions that I read aloud, either I offer the necessary information, or we draw conclusions or summarize our thoughts together as a group. This introductory discussion session typically helps me to gain a better understanding of students' thoughts; as well as gauge peer influences, and their comfort levels. It helps students become more confident in articulating their thoughts in front of their peers. I then move on to other questions, using the same broad approach to facilitate discussion. In order to respond to the questions as holistically as possible, we may touch upon many associated themes, like the human brain, addiction, narcotic drugs, pornography, existing societal taboos, consent, sexual rights, and pleasure. Also, where appropriate, I may play short videos that help students gain a better visual understanding of the points raised during the discussion.

Students consistently show a positive response to these discussions, and many a time I have found it difficult to end the class because the students wanted to continue their discussion to the next period as well. Every class has some students who are chirpy and ask questions aloud, and some shy ones who signal me to approach them to voice their questions. There are also a few who very obviously struggle with their feelings. As we proceed with the questions, the students begin to communicate more and more openly. I have noticed that peers play an important role in easing inhibitions and setting the overall classroom dynamics. For example, seeing a classmate ask questions encourages others to ask as well. Similarly, a light-hearted comment from a classmate eases the tension in the classroom. As a teacher, I facilitate such a supportive environment by being neutral and non-judgemental to all questions from students. This helps establish a circle of trust that allows students to fearlessly ask follow-up questions that are both general and personal in nature. On occasion, students may also share personal experiences of the impact that community/social norms, body images, or stereotypes have on their well-being. Some students continue with these discussions at home and get back to class with more questions. Very often, this practice of asking questions and participating in discussions continues beyond this grade. For example, students from some of these batches wanted to discuss the same topics again in Grade XII. Some students even had the same questions that they had asked in Grade IX. It may therefore be helpful to repeat this module at different academic levels.

(c) Faculty invites: Another interesting approach that I followed was to invite other members of my school community to address specific questions. For example, a mathematics teacher, who was a new mother, discussed different modes of birthing and her experience with water birthing in particular. The school doctor shared his expertise on reproductive health, and a teacher with a degree in psychology discussed some sociological and psychological aspects of reproduction. Each of these was an enriching experience and offered students the opportunity to connect with their teachers in a novel context.

Parting thoughts

Over the years, I have observed that students look forward to this module, both because they are eager to gain more information and because they appreciate the opportunity for discussion. Discussions throughout the module have been consistently intense (except those in the first one or two classes, in which getting student participation is inevitably a struggle). Although some parts of the module are information-heavy, students have enjoyed the overall learning experience. Since the module covers all parts of the related unit in the curriculum, it negates the need for extra classes to cover the unit from an exam-centric view.

While the approaches described in this article may seem daunting to a teacher at first, it can be a truly rewarding experience in the end. The resources shared in this article could help prepare teachers to gain necessary and accurate information. However, it is also important to be mentally prepared to be sensitive to heteronormative, judgmental, and patronizing attitudes; to be inclusive; and to consistently ensure that the discussions are not fear-driven. It is beyond doubt that this is not an easy task, especially with the additional constraints of time and syllabus coverage. But at the end of the day, we need to pause and ask ourselves: Why do we teach? What are our values as a teacher? What are our expectations from students? Is it not our responsibility to enable students to think rationally, reflect, and express themselves freely?

Key takeaways

- Creating an environment that is supportive of students' curiosity provides learning opportunities for both students and teachers.
- Frank and open discussions that allow students to pause and reflect, specifically on sensitive topics, help them overcome their inhibitions.
- It is important for a teacher to be non-judgemental and inclusive in order to provide a secure learning environment for students.

Acknowledgments: I thank my students for asking such wonderful questions, and my colleagues for their enthusiasm and consistent support. I also thank the editors and reviewers for their detailed feedback and suggestions.

Note: Source of the image used in the background of the article title: Discussing reproduction. Credits: Shreya Kedia. License: CC-BY-NC.

Some useful resources:

1. TARSHI. The Yellow Book: A parent's guide to sexuality education. Zubaan Publishers (2010).
2. TARSHI. The Blue Book: What you want to know about yourself. Zubaan Publishers (2013).
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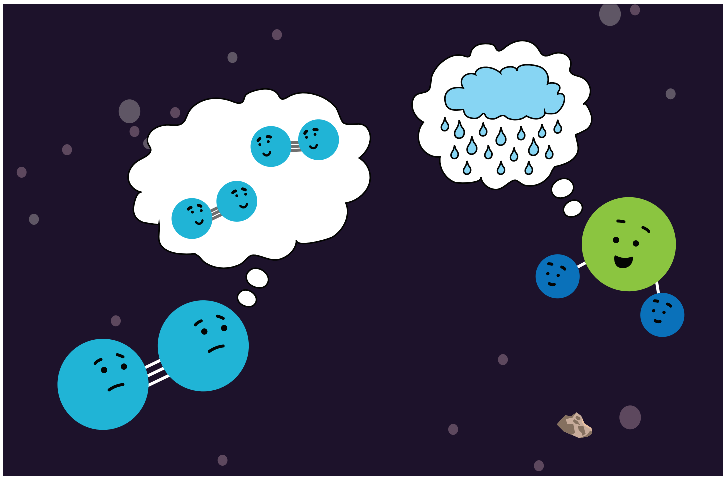
LIQUID LONGING

My countless identical brothers and I
Do relish our vantage from way up high,
Each flying around as a nitrogen pair
And making up eighty percent of the air.

But sometimes it's boring, floating up here,
As part of the gaseous atmosphere,
Though really, I wouldn't complain, if only
It weren't so absolutely lonely.

Because we're a gas, it's clearly a fact
That our molecules rarely do interact.
Our density's measure is simply too low
For our intermolecular friendships to grow.

And if, perchance, two souls are to meet,
They scatter away without missing a beat—
No conversations, no talk of the weather,
No effort to blossom, to grow together.



But one day, however, I got the rare chance,
In the midst of our random molecular dance,
To talk with an H_2O just long enough
To be able to learn some incredible stuff.

He said he had buddies that he used to stick with,
While swimming in something he called a "liquid."
"In liquids, everyone's quite a bit closer.
You ever been part of one?" he asked. "No, sir."

He looked me over. "What do you expect?
You have no strong 'handles' with which to connect!
Hydrogen bonds you clearly won't make;
You lack polar 'H's,' for goodness sake!

If making a liquid were really your goal,
'Twould help if you sported some sort of dipole,
Or also, you could have been bigger in size,
So dispersion-type forces could dictate your ties.

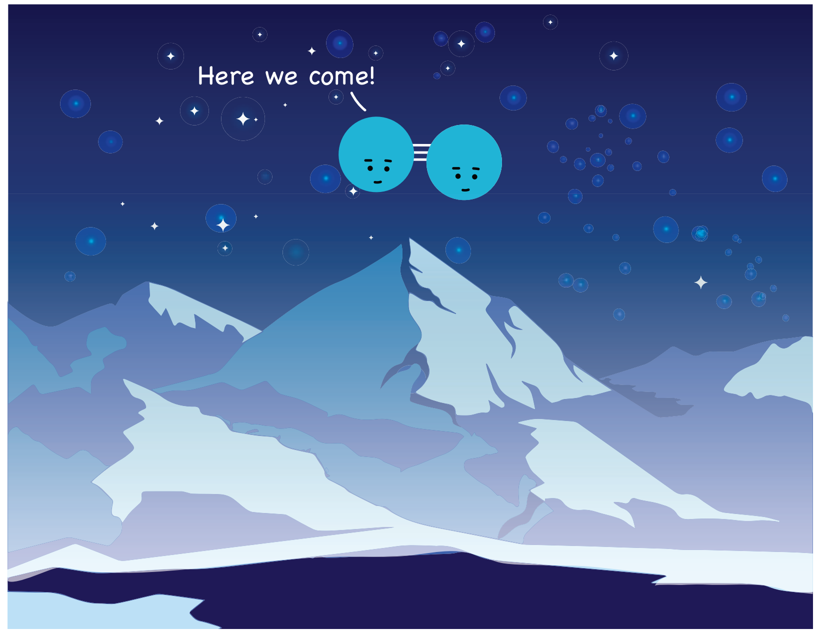
But thus, these friendships that you seek
Can in your case, at best, be weak.
Your intermolecular forces, alas,
Are small. That's why you are a gas.

But wait, there's hope! The truth is that
It also depends what the temperature's at.
The higher the thermal energy,
The more will you fly all around and be free.

But when it's really, very cold,
Then weaker forces actually hold.
So go to a frigid locale, and then,
You will be liquid nitrogen."

And as rapidly as our exchange did commence,
He said, "Bye, I must go away now and condense."
But he taught me the cause of my gaseous deal:
My friendship conditions were just not ideal.

See, some can create many friendships with ease,
Without the need for help from a freeze.
For me, to get some friends clearly meant
I would need a different environment.

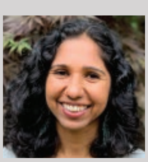


While many may dream of the sun and the heat,
I dream of the countless new friends I would meet,
How I would be popular, everyone's hero
At two hundred Celsius degrees below zero.

I do wish the change didn't need to be drastic.
To have friends right now would indeed be fantastic.
So if you are the type who can mingle with ease,
Just try to make friends with us too... please?

Notes:

1. This poem was first published in Mala Radhakrishnan's poetry collection 'Atomic Romances, Molecular Dances' and is included in this issue of i wonder… with her permission.
2. Source of the image used in the background of the article title: Poem. Credits: Idearriba, Pixabay. URL: https://pixabay.com/photos/poem-butterfly-literature-tale-1104997/. License: CC0.
3. The three illustrations for this poem were conceptualised & created by Vidya Kamalesh (Artist, i wonder...) & Chitra Ravi (Editor, i wonder...). To reuse, please include following details: Credits: i wonder..., Jun 2022 issue. License: CC-BY-NC.



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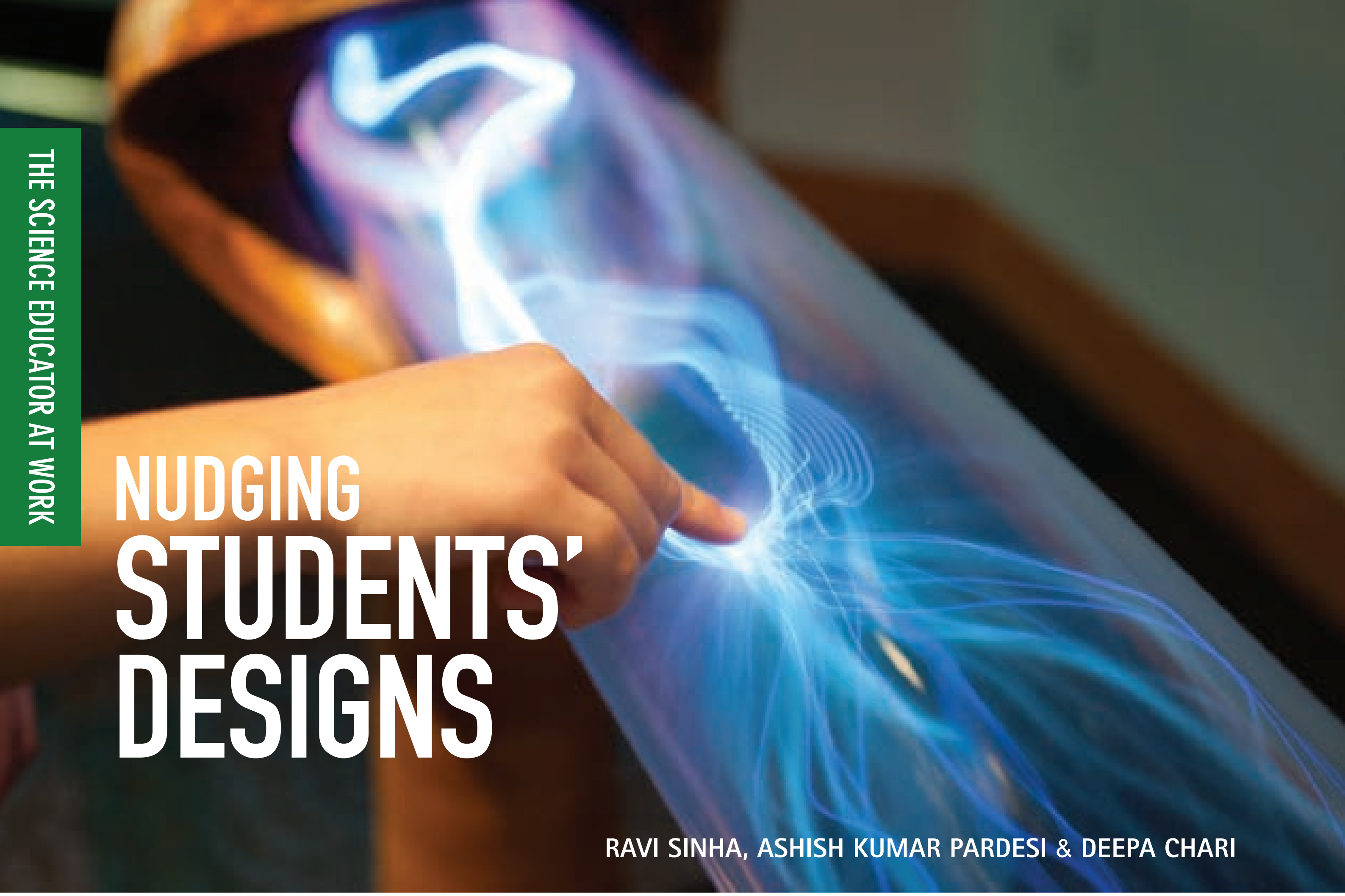

NUDGING STUDENTS' DESIGNS

RAVI SINHA, ASHISH KUMAR PARDESI & DEEPA CHARI

It is common for students to learn scientific concepts through explanations offered by their teachers or textbooks. But what concepts and skills would they learn when they construct and test physical models of simple instruments? What ideas would emerge from encouraging peer discussion around their material and design choices?

The National Curriculum Framework (NCF) 2005, emphasizes the importance of 'working with hands to design technological modules' in teaching science at the upper-primary and secondary stages. One way of doing this is to invite students to design and construct models of simple instruments that appear in their curriculum. In the process, students can be encouraged to explore and critically think about what materials they can use and how they can put these materials together to ensure that the instrument becomes functional. Students can also be offered the opportunity to evaluate the material and design choices made by their peers. Thus, this exercise can be used to help students develop familiarity with the practice of science. Similar to how scientists present laws governing science through investigations/experiments, students can arrive at a better understanding of scientific concepts through this exercise in material exploration, model building, and model testing.

In this article, we share our experiences of conducting one such model-building exercise in an online environment during the pandemic-related lockdown. Upper-primary students were invited to build an electroscope, a charge-detecting device, which appears in the Grade VIII science textbook in a chapter titled 'Some Natural Phenomena'.

The model-building exercise

The Grade VIII textbook introduces students to one method of constructing an electroscope from simple materials. It also offers a set of interesting prompts to encourage observation and exploration of the model after construction (see **Box 1**). We decided to invite students to explore alternative materials and designs to construct the same instrument. This exercise could help in two ways. Firstly, students would have the opportunity to discover multiple functional variations of the electroscope. Secondly, it would help them develop a better understanding of related concepts (like charged bodies, attractive/repulsive forces, deflection, charge quantity, etc) and their practical applications.

Box 1. **Excerpt from the NCERT textbook:**

"Take an empty jam bottle. Take a piece of cardboard slightly bigger in size than the mouth of the bottle. Pierce a hole in it so that a metal paper clip can be inserted. Open out the paper clip as shown in Fig. 15.4. Cut two strips of aluminium foil about 4 cm × 1 cm each. Hang them on the paper clip as shown. Insert the paper clip in the cardboard lid so that it is perpendicular to it. Charge a refill and touch it with the end of the paper clip. Observe what happens.

Is there any effect on the foil strips? Do they repel each other or attract each other? Now, touch other charged bodies with the end of the paper clip. Do foil strips behave in the same way in all cases? Can this apparatus be used to detect whether a body is charged or not? Can you explain why the foil strips repel each other?

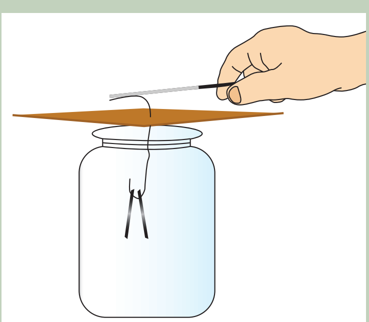

Fig. 15.4. The aluminium foil strips receive the same charge from the charged refill through the paper clip (remember that metals are good conductors of electricity). The strips carrying similar charges repel each other and they become wide open. Such a device can be used to test whether an object is carrying a charge or not. This device is known as an electroscope.

Source: NCERT Science Textbook, Ch. 15: Some Natural Phenomena, retrieved from https://ncert.nic.in/textbook/pdf/hesc115.pdf (pg. 180).

The online environment

In April 2021, we collaborated with the Grade IX science teacher of an English-medium public school to organize two online 'making' sessions. Both sessions were held during regular school timings, and each session was 90 minutes long. Around 29 students from this grade voluntarily participated in these sessions.

(a) Session I: In the first session, we introduced students to one model of an electroscope, and gave them a live demonstration of how it works. We then challenged the students to construct an alternate version of this instrument using other (locally available) materials and designs. During this session, we deliberately deferred any discussion on the working principle of the electroscope. This was to allow students the opportunity to come up with their own descriptions of how associated concepts (like charge, forces, amount of deflection, etc.) contributed to the design of the instrument. In this way, we hoped that students would be able to engage with this exercise with a spirit of inquiry similar to that which scientists bring to their experiments.

(b) Session II: To give students some time to work on their models, the second session was conducted after three days. In this session, we used some discussion prompts to encourage the students to share their journeys of making alternate electroscope models (see **Box 2**). Due to the lockdown, only a few students managed to collect some alternate materials for design, and only one student (Divya) managed to complete the construction of an alternate model. We had anticipated such a situation, and were prepared to facilitate a discussion on the basis of the materials and designs students had considered for their models, even if they had not been able to make one. As Divya had managed to construct a working model, we invited her to start the discussion with her experience of the process. As others joined in with their feedback, the conversation extended beyond her design.

Divya's experience of 'making'

Divya presented an alternate design of the electroscope that was built with a glass tumbler, some paper cards, adhesive tape, copper wire, and aluminium foil (see **Fig. 1**). She also shared a video demonstration of how the aluminium foil in her model was deflected when a charged body (she used metal or plastic scales rubbed with cotton cloth for this purpose) was brought in its vicinity. This offered proof of principle—when a charged object is brought into the vicinity of an electroscope, it should trigger a flow of charge that causes the foil sheet or strip to show a deflection. The magnitude of deflection should vary depending on the amount of charge that the object carries.

Box 2. **Some discussion prompts:**

Questions around making	Questions about conceptual understanding
• How was your journey of making? • Why did you choose these materials/ designs in your model? • Were you surprised by some observation or discovery during this process of making? • Did you find any aspects of this process challenging? • What worked and what did not? • Can you share a sketch of your model?	• Is the sketch you have shared an accurate representation of your model? • What do you all think about this design? • Can you invite two of your friends to share their feedback and comments on your design/ model? • Would anyone like to explain the working of the model? • What else do you think we can learn from this activity?

Fig. 1. Electroscope built by Divya. (a) A top-view, where the spiral shape of the copper wire is visible. (b) A side-view, in which the aluminium foil leaves are visible.

Divya shared that she started off by experimenting with a variety of materials to build a functional electroscope. These included different kinds of wires (like a coated copper wire, bare copper wire, steel wire, guitar string), a plastic scale, a plastic container, paper, etc. When asked how she managed to obtain these materials, she shared that: *"To get the material, ...it was not really hard, because my brother also helped me in it! In a second, I finished my project, like that [same] day!"*

To make tweaks to the textbook design of the electroscope, Divya researched various materials and their compositions online. She also shared how she had arrived at her model after much trial and error. For example, Divya knew that when a charged body is brought near the copper wire in the textbook model of an electroscope, the aluminium foil leaves showed a deflection. When Divya replaced the bare copper wire with a coated copper wire, the aluminium leaves did not show any deflection. So she tried redesigning the device by replacing the copper wires first with a guitar string and then with a steel wire. In both cases, the leaves showed deflection. When asked if she could think of a reason why the coated copper wire had not worked, Divya shared her observation that the: *"Coated copper wire doesn't react to magnets, whereas steel wires and guitar strings react."* Her response suggested that she had worked with the hypothesis that materials with magnetic properties were likely to cause deflection.

Another aspect of Divya's design process was that she made changes to the textbook model of the electroscope iteratively to identify which possible combinations would work. For example, it was only after she had identified some alternatives to the wire that she began exploring alternatives to the aluminium leaves. Divya shared how she had tried using a medicine strip and a thin metallic piece from a container for this purpose. Then, she considered replacing the cover of the container with a straw that would provide support for the wire as well as the materials that were brought near the wire for testing.

When asked about her experience of making these changes in design, Divya shared her frustration while trying out various materials. She also shared how her family had supported her through it: *"I changed my design a lot of times! I got angry (laughs)...it was funny...in the middle of the project my father had to come and say: Don't get angry, have patience ...Scientists also never invented things quickly ... no one is perfect and everyone makes mistakes!"*

Peer discussion

One of the facilitators of the session captured the key design tweaks that Divya had described in a schematic on a digital whiteboard that was visible to her peers (see **Fig. 2a**). This was used to steer group discussions from time to time. Here are two examples that illustrate the nature of the discussion:

(a) On the working principle of the electroscope: Following Divya's demonstration of her model, the group was asked if they could think of a reason why the aluminium leaves showed deflection in the vicinity of a charged object. A student, Amit, shared his thoughts on how the model might be working by connecting it with a real-life example: *"When we rub a plastic scale with something like cloth, a plastic scale will have some charge... it will be negative or positive. When we bring the plastic scale near the copper*

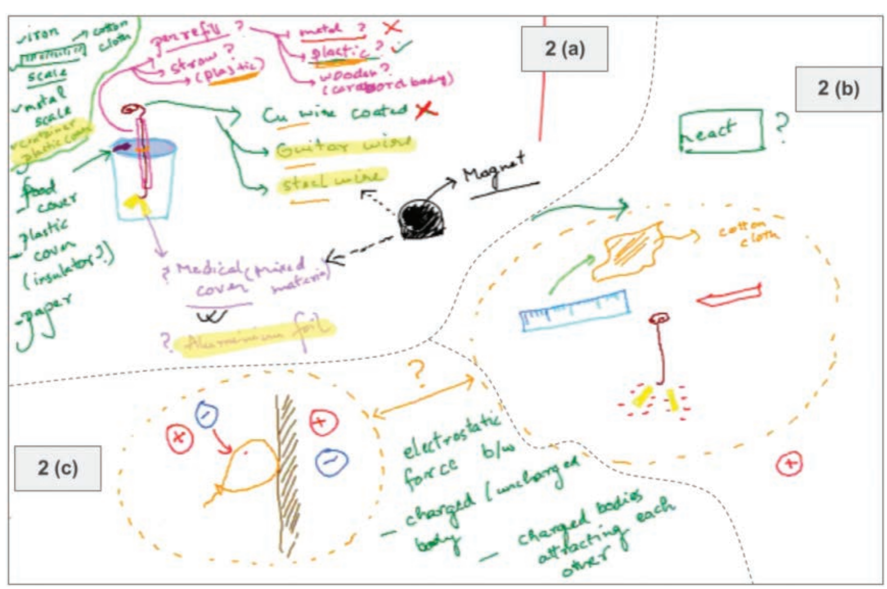

Fig. 2. A pictorial summary of the discussion. This image captures the key points of discussion around: (a) the model making and design process, (b) the working principle of the electroscope, and (c) connections to other phenomena.

wire, the charge will get to the copper wire, and reach the aluminium foil... and the aluminium foil will have the same charge... like if the scale has a negative charge... the same charge will be transferred to the aluminium foil, and the (two) negative charges will repel each other. So the aluminium foil is deflected."

When asked if the students could relate their experience of using the electroscope to any other real-life experiences where charges are involved, another student, Arjun, recalled his interaction with his mother when he wanted to stick a balloon on the wall: *"I wanted to stick a balloon on the wall. My mother said that I shouldn't stick the balloon with tape since the walls will get damaged... She said that if I rubbed the balloon against my head, it would attach to the wall."*

Both Amit and Arjun could identify that the deflection of the aluminium foil in Divya's design was due to the charge that travels from the charged object to the foil strips (via the copper wire). This is perhaps why, when asked to share similar observations, they came up with instances where a similar transfer of charge had occurred (see **Fig. 2b, 2c**).

(b) On alternatives to the straw in Divya's model: After Divya had shared the different materials she had used to tweak her design, the students were asked if metal, cardboard, or plastic pen bodies could be used instead of the straw she had used in her model. One student, Anuj, asserted that a metallic body would not work. He shared the following justification: *"I think a plastic refill will work, but a metal refill will not work. Because when we try to test our electroscope, the energy (from a charged material) needs to be transferred to the aluminium foil for it to deflect. A metal refill will soak all that energy and... and the foil will not react (to the charged material)."* Divya expressed the view that the plastic body would work: *"Both (the materials I used in my design) are (made of) plastic... basically, I used a plastic straw and a plastic pen refill."* She also disagreed with Anuj's view: *"I don't think plastic will act differently from metal."*

While we have shared responses of a few of the participants, many others contributed to the discussion around Divya's material exploration, as well as Amit and Arjun's ideas about charges and charge transfer/flow.

Parting thoughts

The electroscope sessions offered one possible way to redesign a model-based science activity for an online environment. We started by inviting Divya to share her experiences of model-building and testing. The collaborative home environment emerged as an important factor in her model-making process. The support of family members in procuring different materials to explore, and their encouragement at different stages of making the model enabled Divya to sustain her inquiry. We extended this conversation by encouraging Divya's peers to reflect on her material and design choices as well as share any experiences that they felt were relevant to the discussion. This offered the rest of the students the opportunity to closely evaluate Divya's model, even if they couldn't make one at home. The discussions that followed also revealed some alternate conceptions. For example, some participants used the word "react", "attract", or "repel" to explain the action of forces by charged particles. In contrast, other students used the correct choice of words to explain how deflection varied with the magnitude of charge. Thus, instead of starting with predefined goals and procedures, these sessions tried to build on the experiences of the group with gentle nudges from the facilitators. Our prompts helped discussions flow smoothly, and made the sessions more student-centric.

In light of this experience, we suggest that it is crucial to build a shared space that invites students to participate in model-designing directly or indirectly. The exemplar discussions described in these sessions may help teachers to understand the nature of students' engagement with science explorations and utilize their experiences for scaffolding.

Key takeaways

- The National Curriculum Framework (NCF) 2005 emphasizes the importance of 'working with hands to design technological modules' in teaching science at the upper-primary and secondary stages.
- Inviting students to construct and test models of simple instruments, like the electroscope, can improve their conceptual understanding.
- Encouraging peer discussion around their material and design choices in a collaborative environment can help build the spirit of inquiry and an appreciation for the scientific process.
- Such exercises can also help students develop patience, observation skills, critical thinking, and the ability to collaborate with and seek feedback from peers—all of which are important in the practice of science.

Notes:

1. The electroscope project was introduced via the Metastudio website to the students. Metastudio (metastudio.org/) is an open-to-all and free-to-participate platform designed at Gnowledge Lab, HBCSE. Once registered, students can document their ongoing STEM projects, participate in discussions, as well as receive feedback from the rest of the community.
2. At the time of this activity, the Metastudio post related to the electroscope had some previously documented designs, contributed by community members. These designs can help seed initial ideas about how students may pursue or even document their investigations. For more details, visit: https://metastudio.org/t/build-your-own-electroscope/3730.
3. Source of the image used in the background of the article title: Static electricity. Credits: LaSombra, Flickr. URL: https://www.flickr.com/photos/la_sombra/6036168427/. License: CC-BY.

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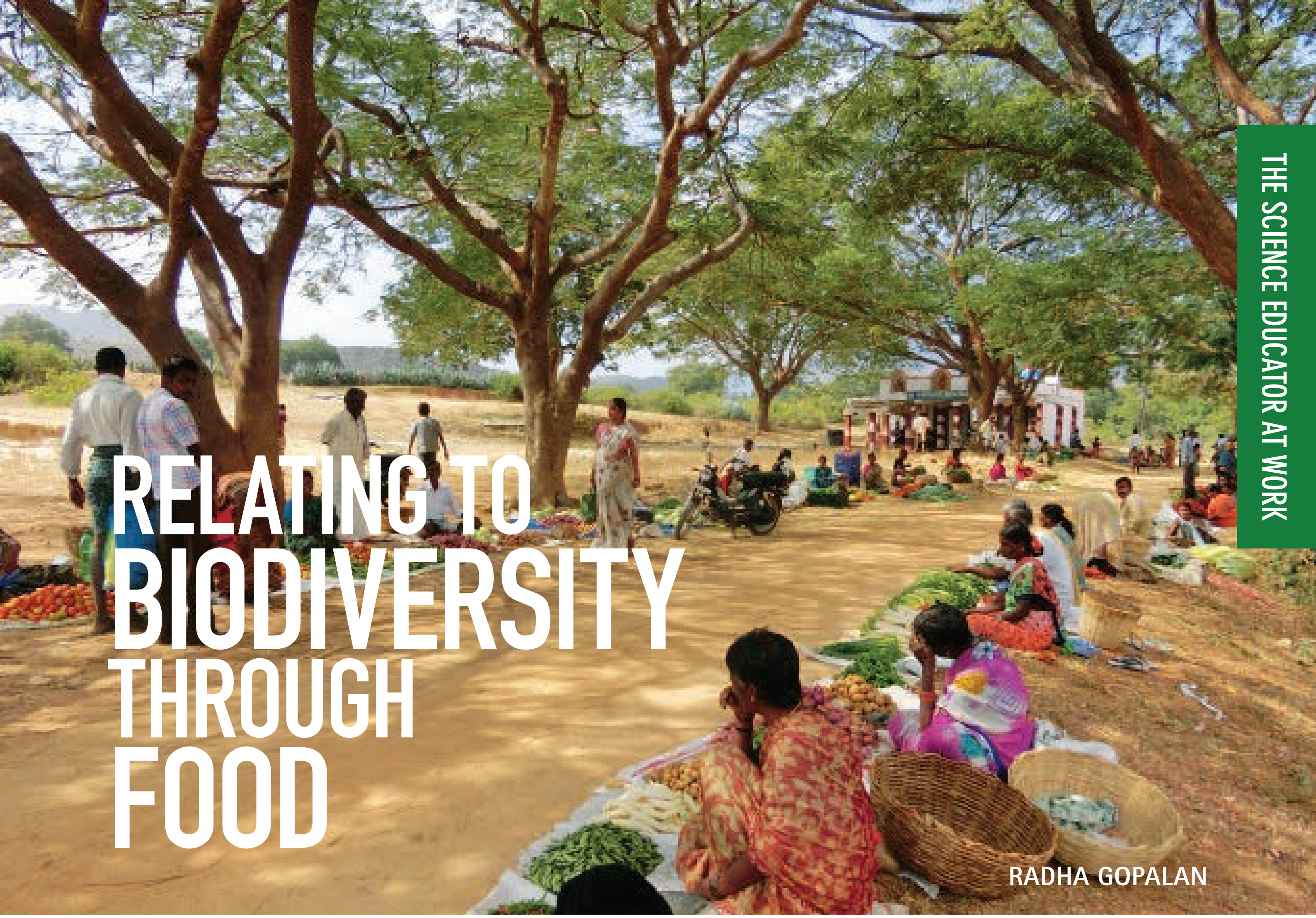


RELATING TO BIODIVERSITY THROUGH FOOD

RADHA GOPALAN

The concept of biodiversity is usually introduced in middle school in the context of forests, wildlife, and protected areas. But is it possible to relate to this concept through the diversity in our local food systems?

The concept of biodiversity is introduced in a chapter on 'Conservation of Plants and Animals' in the Grade VIII science textbook as: *"the variety of organisms existing on the earth, their interrelationships and their relationship with the environment".*[1] This definition is accompanied by images of tropical forests and protected areas with large wild animals. Many students may find these examples alien to their real-world observations and experiences. This disembodied way of relating to biodiversity can limit their understanding of this concept to knowing the term and remembering its definition to pass examinations. Therefore, the main challenge for teachers is to find ways to help students relate to biodiversity in their local lived contexts.

In this article, I share some learning experiences from how teachers and students at a local Zilla Parishad High School (ZPHS) in rural Andhra Pradesh addressed this challenge by exploring the diversity of their local food systems.

Biodiversity in a semi-arid landscape

Located in the semi-arid Rayalaseema region of Andhra Pradesh, ZPHS is surrounded by a mosaic of scrubland grasses, hillocks, agricultural fields, and a few patches of dry deciduous forest (see **Fig. 1**). Its students belonged to a rural community of pastoralists and small farmers. A small group of us, who lived and taught in a residential school in the area, worked closely with teachers from the ZPHS, supporting them with ideas for lesson plans and teaching resources.

During one of our discussions, the Grade VIII biology teacher sought our help in setting up a public exhibition on the occasion of the International Day of Biodiversity. She shared how her students were unable to relate to the concept of

Fig. 1. The semi-arid landscape of Rayalaseema.
Credits: Radha Gopalan. License: CC-BY-NC.

biodiversity because they had not seen any of the plants or animals mentioned in relation to this concept in their textbook. Therefore, she intended to introduce them to the diversity of tree species native to the dry deciduous forests of the region. For this purpose, she wanted to borrow well-grown saplings of a few such tree species from the nursery of our residential school, which her students would present in the public exhibition. In preparing for their presentation, the students would have the opportunity to learn more about each of these species, and their role in the local forest and landscape.

At the time, we were engaged in an ongoing dialogue with the local community to understand and document the diversity in their traditional food systems. This led us to suggest an alternative to the teacher—what if her students were to prepare exhibits to capture the diversity in local food crops, vegetables, leafy greens, berries, fruits, etc.? This could be an excellent way for students to learn to connect concepts in their textbooks with their real-world experiences. It would also allow them to showcase the knowledge and lived experience of agrobiodiversity embedded in their own community.

The biology teacher as well as the other teachers who were helping with the exhibition were willing to give this a try. They requested our help in working with the students to plan, collate information, and set up the exhibition. While the students were not able to immediately relate this to what they had learned about biodiversity in the classroom, they greeted the idea with a lot of excitement and questions. With the planning of the exhibition being a priority, we agreed to come back to the students' questions after the preparations were done.

From planning to preparation

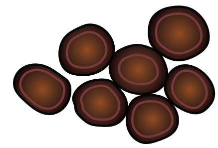
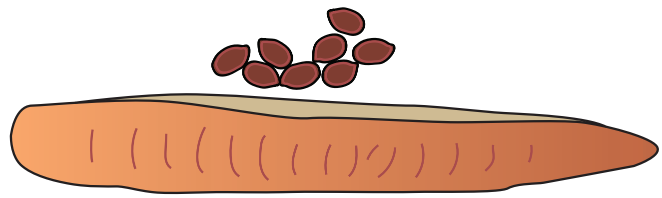
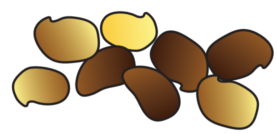
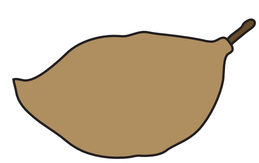
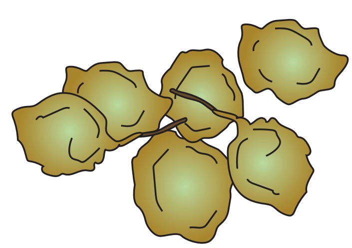
The students of Grade VIII came from eight villages in the area—some located in the hills and others in the valley. This topography influenced the availability of groundwater, precipitation patterns, soil type, and access to the nearby town market. As a result, these villages differed in the crops they grew, how they grew them, and the breeds of animals they reared (see **Box 1**). After much discussion among the students and teachers on what to include as exhibits, it was agreed that each student would bring samples of the seeds of traditional or local grains, vegetables, edible greens, and fruits available in their homes. They were specifically asked not to procure commercial seeds. Students were also encouraged to consult their parents, grandparents, and other elders in the village for information on each seed and record this in their notebooks.

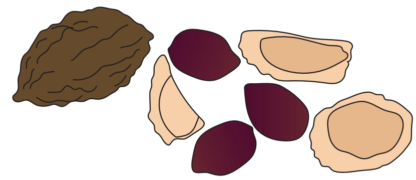
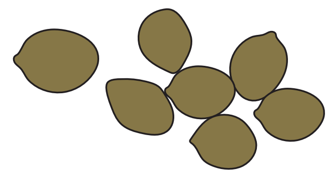
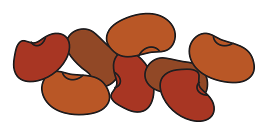
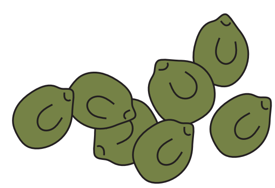
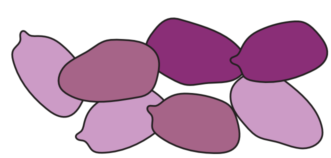
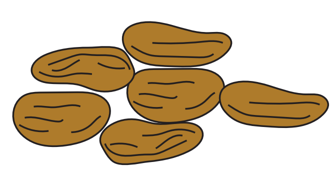
Preparation for the exhibition began in earnest as the students started bringing in seeds of different varieties of millets, dryland paddy, oilseeds, leafy edible greens, gourds, and other vegetables. As each student shared the information they had collected, the teachers were amazed at how much knowledge existed in the community, and how easily the students related to it. Similarly, when the students took stock of the many different seeds and the amount of information they had collected, they were surprised by the diversity of both, even within a single village (see **Table I**). Much of what they had documented

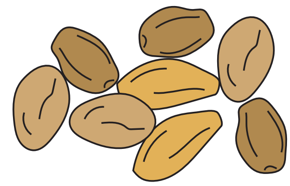
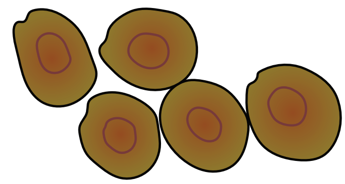
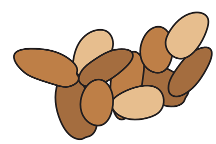
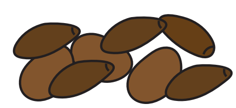
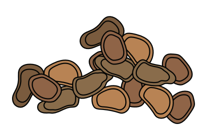
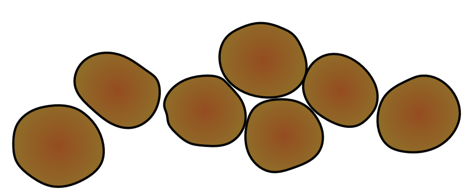
Box 1. Diversity of food plants in the area:

The traditional food system of this region was built on a diverse range of food crops (millets, pulses, oilseeds, and dryland paddy), herbs, uncultivated edible greens, gourds, and berries. Some of these were cultivated, and others foraged (uncultivated). The kind of food crops seen in any particular part of the region depended on its topography, soil conditions, and water availability. In the hills, for example, people cultivated dryland paddy, oil seeds, 7-8 varieties of millets, cluster beans, as well as a wide range of gourds and chillies; and foraged for many wild edible leafy greens, tubers, and berries. In contrast, people in the plains cultivated tomatoes, chillies, brinjals, very few gourds, and 3-4 varieties of millets; and foraged for many wild edible leafy greens from the fields, bunds, and uncultivated areas.

Table I: Seeds of local tree species from a farmer's collection

Sl. No	Botanical Name	Telugu Name	Image of seed
1.	*Acacia nilotica*	Nalla thumma	
2.	*Leucaena leucocephala*	Kanti subabul	
3.	*Dalbergia paniculata*	Pachari	
4.	*Acacia leucophloea*	Tella thuma	
5.	*Hemidesimus indicus*	Pala	
6.	*Pongamia pinnata*	Kaanuga	
7.	*Pterocarpus santalinus*	Rakta chandana	

Sl. No	Botanical Name	Telugu Name	Image of seed
8.	*Zizyphus jujube*	Reni	
9.	*Elangium salvifolium*	Ooduga	
10.	*Wrightia tinctoria*	Palavareni	
11.	*Seisbania grandiflora*	Avisi	
12.	*Acacia catechu*	Sandra	
13.	*Syzygium cumini*	Alli Neradu	
14.	*Azadirachta indica*	Vepa	

Sl. No	Botanical Name	Telugu Name	Image of seed
15.	*Melia dubia*	Pedda vepa	
16.	*Albizzia lebbeck*	Pedda Sandra	
17.	*Albizzia amara*	Chigara	
18.	*Annona squamosa*	Sitapalam	
19.	*Calotropis gigantea*	Jilledu	
20.	*Litsea glutinosa*	Nara mamidi	
21.	*Boerhavia diffusa*	Punarnava	

came from their own real-world observations and experiences. For example, many of the students helped their families with farming; and knew how seeds were selected, stored, and tested for their viability before planting. They also knew of many traditional cultivation practices that were used to conserve the fertility of their soils and local plant varieties (see **Box 2**).

Arriving at a shared understanding

The exhibits were ready two days before the exhibition. Students had arranged the seeds in small containers, labelled them, sketched colourful images of plants that the seeds would grow into, and recorded all the information they had collected on charts. It was time to come back to the students' questions on how their exhibits (of local plants that contributed to their food system) were connected with the textbook definition of biodiversity (the theme of the exhibition).

We started the discussion by listing the many varieties of millets and gourds that were able to adapt well to the local conditions because of their ability to grow on marginal soils, and tolerate heat and drought. We also discussed the many local varieties of vegetables, pulses, and oilseeds that had evolved resistance to local pests. This led to a discussion on how the crop varieties cultivated on the hills were different from those cultivated on the plains.

This allowed students and teachers to explore how differences in soil, rainfall, and microclimates within the same region can influence the diversity of organisms in different areas.

This led to a discussion on the local ruminant and fowl breeds that had adapted to survive on the local scrub vegetation and were able to tolerate the water-scarce, hot, dry summers of the region (see **Fig. 3**). These drought-resistant breeds contributed to the food system by providing meat, milk, manure, and a means for livelihood. The students wondered about other animals that fed on the food crops—including the insects and birds that were found on or visited their fields. Were these too part of the local biodiversity? It was through

Box 2. Local agricultural practices to conserve soil fertility and local plant varieties:

Since most of the landholdings were small (less than an acre to two acres), the local community had developed practices that helped maximize the food, fodder, and fibre that they could produce or forage from the land. To grow diverse plants (grains, pulses, oilseeds, vegetables) on the same piece of land, they used multicropping and /or intercropping practices (see **Fig. 2**). This meant that certain crops were grown in combination (like certain kinds of millets intercropped with leguminous plants like pigeon pea, oil seeds, or vegetables). Another practice involved the sowing of seeds at differing depths based on their size. This meant, for example, that smaller finger millet seeds were sown closer to the surface for better germination, while larger kodo millet seeds were sown at more depth so that their tender roots were not exposed at germination.

Fig. 2. Multicropping of grain, oilseeds, and vegetables in a field where minimal weeding is done.

Traditional practices for the rejuvenation of soil health included manuring, soil moisture protection using shade crops and mulching, and seasonal variations in crop choices. Many of these farmers were able to identify specific pest attacks on plants by observing changes in leaf appearance and texture, the presence of protuberances or fungal growth on the stem, etc. The farming community had developed practices and formulations to manage some of these pests. Most of these practices allowed the fields to remain habitable for insects, worms, reptiles, frogs, and birds; and some of these, in turn, helped control crop pests. Since the farm animals (like cattle, goats, and sheep) grazed and browsed in the surrounding forest and on the hillocks in the area, their dung would contain the seeds of local uncultivated herbaceous species that would take root and grow in cultivated areas. Weeding was minimal and typically took the form of local women harvesting edible greens for food. Local species of agave (*kalamanda* in Telugu) were used as live fences, and hardy non-native species such as *Seisbania grandiflora* were used as windbreakers and mulch. In this way, traditional practices helped conserve many local and non-local non-food plants. Underlying these practices was the knowledge that this community had developed, over many generations, through sustained observation and learning from experimentation.

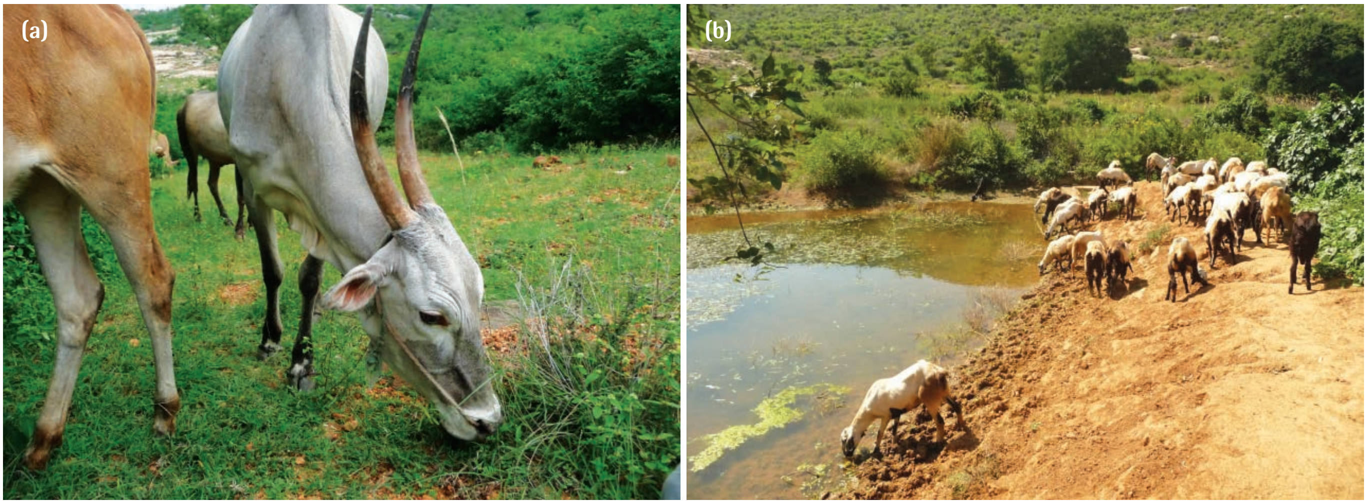


Fig. 3. Hardy local species of cattle and goats that have adapted to the water-scarce, hot, and dry landscape. The hardy Hallikar breed of cattle seen in (a) are grazing animals reared for both dryland agriculture and milk. The sheep (white-and-black) seen in (b) are of a local hair breed reared primarily for meat. Similarly, the goats (black) seen in (b) are of a local hardy breed reared for meat. Since these animal breeds require minimal resources, they are of immense value in this resource-fragile region, especially in the face of the increasing uncertainties of climate and resource availability.

this question that we were able to explain how the biodiversity of an area extended beyond the plant varieties and animal breeds (whether indigenous or commercial) that provided us (humans) with food to include all the different kinds of organisms found there and their interrelationships. And that this included all the plants (the trees, grasses, shrubs—even those that were seen as weeds); animals (like birds, snails, bats, insects—even those that were seen as crop pests); and microbes (like bacteria and fungi—even those that were seen as pathogens) that lived in and built the soil.

This prompted questions on the many factors and interactions that shape the biodiversity of an area and our (human) role in this. In response, we explored the ways in which our many activities (including our farming practices, how and where we graze our animals, and where we build our houses) could influence the kinds of organisms that we saw around us and their dynamics. Limitations of time did not allow for a deeper discussion on differences in the nature and richness of biodiversity in cultivated and uncultivated areas, or the effect of cultivation practices on the biodiversity that existed before the land was cleared and prepared for cultivation. Teachers interested in using this article to encourage students to explore biodiversity in their local contexts might like to build this into their lesson plans.

From the exhibition to the classroom

The teachers of the ZPHS felt that the exhibition had been a great success

Box 3. Reactions of visitors to the exhibition:

"This is the first time I have seen my students expressing themselves so confidently. (Especially) the way they answered questions. I was so surprised at how well they were able to explain the relationship between soil, water, seasons, and the food they grow!" — Grade VIII, science teacher.

"I could not believe it was our Grade VIII students. They were able to answer all the questions about their exhibits. How did they know all this? A lot of this information is not from their science textbook." — Headmaster, ZPH school.

"Three, four of us were answering many questions like, why we grow millets, pigeon pea, and oil seeds in the same field, how it improves and protects the soil and groundwater, how mulching and green manure made from many different kinds of leaves is important for soil bacteria and fungi. As we were explaining these things, they became even more clear to me." — Grade VIII student.

"As a Grade IX student I was very surprised to learn so much about why and how we can protect our jeevavaividyam. We should do more such activities as part of our studies..." — Grade IX student.

"We never went to school. So when my grandchild told me that our stories, our seeds will be in an exhibition on jeevavaividyam I was very curious. How well they have understood the importance of jeevavaividyam in our life. They need it for their future..." — A student's grandparent.

"I have studied only up to Grade VII and studied a little bit of science but that had no connection to our farming, our work, and life. I learned today from our children how our knowledge of seeds, local plants, our food culture, our animal breeds are related to what they are learning in school and that too in science..." — A student's mother.

(see **Box 3**). Reflecting on their experiences allowed us to identify several ideas on how this learning could be connected to the curriculum. For example, information on traditional crops and farming practices could be directly connected to the chapter on 'crop production and management' in the Grade VIII social studies textbook. Similarly, the relationship between water resources and water conservation in the Grade VII science textbook could be explored by relating it to the crop choices in this semi-arid region, the plant adaptations that influence these choices, and the way these are grown. We were also able to identify topics in the Grade VII-IX textbooks for which similar activities could help students explore the connections between soil fertility, food production, and the microbial world in local contexts (see **Box 4**). Lastly, involving the families of the students in the preparation and display of exhibits opened up the potential for creating more such opportunities for meaningful intergenerational learning.

Parting thoughts

As they worked on putting together the exhibition, the students and teachers of ZPHS started exploring the relationship between local food systems and the larger environment. Rather than seeing biodiversity as a scientific concept that applied only to forests and protected areas, students were able to relate this term to their local context and lived experiences.

The exhibition also presented a unique opportunity for the rural farming community, school teachers, and students to come together. Learning from such projects can help students develop an appreciation for the knowledge that resides in their communities. Recognizing that knowledge can come from multiple sources can help build students' confidence in being active participants in their own learning. As a result of this intergenerational learning effort, many students became interested in our ongoing efforts with their community to document the agrobiodiversity in their traditional food systems. Some of the students started attending and often participating in these discussions. This may have sown the seeds for a deeper understanding of how the land, people, and other organisms around them form a network of interdependent relationships.

Box 4. Topics in the NCERT science syllabus that can be used to connect students' real-world experiences to the science classroom:

Grade VII: Soil—our life

Grade VIII: Microbial world (soil diversity), Food production from plants, Food production from animals

Grade IX: Natural resources, Improvement in food resources

Key takeaways

- Engaging students in an investigation of the food systems and practices of their own community allows them to understand the many factors and interactions that shape biodiversity in their context, and our (human) role in it.
- Creating opportunities for intergenerational learning around traditional food production practices can help students appreciate the knowledge that resides in their communities.
- Working on such projects can help students understand that knowledge can be built from the classroom as well as lived experience, build their confidence, and help them become active participants in their own learning.

Acknowledgements: This opportunity to engage with students and teachers at the ZPHS, Thettu, was made possible by the enthusiasm of Mr. Surendra Babu, who was the headmaster of the school at the time. I thank him for his unconditional support. I thank Kavita Krishna and Santosh Kumar for the conversations around school science teaching that contributed to shaping this project. A big thank you to the Grade VIII students and teachers at ZPHS for the energy they brought into our discussions, and in putting together the exhibition.

Note: Source of the image used in the background of the article title: Local Shandy. Credits: Radha Gopalan. License: CC-BY-NC.

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SODIUM CHLORIDE

I am sodium
The 11th element on the table
Soft, silvery-white, highly reactive
In the free state, I'm unavailable

I am chlorine
Atomic number– seventeen
A halogen, the second most abundant
With the third highest electronegativity

There are many like me they say
Li, K, Rb, Cs
Yet we never click with each other
I can never coexist with them

I have my own family of halogens
All similar to me in every way
But even though our properties are all alike
I don't imagine us mingling any day

In this big group of alkali metals
I find myself alone and unwanted
Sure, we were ALL born in the earth's crust
Then why do I feel so secluded and haunted?

Highly social and reactive we seem to be
Yet to each other we're mere strangers
All so lost in this fight for nobility
No one wants their electron stabilities endangered

(But sometimes)

Sometimes I wonder who is beyond my group
Could there be a possible friend?
Maybe all there is across that period
Are elements with their own different trend

Sometimes I wander in my gaseous state
Aimlessly stumbling upon possible partners
But they're all so different; nothing like me
So I return home, disheartened

So alone so unstable
So distant so incapable
Do I belong here?
But this is my family
Says who I ask
Says Mendeleev's periodicity
But just because
Yes, just because
They all have the same electronic configuration as me

Doesn't mean at all
By any law of chemistry
That together we're meant to be

(Long pause)

All I want to do
Is gather enough enthalpy
To turn myself around
And glance at what's behind me
(Sodium slowly turns around during this para)

But if I turn, I'm afraid
They'll see how imperfect I am
Incomplete is my valence shell
I'm not as noble as I think I am
(Chlorine slowly turns around during this para)

So I look around anxiously
Finding someone whose valencies would be a match
Not catching anyone's eye
Stifling all urges to say a 'Hi'
(Both try to wave but stop themselves mid-way)

But one fine day
When we both least expected it
We both left our respective groups
And went our way
Lost but not astray
Hope that chemical kinetics
Its role would soon play
As it turns out
All we needed was an accidental collision
A collision in the correct orientation
For our energy barriers to be crossed
For our instability to be lost
And all that remained
Was an introduction, two valencies, two names
But I was scared
She's nothing like me
I'm electropositive
I'm electronegative
Poles apart
A whole period apart

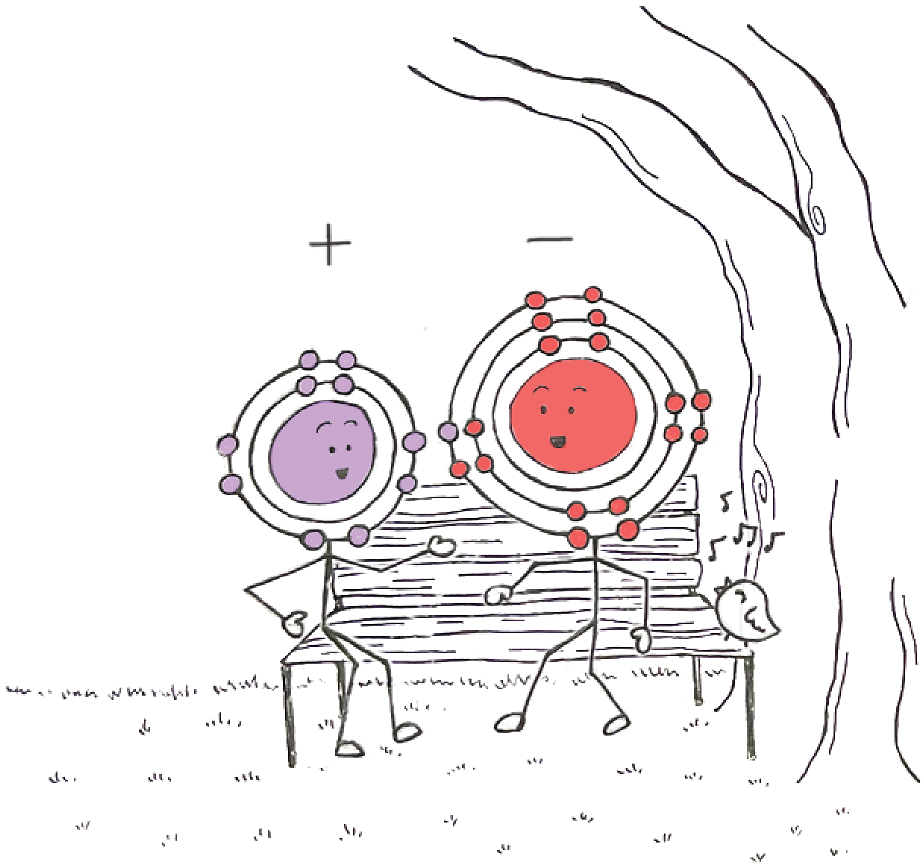
Can this brief encounter
This one 'chance meeting'
Give me a friend?
Or be my end?
Our equation seems unbalanced somehow
Maybe it isn't meant to be
Should we even bother attaining equilibrium now?
Or would it be a waste of energy?
A waste of substrate?
Maybe we should just go our different directions now

(They walk separate ways, two seconds later sodium looks back)

Hey wait!
Yeah?
I know you're really busy
Yeah right! Making people dizzy?
But maybe you'd want to
Probably meet sometime?
Share an electron maybe
That sounds fine
So I'll meet you there
By the shore of the sea?
And maybe interact for a while
At -757.3 kJ/mol enthalpy
You never know
How this may turn out for you and me
We might even start bonding
Bonding a bit ionically.

And that's the story of how a great
friendship began
Who would have thought two
opposites could complete each other's
electron band?
So much is still said about this
legendary pair
Sustaining life both on land and air
Who would have thought that beyond
yours and my comfort zone?
Was present an element in whom we'd
find home
Someone to share with, someone to
interact
Someone to dissipate with, someone to
hold intact
But that does not mean things won't
turn exothermic
Sometimes the heat will become too
much to take
But just because there's an uproar and
an effervescence
Does not mean our bonds have to break
So every time we seem distant
I'll ride the Haber's cycle down your lane

Until we both are ready
To rebuild our lattices
Every single time
Again, and again



Notes:

1. Sodium and Chlorine, two elements from across the periodic table and with very different properties, come to form one of the most iconic and underrated chemical compounds of all time. Inspired by my bond with my best friend Anshu Saran, this spoken word poem (narrated through the perspective of both elements) explores how the unlikeliest but greatest friendships form only when we dare to venture outside our comfort zones. How to read the poem: The poem is a verse-based skit (written to be performed on stage) with the sections in purple being spoken by 'Sodium', those in red being spoken by 'Chlorine', and sections in black being spoken by both.
2. Source of the image used in the background of the article title: Poem. Credits: Idearriba, Pixabay. URL: https://pixabay.com/photos/poem-butterfly-literature-tale-1104997/. License: CC0.
3. The three illustrations for this poem were inspired by sketches of the sodium and chlorine atoms by Dalia Saldanha (the author). They were conceptualised & created by Vidya Kamalesh (Artist, i wonder...) & Chitra Ravi (Editor, i wonder...). To reuse, please include following details: Credits: Dalia Saldanha, i wonder..., Jun 2022 issue. License: CC-BY-NC.

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A COMPETENCY-BASED LEARNING FRAMEWORK FOR SCHOOL SCIENCE

AANCHAL CHOMAL & SHILPI BANERJEE

Many education policies recommend science curricula that help students develop competencies like scientific temper and skills, and not merely learn facts. How can teachers connect these competency-based outcomes with the curriculum, as well as with their pedagogical and assessment practices?

In the past few years, there has been a thrust towards a competency-based approach to education across all educational policy documents (see **Box 1**). For example, the National Educational Policy (NEP) 2020 strongly recommends that the science curriculum adopt an interdisciplinary, competency-based approach that helps develop sensitivity, evidence-based thinking, scientific temper, and innovativeness in students (see **Box 2**).

However, schools face many challenges in implementing this approach in the teaching and learning of science. Important systemic challenges include a shortage of secondary-level teachers with training in science, a lack of physical infrastructure such as labs, etc., and inadequate teacher support. At the classroom level, pedagogical processes and assessment practices at all grades tend to reinforce the memorization of scientific facts over mastery of scientific skills. This is partly due to what is commonly understood as being the goals of science education, and partly because of the nature of board examinations. For example, a study conducted by Azim Premji University showed that an average of 60-70% of the questions in the Grade X science examination papers of selected Boards of India tested recall of facts and information. Also, close to 40-50% of questions in the paper were directly lifted from the prescribed textbooks. In contrast, almost all the process skills of science, such as hypothesizing, drawing inferences, predicting, analysing, etc., were left untested. Several secondary

Box 1. What is competency-based teaching and learning?

Competency-based education aims to ensure that learners demonstrate the attainment of expected learning outcomes for the school curriculum. It requires learners to be involved as active participants in teaching-learning processes in the classroom; and also emphasizes the need for them to be capable of applying the desired knowledge, attitudes, and skills in diverse contexts.

Box 2. What is the NEP 2020?

It is a comprehensive framework of recommendations for guiding the development of our country's education system. These recommendations cover many aspects of education—including the structure of schooling, curriculum, pedagogy, assessment, teacher training, school administration, and its governance.

school science teachers have shared how such examination papers contribute in significant ways to a narrowing of the science syllabus that gets transacted at the secondary level.

In order to overcome these challenges, it is important to arrive at a common shared understanding of the goals and outcomes of science. It is from this perspective that the National Council of Educational Research and Training (NCERT) has identified and published Learning Outcomes (LOs) for Grades VI-X. However, several teachers find the LOs quite abstract and disconnected from their practice. This is mainly because these documents offer little clarity on the interlinkages between these LOs and the prescribed textbooks for these grades. Also, they lack adequate guidance on ways to translate these LOs into classroom practices through appropriable pedagogical and assessment strategies.

It is to address these gaps that the Central Board of Secondary Education (CBSE), with the support of Azim Premji University, has developed a science Learning Framework (LF). This framework helps practicing teachers see connections between the many different aspects of school science education—the curriculum (particularly its aims and objectives at various stages of schooling), NCERT's grade-appropriate LOs, pedagogical principles of teaching science, and the assessment of science learning in relevant and authentic ways (see **Fig. 1**).

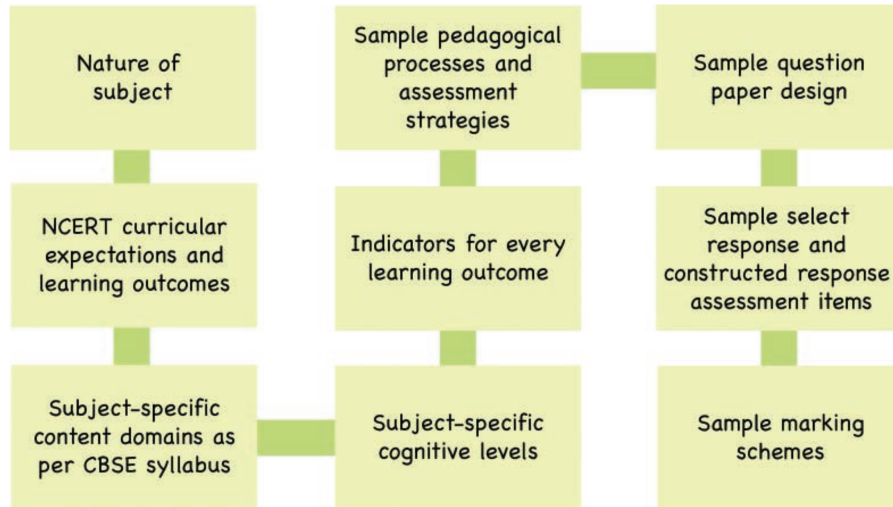


Fig. 1. Components of the Learning Framework.

Components of the LF

(a) Nature of subject: The LF outlines the various interconnected steps in the practice of science. These include making observations; looking for regularities and patterns; making hypotheses; devising qualitative or mathematical models; deducing the consequences of these models; verifying theories through observations and controlled experiments; and arriving at the principles, theories, and laws governing the physical world.

(b) Learning Outcomes: The LF connects the LOs with the science-specific skills that students need to attain through different concepts addressed in their syllabus. For example, it recognises the fact that the focus of the secondary school curriculum shifts from familiarity with formal definitions to the comprehension of concepts, principles, and laws of science. Thus, it emphasizes the role of experimentation, often involving quantitative measurement, as a tool to discover or verify theoretical principles. In addition, it also stresses the need for students to be introduced to the skills of interpreting data and drawing inferences.

(c) Subject-specific content domains: To help teachers connect science-specific LOs with the CBSE syllabus and the prescribed textbook, the LF maps these outcomes to related content domains (like Food, Materials, The world of the living, How things work, Natural phenomenon, and Natural resources).

(d) Subject-specific cognitive levels: The LF expresses the LOs for science in terms of three subject-specific cognitive levels—knowing, applying, and reasoning (see **Box 3**). These levels describe the intellectual processes that students need to engage in to demonstrate the expected LOs (see **Fig. 2**).

Box 3. Cognitive dimensions in school science:

Knowing: This domain addresses the student's ability to recall, recognize, describe, and provide examples of facts, concepts, and procedures that are necessary for a sound foundation in science. Having accurate and broad-based factual knowledge enables students to successfully engage in the more complex cognitive activities essential to the practice of science.

Applying: This domain focuses on the student's ability to use knowledge to compare, contrast, and classify groups of objects or materials; relate knowledge of a science concept (facts, relationships, processes, concepts, equipment, and methods) to real-life contexts; generate explanations, and solve practical problems.

Reasoning: In contrast to the more direct application of facts and concepts in the previous dimension, LOs in the reasoning domain involve the application of facts in unfamiliar or more complex contexts. Thus, this domain focuses on the student's ability to engage in reasoning to analyze data, draw conclusions, and extend their understanding to new situations. Scientific reasoning also encompasses developing hypotheses and designing scientific investigations within and beyond classrooms.

Knowing

- Identifies the major cell structures such as nucleus, mitochondria, ER etc.
- Describes the differences between prokaryotic and eukaryotic cells.
- Provides examples of cell types that have chloroplasts.

Applying

- Compares plant and animal cells.
- Relates how guard cells help gas exchange in leaves.
- Uses a model to demonstrate how a cell is a dynamic entity.
- Interprets tabular, pictorial, and graphical information related to cells.
- Explains the 'how' of cellular respiration.

Reasoning

- Analyzes the structure and function correlation between intestinal villi and the rate of absorption.
- Responds to why calling cells as 'bricks' of our body doesn't justify what they actually are.
- Investigates, predicts, and verifies 'what if' scenarios for living cells under certain conditions.
- Justifies the complexity of animal and plant cells in contrast to bacterial cells.
- Designs an experiment on determining cell size.
- Investigates a sample of pond water to observe, draw, and record the variety of life forms in it.

Fig. 2. Examples of different cognitive dimensions from the chapter 'A living cell' in the Grade X NCERT textbook.

(e) Indicators for every Learning Outcome: For each LO, the LF also defines indicators aligned to the science-specific skills that students need to attain through different concepts addressed in the CBSE curriculum. This offers teachers a clear understanding of the scope of each LO, which can be immensely helpful in their ability to plan how to teach each chapter in a better way (see **Fig. 3**).

(f) Sample pedagogical and assessment strategies: The sample pedagogical processes and formative assessment strategies in the LF are designed to enable teachers to derive common principles that can help align their pedagogy and assessments with the LOs (see **Box 4**).

(g) Assessment items, sample questions, and marking schemes: The LF shares a sample set of assessment items that are designed to elicit two different kinds of responses from students—select responses and constructed responses. In select response type questions (see **Fig. 4**), the student is required to select the correct response from the many options provided; while in constructed response questions, the student is expected to produce the correct response (see **Fig. 5**). Each sample item is tagged with the corresponding textbook chapter, content domain, competency level, cognitive level, thinking process, difficulty level, marking scheme, and the average time required to respond to it. The LF recommends that the marking scheme be given as much importance as the assessment item. For example, in designing constructed response questions, particularly those assessing higher cognitive levels, it recommends that teachers allow scope for variations in student responses—fully correct, partially correct, as well as many levels of partially correct responses. Similarly,

Content domain, chapter & key concepts	Learning Outcome	Indicators
Materials; Chapter 1 – Matter in our surroundings Key concepts: Physical nature of matter; Characteristics of particles of matter; States of matter – solid, liquid, and gaseous; Changes in states of matter; Sublimation; Boiling; Evaporation – factors influencing the process.	Differentiates between the three states of matter - solid, liquid, and gas.	• Defines matter as solid, liquid, and gas using their characteristics. • Differentiates between the latent heat of vapourisation and the latent heat of fusion. • Differentiates between sublimation and evaporation. • Differentiates between the three states of matter based on shape, intermolecular spaces, and the continuous movement of particles. • Emphasizes the contrast between the three states of matter using specific examples. • Differentiates between plasma and Bose-Einstein Condensate.

Fig. 3. An example of Indicators for a Learning Outcome.

Box 4. Key principles involved in the design of sample pedagogical processes and assessment strategies in the LF:

Student-centred: Since new knowledge is built over existing knowledge, pedagogical and assessment strategies focus on the prior knowledge, skills, attitudes, and beliefs that students bring into the class. They are also designed to empower students to take charge of their own learning; and encourage classroom processes that involve cooperative and peer-supported hands-on activities.

Competencies-centred: How well students learn depends on how strongly the methods of teaching, the learning activities, and the assessment strategies are aligned to the competencies that students are expected to develop in each grade. Thus, the sample pedagogical processes and assessment strategies are aligned to both the content domains and the cognitive skills indicated in competency statements.

Assessment-centred: Since assessments are an integral part of the pedagogical process, the LF shares strategies for formative assessments. These strategies have been designed to help students modulate their understanding of their own learning, and help teachers adaptively refine their pedagogical approach based on student performances. To increase the possibility of reflecting the individual capacities of students, these strategies are designed to allow multiple modes of assessment, including portfolios, project work, presentations, as well as written and oral assignments. They are also designed to include peer assessment, where students assess the work of their peers against pre-decided assessment criteria.

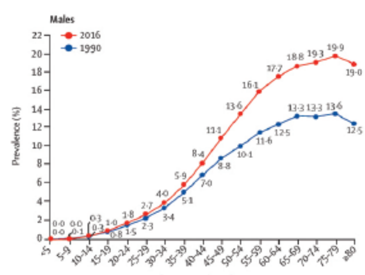
Content domain/ Chapter name	Materials (Is Matter Pure)	
Grade	Grade IX	
Learning Outcome	Describes different methods of separation to get individual components from a mixture	
Indicator	Explains the separation of sand and water using filtration	
Cognitive level	Applying	
Thinking process	Relate	
Difficulty level	Low	
Marks **Time**	1 1 min	
Item stem	Sea salt is a mixture of sand and sodium chloride. Sand is insoluble in water and hexane. Sodium choride is soluble in water but not in hexane. What is needed to separate sand from sodium chloride? 1. Filter paper 2. Fractionating Column 3. Hexane 4. Water	
Correct answer	1 and 4	As water is the only solvent that will dissolve sodium chloride.
Distractor 1	2 and 3	A fractionating column is not needed to separate this kind of mixture. This apparatus is used to separate miscible liquid mixtures.
Distractor 2	1 and 3	Hexane is not a solvent for either sand or sodium chloride. The student does not understand the importance of the solvent for separating the mixture.
Distractor 3	2 and 4	A fractionating column is not needed to separate this kind of mixture. This apparatus is used to separate miscible liquid mixtures.

Fig. 4. A sample select response question.

Content domain/ Chapter name	World of Living/ Control and Coordination in Animals
Grade	Grade X
Learning Outcome	Analyses and interprets data/graphs/figures relating to the prevalence of diseases resulting from the failure of control and coordination mechanisms.
Indicator	Analyses and interprets data/graphs/figures (district/state/national) relating to the prevalence of diseases due to hormonal imbalances and failure of similar mechanisms (like, diabetes, goitre, gigantism, and dwarfism)
Cognitive level	Applying
Thinking process	Interpret information. Explain.
Difficulty level	Medium
Marks **Time**	3 5 min

Item stem

The graph below shows age-specific prevalence of diabetes in males in the years 1990 and 2016.



Which age range shows the highest prevalence percentage of diabetes for the year 2016?
What is the increase in prevalence percentage for the age group 25-29 from the year 1990 to 2016?
Explain the requirement of artificial insulin for diabetic patients.

Image source: https://www.thelancet.com/journals/langlo/article/PIIS2214-109X(18)30387-5/fulltext#seccestitle10

Marking scheme

Part	Mark	Answer	Further information
a.	1	For 2016 Age range: 75-79	
b.	1	Increase in prevalence percentage from 1990 to 2016 for age group 25-29: 0.4%	
c.	1	Insulin is a hormone produced in the pancreas. It helps regulate blood sugar levels in the body. When this hormone is not secreted in sufficient amounts, the blood sugar level rises and has harmful effects. Blood sugar levels in people who suffer from a malfunction of the insulin release mechanism are controlled through artificial insulin injections.	Similar explanations shall be accepted.

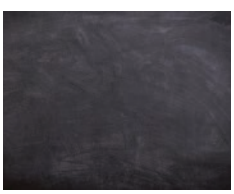
Fig. 5. A sample constructed response question with its marking scheme.

it also recommends that teachers choose a marking scheme that is aligned to the cognitive level of the assessment item. So if an item is designed to test the application of a concept, the marking scheme needs to illustrate the many possible responses that could represent its application. The LF provides some sample responses for its sample assessment items—these responses are meant to be indicative since including an exhaustive summary of all possible responses may not be possible.

Parting thoughts

As teachers, each one of us is gradually moving toward new and engaging ways of teaching and learning aimed at preparing our students for a rapidly changing world. One of the ways that we can do this is by helping them build competencies such as asking questions, testing hypotheses, communicating the results of investigations, collecting data, justifying assertions, etc. This framework aims to help teachers to make this shift in their classroom by redefining the curriculum in terms of Learning Outcomes and Indicators. As of now, the framework is hosted on the CBSE website and can be downloaded for use. A set of teachers and administrators nominated by CBSE schools found the framework to be helpful to educators in the development of scientific temper, freedom from fear and prejudice, and respect for human dignity and equality.

Key takeaways



- Many policy documents, including the NEP 2020, recommend a competency-based approach to education as a way to develop sensitivity, evidence-based thinking, scientific temper, and innovativeness in students.
- While the NCERT has identified and published Learning Outcomes (LOs) for Grades VI-X, several teachers find these abstract and disconnected from their practice.
- The science Learning Framework (LF) is designed to help teachers see connections between these LOs the science curriculum, pedagogical principles of teaching science, and the assessment of science learning.
- By redefining the curriculum in terms of LOs and Indicators, the LF can enable teachers to build competencies such as asking questions, testing hypotheses, communicating the results of investigations, collecting data, justifying assertions, etc., in students.
- A select group of teachers and administrators who have reviewed the LF have found it to be helpful to educators in the development of scientific temper, freedom from fear and prejudice, and respect for human dignity and equality.

Note: Source of the image used in the background of the article title: Blackboard. URL: https://pixabay.com/photos/black-board-traces-of-chalk-school-1072366/. Credits: stux, Pixabay. License: CC0.

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INTERVIEW
WITH MALA RADHAKRISHNAN

Mala Radhakrishnan is a scientist-poet and a professor of chemistry at Wellesley College, US. She writes and performs chemistry-themed poetry, and has published two poetry books. In this interview, she shares insights into how chemistry and poetry can be integrated into education.

Q1. Mala, could you tell us a little more about what you do at present?

Mala: As a computational biophysical chemist, my students and I like to say that we play the role of 'matchmakers' for molecules—we use models based on physics to predict how strongly molecules will interact with each other. These predictions can be used to analyse and design drug molecules or other molecules of biological importance. I'm also working with my research team to develop molecular modelling activities to engage high school students in interdisciplinary science.

I teach a wide array of courses, from introductory chemistry to physical and computational chemistry. I also teach a seminar that engages students with models across disciplines—looking at what models are from philosophical, psychological, and scientific perspectives. This course highlights the power of connecting the humanities, social sciences, and natural sciences to understand the world and our connection to it.

My science-related poetry is also rooted in my interest in combining creativity and science. Currently, I'm also interested in collaborative projects to engage science students in writing poetry to reflect on their scientific journeys.

Q2. When and how did your interest in chemistry begin?

Mala: My high school chemistry teacher was one of the most enthusiastic teachers I have had. It was so clear that he was excited about the discipline and wanted us to see how exciting it can be. I think it is important to embrace and honestly own your passion for whatever it is that you like, and he taught me that it is okay to do so (in addition to teaching me a lot of chemistry)!

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Q3. What inspired you to write poems, particularly ones on chemistry?

Mala: My journey started from the world of spoken-word poetry. My inspiration came from attending poetry open mics and poetry slams, where I listened to what others wrote about and performed. Before this, I had known 'in theory' that poetry could be written about 'anything', but I had never explicitly appreciated the diversity of topics that one could engage with via poetry. The first time I read a poem I had written at an open mic, it was not about chemistry.

The inspiration to write poems about chemistry came from some amazing students I had taught at a high school in California, U.S. I would often talk about chemistry as a soap opera on the molecular level (atoms come together, break up, etc.). When the students painted a mural that narrated the story of ions within such a soap opera, it inspired me to think about other creative ways to communicate chemistry.

So I wrote a poem that narrated a molecular-level soap opera and read it at a poetry venue's open mic. The (non-chemistry) audience loved it! So I wrote another, and another, and I kept coming back each week. The audience would always react (pun?) favourably and would sometimes comment on how they learned a little bit about chemistry through the poems. I realized that such poems could have educational value, so I started to write with an eye toward communicating specific chemical concepts, while still keeping the storylines compelling and entertaining. Eventually, I started doing poetry features, and was even part of a spoken-word poetry troupe. It was an amazing experience, and I found the other poets very inspiring.

Q4. For readers who may want to try their hand at poetry, could you tell us something about the process you use to compose poems?

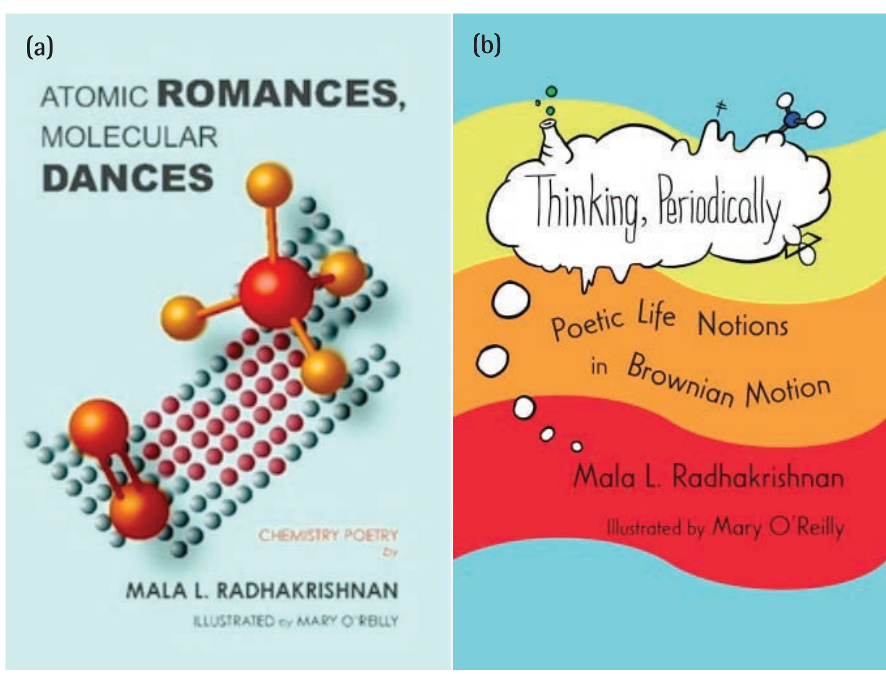
Mala: The answer to this question really varies. If I have a good storyline for a poem, it sometimes almost writes itself. The poems that require more effort are the ones written for a particular purpose (like to teach a specific concept) because the storyline has to be created around this goal as opposed to just arising "organically". For example, in some poems, I try to focus on developing one skill, like rhythm. Or I think up a good rhyme and craft a poem all around that. For example, a poem in my book 'Atomic Romances, Molecular Dances' was inspired by an effort to rhyme as many things as possible with the word 'anonymous'. In my opinion, rhyming verse can help reinforce concepts, and make the content feel more 'approachable'. This is because we associate rhyming verse with songs and stories from our youth.

Longer poems can take anywhere from just a couple of hours to days to draft, but I always go back, edit, and reword them multiple times. In contrast, couplets (two-line poems) are often rather spontaneous. Part of the point with couplets is to show that anyone can be a poet. In fact, I moved to mainly writing short couplets in part because my life has been so busy recently that I rarely have time to sit down and write a longer poem. This is my way of still engaging that side of my brain with whatever time I have.

Q5. Could you tell us a little bit about your two poetry collections?

Mala: The two collections (each dedicated to one of my children, incidentally), complement each other.

The first one (Atomic Romances, Molecular Dances) is more pedagogical in the sense that I specifically crafted many of the poems to teach



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particular concepts in chemistry (the common ion effect, the second law of thermodynamics, etc.). It consists of narrative poems that use personification to describe chemical concepts and processes from the perspective of the atoms and molecules experiencing them first-hand. In other words, it uses everyday language to describe chemistry.

In contrast, the second collection (Thinking, Periodically) is meant to be more whimsical, representing 'spontaneous' thoughts I had in my daily life (as a working mother of young children) that were articulated through chemical language. In other words, it uses the language of chemistry to describe everyday life. This collection consists of individual rhyming couplets that can make great 'exclamation points' at the end of a class period, and are also valuable resources for teachers.

In this way, both books bridge the everyday world with the chemical world, but they do this by moving in opposite directions.

Q6. That you humanize chemicals and give them personalities makes your poems both relatable and interesting. Does this approach present any challenges or limitations?

Mala: Personification can help people relate the 'unfamiliar' molecular world to their own familiar, everyday lives. It also can remove the barrier of unfamiliar lingo. One challenge is that I obviously take some poetic license—clearly, molecules don't 'talk' or have the emotions the poems ascribe to them. But one can think of a narrative poem as yet another type of model. Just like a Lewis structure or a balanced chemical equation, it has limitations in how and what it can represent. It is, therefore, important to discuss the limitations of models, analogies, and other constructions used to convey information. But these different representations complement each other, and when used in conjunction can help a student get a better, more holistic understanding of chemistry.

Another challenge is that whenever one uses personification, pop culture, or other human-oriented strategies to communicate, it will not work for everyone and can even make some people feel uncomfortable. For example, in my first collection, there are some poems that touch on themes that may be more appropriate for older audiences (as indicated in the Table of Contents). There are others that make references to, for example, a television show that people at only one point in time or in one part of the world may be familiar with. It can be difficult to find analogies and narratives that can appeal to and be pedagogically effective for a broad audience. Realizing that, I think it is important to continue evolving one's poetry, keeping inclusivity and the audience in mind.

Q7. How do you see the intersection of art and science? For example, do facts, wonder, passion, beauty, and metaphor take on different meanings in science and poetry?

Mala: I think the arts and sciences are more similar than people recognize. Both use ideas that have been generated by people to help us understand the world and our connection to it. Such constructions are called models in science, but in the philosophical sense, they are not all that different from, say, realistic fiction (or even science fiction). Both are meant to make us think differently about, say, how humans respond to a mass epidemic.

Obviously, there are differences in approach. In the arts, more focus is put on the process, the intention of the artist, and the artist's connection to the work. Science, sadly, has become dehumanized to the point where publications are often written in passive voice and the process is distilled to only the 'minimum necessary path' to get from the hypothesis to the results. The 'reproducible' path, results, and end-products are obviously important in both the arts and science. But, I think, focusing more on subjective processes and interpretations can help us remember, for example, that it is possible that you and I could look at the same data and still arrive at different conclusions. And these conclusions could both be reasonable in different contexts. There is a lot more subjectivity in science than people recognize. Seeing it as just facts and a reproducible process rather than an ongoing dialogue and an evolving, subjective process can make it less exciting—and less impactful—for people who want to make a difference and contribute creatively. And science needs creative people to maximize impact! For example, wonder, passion, beauty, and metaphor are just as much a part of science as they are in any other discipline, but they do not appear to be celebrated as much in science. This is one of the reasons why many people view science as dull.

Q8. Are there some considerations that the scientist-poet needs to keep in mind to balance the rigour of science with the creativity of poetry?

Mala: It depends on one's goals. For poems aimed to teach chemical concepts in the classroom, I think it is very important to be as accurate as possible within the constraints of poetic license (like atoms and molecules talking, etc.). But if one's goal is to be thought-provoking in other ways, or to convey emotions (as it sometimes is), then I might just use imagery in ways that might not be 100% accurate but still generates the intended effect.

I think different poets fall on different parts of the continuum, and I don't think that creativity and accuracy are mutually exclusive. On the contrary, sometimes you need to be creative to accurately convey something (quantum mechanics, for example).

Q9. In one of your writings, you share: *"I ask that all scientists take time to write poetically about their personal scientific stories and share widely with each other, so we are regularly reminded that science is a human endeavour".* Could you elaborate on this?

Mala: Poetry is special because it is inherently personal. If asked to write a poem about how a chemical reaction progresses, for example, your poem will not look like mine, whereas our prose descriptions will likely be much more similar.

Poetry gives each person a way to connect to science in a way that **they** feel comfortable with, that draws from their own experiences in a non-judgmental way, because there is no one 'right' poem about something. It can give each person a unique voice, and complement the standardized scientific writing that we're all familiar with.

Q10. Most of our readers are school science teachers, who we hope will use your poems in teaching chemistry. Would you have any suggestions for them?

Mala: There are many ways to incorporate poems, and to use them as a catalyst for students to create their own. I use my poetry in nearly all my classes, and students almost universally find them helpful as another way to engage with concepts. When I assign creative assignments, students often write impressive poems. Similarly, I know of teachers who either simply read a poem, have students illustrate or create a poster depicting the story in a poem, or have students work through a numerical or conceptual problem based on a poem.

My suggestion to teachers would be to encourage their students to write poems about a chemical concept or process. They are likely to be amazed at what their students can come up with. Students' poems may provide interesting windows into their understanding, while also being a fun way for them to engage with science. Sometimes, they may also help teachers get insights into student misunderstandings that may not have been apparent in traditional assessments.

Q11. Any thoughts that you'd like to leave our readers with?

Mala: We often think about science as a bunch of 'facts' that live outside of us. But the models that shape how we think about the world were developed by people, and would probably be different if different people had participated. What this means is that YOUR perspective will make you a unique contributor to science. So be creative as a scientist. And in addition to the more 'traditional' ways of communicating science, find ways that work for you—in doing so, you might inspire others to understand the world in a new way!

Notes:

1. Excerpts from some of Mala Radhakrishnan's poems can be found here: https://oreillyscienceart.com/chemistry-poetry.
2. Teachers interested in connecting with Mala Radhakrishnan can reach her at: mradhakr@wellesley.edu.
3. The questions for the interview were prepared by Radha Gopalan & Chitra Ravi (Editors, i wonder...).
4. Source of the image used in the background of the article title: Chemistry Lab. URL: https://pixnio.com/science/chemistry/science-laboratory-bottles-chemicals-chemistry. License: CC0.

STEADYING A BALLOON'S FLIGHT

One of the first things I noticed on entering the Grade IV classroom at Poorna Learning Centre for a science activity session was the balloons on the students' desks. The students shared that they had just discussed things related to air with their class teacher. One of them demonstrated how he could get his balloon to make weird sounds by compressing its mouth while the air went out of it. All of us laughed with him.

Many of the students expressed fascination with what they had observed happening when they inflated a balloon and let it go without tying up its mouth. When I asked them to describe how these balloons moved, the children used words like "squiggle", "wiggle", and "flutter". When asked for ideas about what made these balloons move, a student suggested that the air rushing out of the mouth of the balloon pushed it forward.

A few children volunteered to demonstrate how the balloon moved. We observed the paths of 7-8 balloons in flight. I drew these on the blackboard one after the other, to help the students observe their paths more carefully (see **Fig. 1**). We noticed how the balloons seemed to go in unpredictable directions, changing speed and direction rather quickly and randomly. I wondered out loud, *"Can we make the balloon go in a straight line?"*

A student spontaneously inserted a pencil into the mouth of a balloon, blew air into it, and let it go, perhaps to see if the pencil would guide it to move in a straight line. As the rest of the students had also jumped out of their seats to try out their own ideas, I found myself in the usual position of a grown-up caught amidst spirited and creative children.

Within minutes, the students had spontaneously assembled into groups, each with about 3-4 children who generally hung out together. A few students filled sand in a balloon before blowing air into it. But on releasing this, it fell straight down to the ground. So they tried seeing how much sand they could scoop out for the balloon to still be able to fly up, but take a straighter path. Another group tried a similar experiment with tiny pebbles.

Yet another group of students filled a balloon partly with tap water, and then blew air into it. On letting it go, they observed that the balloon did not take its usual zigzag path. Instead, its mouth moved in a circle, squirting water like a garden sprinkler. Amidst squeals and peals of surprise and delight, the students started flinging it higher to make it stay in the air longer.

The student who had inserted the pencil into the balloon had been trying out other things with his group. I noticed that his group had now moved on to using adhesive tape to stick one end of a string to the surface of a balloon. They tied a pencil to the other end of the thread, but it still weighed down the balloon and it could not take flight. Then, they tried replacing the pencil with an eraser, which they had to progressively cut into smaller pieces. It was by trying out these variations that they were able to arrive at one that could steady the balloon's flight without causing it to sink to the ground.

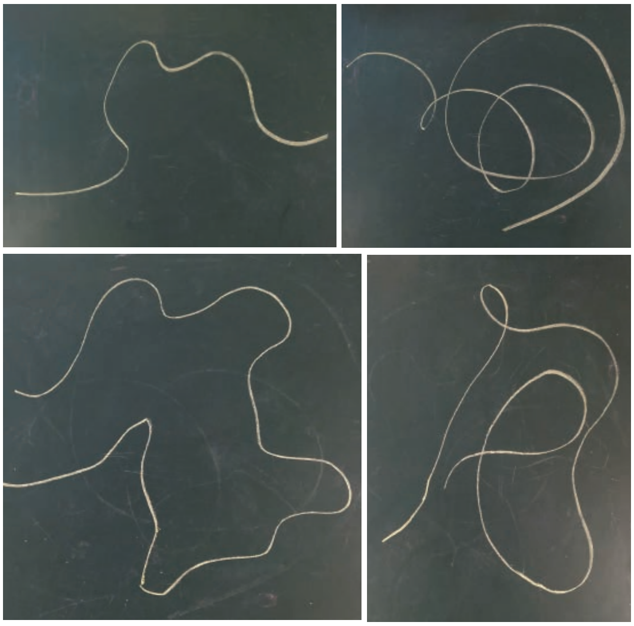

Fig. 1. Tracing balloon paths.

I used my phone to take slow-motion videos of these attempts to steady the balloon's flight. When I replayed these videos towards the end of the class, the children shared some of their thoughts and observations (not all of them were science-related). I tried to collate these ideas on the blackboard, mostly in the children's own words.

My reflections

I found it interesting that the children designed their experiments using whatever materials they could find in their surroundings, and that they were familiar with. It was also quite apparent that the children had their own ideas about the factors that affect motion. It is likely that they arrived at these ideas from their earlier experiences with the movement of objects in the physical and natural world. Although these ideas and conceptions did sometimes appear in the class conversations, they were mostly implicit in the decisions and directions the children took in their explorations with the balloon's motion. Incidentally, these ideas happened to be just adequate for most of their iterative efforts to be moderately successful. In their attempts to steady the balloon's flight, it is possible that the students picked up and formed more such ideas and conceptions about motion.

One such student preconception about motion that was most evident during this exercise was the belief that the lighter an object is, the more easily it changes its path. If this were true, adding extra mass to the balloon in some form or the other would make it less susceptible to whatever was causing its path to change (such as random changes in the direction of air being released from its mouth, anisotropic air resistance due to irregularities in its shape, and stray air drafts in the room). This is what seems to have led to attempts to steady a balloon's flight by filling it with sand, water, and stones; or using thread to suspend a pencil or eraser pieces from the balloon. Interestingly, this idea is identical to the age-old idea of using a ballast or a weight to steady the motion of a ship. This idea is also related to an aspect of inertia that is embedded in Newton's Second Law, which states that for a given force (here, the reaction force on the balloon due to the air rushing out of its mouth), the acceleration of an object (which is the rate at which the magnitude and/or direction of the balloon's velocity changes) is inversely proportional to its mass (see **Box 1**). While children of this age may not have a conceptual grasp of the exact mathematical meaning of acceleration, the nature of their explorations suggest that they do seem to hold some related ideas about inertia and motion. These ideas need to be acknowledged and addressed with care while introducing Newton's laws in higher classes (see **Box 2**).

In the process of testing out their ideas, the students sometimes also stumbled upon and explored other

Box 1. The changing momentum of these rocket-like balloons:

The mass of these balloons decreases as they deflate, which is like the classic case of the motion of a rocket that is simultaneously using up fuel and losing mass. The form that Newton's Second Law takes for describing such a situation is slightly different from that given in most high school textbooks. In this more general form, we account for the fact that the momentum of an object can change both as a result of a change in its mass and/or its velocity.[1]

Box 2. Introducing Newton's Laws of Motion:

Extensive research in the field of science education has shown that Aristotelian notions of inertia of motion are held even by people who have formally studied Newton's laws of motion at both high school and undergraduate levels. These include, for example, the belief that 'a force is needed to keep an object in motion', or 'in order to make an object go at a higher speed, one needs to apply a stronger force'. Since these notions happen to emerge quite naturally from our everyday experiences with physical phenomena, they are quite difficult to correct.

Aristotle believed that all objects seek to go to their natural place. A stone falls because it is made of the earth element and so belongs to the earth. Similarly, a bubble is made of air, so it rises. Galileo questioned this notion, disproved it, and instead argued that inertia was the natural tendency of all material objects.[2] This is Newton's first law. Systematic and persistent efforts are needed to introduce students to the idea of inertia in the way Galileo corrected and replaced Aristotle's idea of 'natural motion'. These are also needed to help them see the effects of forces such as friction and air resistance along with the effects of other forces that are applied on an object.

Research has also shown that merely watching demonstrations or doing experiments does not guarantee that students develop an accurate understanding of such concepts that are often counterintuitive. Rather, a combination of experimental work, articulation of students' ideas, argumentation, and snippets from the history of science is needed. Also needed is more back-and-forth between all of these based on students' responses. Such processes may enable teachers to create the right pedagogical brew for meaningful sense-making.

Perhaps, posing this (and similar) challenges of steadying a balloon's flight could be an effective way to start a unit on 'Motion' for high school students. In addition to eliciting student ideas about motion, it could help teachers connect such concrete experiences to the somewhat abstract, cryptic, and finished form in which Newton's laws of motion appear in most textbooks.

unexpected phenomena. This included, for example, the balloon that spun around squirting water due to the pressurized air inside, or the fact that a ballast that is too heavy makes the balloon fall to the ground before the air coming out can set it into any noticeable horizontal motion. These explorations also provoked some conversations before, during, and after their experiments in which they shared and developed some thoughts and ideas about such phenomena.[3]

Another interesting thing to note is how the social aspects of learning emerged organically in these explorations. Some of these took the form of an immediate peer group to work with as well as to compare and learn from. Every time someone had an idea, they tried to explain it to the other children in their group while showing the object or accessory (like sticking tape) that they intended to use. The others would then express their opinions and suggestions. The way students took charge of their learning was something that made me glad as a teacher. Also, the way the students moved around for the entire 40-minute class while being intellectually active and engaged, pointed me to the pitfalls of treating teaching-learning as a solely cerebral activity that Rabindranath Tagore has cautioned against.[4] In retrospect, I find it exciting to see how such experiences seem to echo ideas of Constructionism by Seymour Papert, which suggest that the construction of knowledge is facilitated by tactile and tangible manipulation of material.[5]

Around the world, there have been innovations in teaching science that have supported the idea of involving students in working on an engineering design challenge such as the one discussed here. In India as well, there have been efforts to help children learn through makerspaces or tinkering labs (a space that has resources such as tools and materials to build and create objects and contraptions).[6] This experience with primary students at Poorna points to the potential of such exercises even within a classroom setting. They help create space for students to take ownership of their learning rather than simply being passive listeners. They also offer teachers the opportunity to listen to student ideas and document their work. This, in turn, can expand the range of approaches and examples that a teacher can use to connect students' 'feel for phenomena' to school science in a more immediate and embodied sense.

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

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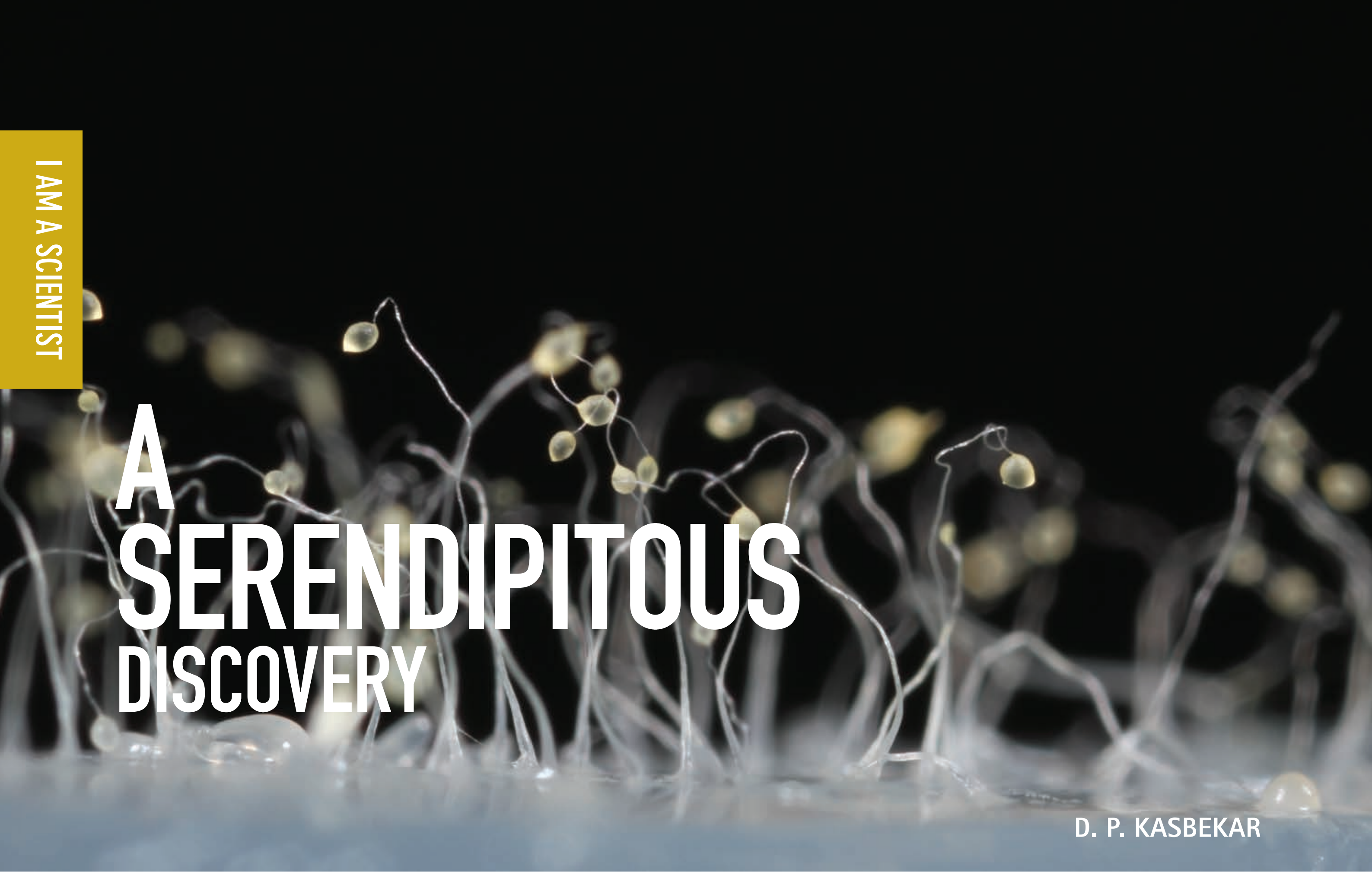


A SERENDIPITOUS DISCOVERY

D. P. KASBEKAR

How often do we associate luck or chance with scientific discoveries? A scientist shares how his reluctance to throw some extra cell culture plates into the trash helped him see a failed experiment in a new light, and led to an interesting discovery.

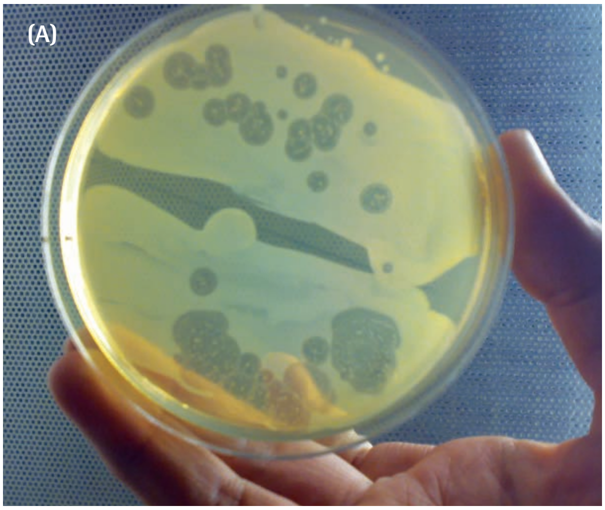
Sterols are ringed lipids that play an important role in maintaining the integrity of cell membranes in eukaryotes like us. For example, studies show that errors in the biosynthesis of cholesterol, one of the most widely-known examples of sterols, cause serious defects in human embryonic development that almost invariably result in foetal death. This raises the question—do sterols play a role in cellular differentiation and morphogenesis in eukaryotes?

One way to answer this question is by studying the effects of mutations that cause errors in the sterol biosynthesis pathway of a fast-growing, easy to maintain, eukaryotic multicellular (model) organism. This was the aim of my doctoral research (1978-1984). I sought to obtain mutants of the free-living soil amoeba *Dictyostelium discoideum*, in which normal membrane sterol was replaced by a precursor sterol (see **Box 1**). These mutants would allow us to evaluate the importance of normal membrane sterols in the development of the *Dictyostelium* fruiting body (see **Fig. 1**).

How do we obtain such mutants? At the time, the easiest way to do this was to select for amoebae resistant to the antifungal nystatin. Nystatin is related to the antifungal amphotericin B, which is used to treat the COVID-19-associated mucormycosis (black fungus) infection. Both antifungals bind to the normal membrane sterols, forming sterol-antifungal complexes. These complexes puncture holes in the cell membrane, destroying its integrity and causing cell death. A mutation that replaces normal membrane sterol with a precursor sterol alters this outcome. Since nystatin does not bind with the precursor sterol very well, these mutants are more nystatin-resistant.

Nystatin resistance can be the result of recessive or dominant mutations. While members in the lab I worked in had already isolated amoeba with some recessive mutations, my aim was to obtain ones with dominant mutations. Why? We knew, from previous work, that recessive mutations often completely inactivate genes, and the complete inactivation of some sterol biosynthetic

Fig. 1. Growing amoeba in the laboratory.



(A) What are lawns and plaques? Much of the agar medium surface of the Petri dish is covered by a turbid bacterial lawn. The circular clear zones in the lawn are plaques formed by *Dictyostelium* amoeba feeding on the bacteria. The plaques enlarge and merge with each other. Within a plaque, starvation induces the amoebae to aggregate into multicellular clumps, which then transform into fruiting bodies. The aggregates and fruiting bodies are just about visible to the naked eye.

(B) Visible towards the left of this award-winning image is the edge of an amoebal plaque on a bacterial lawn, as seen at 100X resolution. The bacteria (visible as a concave blurry layer on the far left of the image) have been cleared by aggregating amoebae. Further right, these aggregates can be seen transforming into fruiting bodies, each with a slender stalk that is a few millimetres tall and holds aloft a ball of vegetative spores.

genes might produce only inviable amoebae. In contrast, dominant mutations may either retain partial gene activity or induce novel patterns of gene activity. Thus, for some sterol biosynthetic genes, dominant mutations might be the only way to obtain viable amoebae. There was also a chance that such mutants (with dominant mutations) would help identify new genes affecting sterol biosynthesis.

Since both dominant and recessive mutations affect the same pathway, how would one differentiate between the two? This difference becomes evident in diploid amoeba (see **Box 2**). If a nystatin-resistant (mutant) haploid cell and a nystatin-sensitive haploid cell fuse, and the resulting diploid cell is nystatin sensitive (in genetics-speak, it shows the 'nystatin-sensitive phenotype'), then we can infer that the mutation is recessive. In contrast, if the diploid cell shows nystatin resistance, then we can conclude that the mutation is dominant.

Box 1. *Dictyostelium discoideum:*

In the wild, *Dictyostelium* amoebae feed and multiply on bacteria that grow on decaying vegetative matter. When the amoebae run out of bacteria to feed on, they gather in hundreds of thousands to form visible multicellular aggregates. The aggregates transform into fruiting bodies, each a few millimetres tall. Each fruiting body is composed of a slender stalk bearing a droplet of spores. Small fauna, such as ants and earthworms, disperse the spores to new food sources where they germinate to release amoebae. These newly released amoebae go on to repeat the growth-division-dispersal cycle.

That these fast-growing, haploid, eukaryotic, unicellular amoebae can be induced to form multicellular aggregates makes them very useful as model organisms to study cell-cell interactions in development. Also, they are easy to grow in the laboratory—they can be plated on a bacterial lawn (which, in turn, is grown on an agar-based medium in a Petri dish). Therefore, *Dictyostelium discoideum* is used by several developmental biologists to study cell differentiation and morphogenesis during fruiting body development.

Box 2. Diploidy in *Dictyostelium:*

Cells with two sets of the genome are called diploid, and those with only one set are called haploid. For example, most human cells are diploid, but our sperm and eggs are haploid.

While *Dictyostelium* amoebae are commonly haploid, they can occasionally fuse to form diploid amoeba. Fusion occurs among starving amoebae and it might reflect a form of proto-cannibalism (cannibalism was observed in the related species *Dictyostelium caveatum*). Once formed, these diploid amoebae are stable through several cell divisions, but, eventually, lose the extra set of chromosomes and revert to haploidy.

Earlier scientists had obtained their mutants by exposing haploid amoebae to nystatin, and isolating those that showed resistance to it. I set out to obtain mine from diploid amoebae. Why? For a diploid cell to show nystatin resistance due to a recessive mutation, two independent mutations would have to occur—each inactivating one copy of the same gene. In contrast, only a single dominant mutation would be sufficient to confer nystatin resistance. This meant that the probability of getting resistance in diploid cells due to a single dominant mutation was much higher than that of getting resistance due to two recessive mutations (see **Fig. 2**).

I started my experiment by preparing Petri dishes with agar medium to which nystatin was added. Since *Dictyostelium* feeds on bacteria, I transferred cells of the bacterium *Klebsiella aerogenes* to these plates and allowed them to grow into a lawn that covered the surface of the agar. Most bacteria do not contain sterols, and hence they are unaffected by the nystatin. I also transferred about 100,000-500,000 amoebae to these plates. The vast majority of these amoebae were killed by the antifungal. A very small number of amoebae (typically, 1 in 100,000) survived the antifungal, fed on the bacterial lawn, and formed a plaque or colony (this is a clear circular zone from which all the bacteria are cleared). For these to survive, they would have to carry a mutation that prevented the biosynthesis of the normal membrane sterol. In this way, I was able to readily obtain several nystatin-resistant diploid amoebae.

In the next stage of my experiment, I induced each of these colonies to revert to haploidy by growing them on normal plates without nystatin (see **Box 2**). Next, I plated the haploid derivatives on a bacterial lawn—those that retained their nystatin resistance in the haploid state would be likely to carry a dominant mutation; while those that showed nystatin sensitivity were likely to carry the unmutated gene.

Unexpectedly, none of the haploid derivatives survived on the nystatin plates. To check for errors, I repeated these experiments several times. Each time, the nystatin-resistant diploids produced only nystatin-sensitive haploid derivatives. I began to worry that my colleagues might think I was an incompetent researcher who was squandering lab resources.

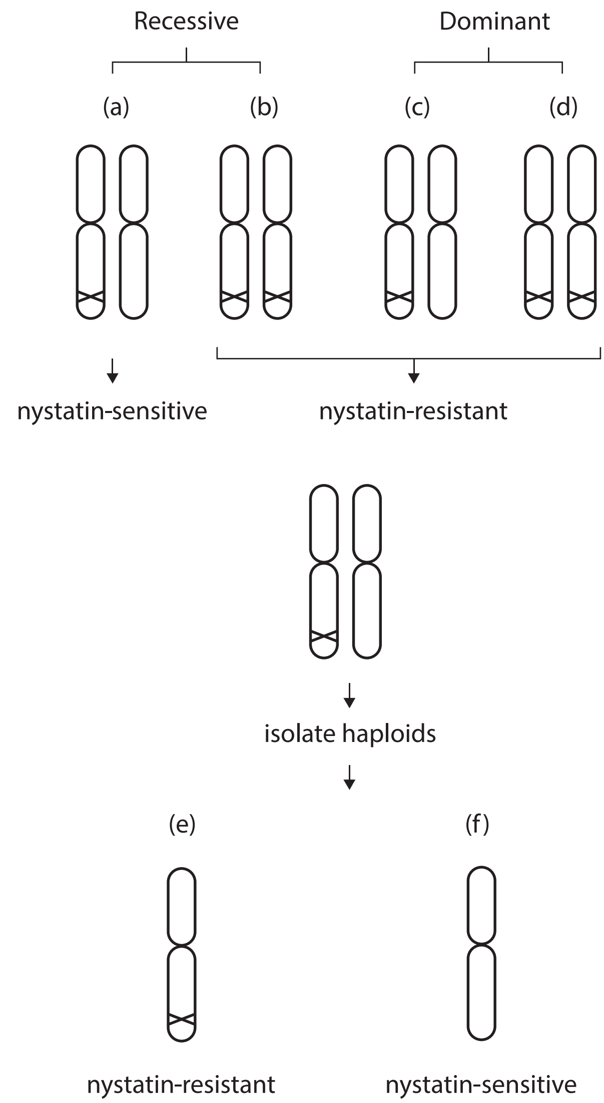


Fig. 2. The difference between dominant and recessive mutations. The elongated figures of "8" represent chromosomes. Each chromosome schematically represents one set of the genome. "X" marks a mutation. "a", "b", "c", and "d" are diploid cells (i.e., they contain two sets of the genome), whereas "e" and "f" are haploid cells (i.e., they contain one set of the genome). **Upper panel:** The recessive mutation is present in only one genome set in "a", making "a" nystatin-sensitive. It is present in both sets in "b", making "b" nystatin-resistant. In contrast, a dominant mutation confers nystatin resistance regardless of whether it is in one set as in "c", or in both as in "d". Selection for nystatin resistance in a diploid is more likely to select "c" type cells with a single dominant mutation, rather than "b" or "d", in which two independent mutations inactivate both gene copies. **Middle and lower panels:** When a "c" type nystatin-resistant diploid reverts to haploidy, haploid cells with the mutation ("e") are nystatin-resistant and those without the mutation ("f") are nystatin-sensitive. That we found no "e" type haploids following haploidization on nystatin-free medium cast doubt on whether the nystatin-resistant diploids were in fact type "c". Later, I showed that the nystatin-resistant diploids were not "c" type cells produced by mutation, but instead were induced by a novel nystatin-dependent nystatin-resistance (NDNR).

The answer to these puzzling findings came much later when I was setting up a different experiment. The aim of this experiment was to isolate nystatin-resistant mutants with recessive mutations, and then screen the mutants for their relative sensitivity towards azasterol, another antimicrobial. I had previously found that one type of nystatin-resistant mutant was sensitive to azasterol; another, like the wild type, was not. I used a preliminary control experiment to verify that the wild-type haploid amoebae could grow on agar plates supplemented with azasterol. In the second step, I transferred these amoebae onto nystatin-agar plates to isolate nystatin-resistant mutants with recessive mutations. As it turned out, I happened to run out of wild-type amoebae. This meant that I had a few extra nystatin-agar plates in hand. Meanwhile, the wild-type amoebae had grown well on the azasterol supplemented plates I had used in the control experiment. So, instead of tossing out the extra nystatin plates, I transferred some of these control amoebae onto them, and labeled the plates accordingly.

I expected the wild type amoebae grown on azasterol-supplemented plates to respond to nystatin in the same way as the ones grown on plates without azasterol. Why? I knew that azasterol blocked a step in the biosynthesis of sterols. Thus, much like the nystatin-resistant mutants, amoebae grown in its presence accumulate a precursor sterol in place of the normal sterol. This precursor sterol would make these amoebae resistant to nystatin if it were added to the same plates. But when these amoebae were transferred to nystatin plates without azasterol, they would regain the ability to synthesize normal membrane sterols, which would make them nystatin sensitive.

To my surprise, in a couple of days, the wild-type amoebae transferred from azasterol-supplemented plates showed exuberant growth on the nystatin plates. In contrast to the sensitivity of the wild-type amoebae transferred from normal plates, these amoebae had grown as well as the recessive nystatin mutants. That the azasterol-derived amoebae had remained nystatin-resistant seemed to imply that the nystatin in their growth medium was capable of inducing resistance to itself.

This nystatin-dependent-nystatin-resistance (NDNR) could also explain the results of my experiment to identify nystatin-resistant amoebae with dominant mutations. When the wild-type diploid amoebae were plated directly on nystatin supplemented media, most were rapidly killed by the antifungal. Only some amoebae survived and developed nystatin resistance. Since this happened at frequencies low enough to be comparable to the mutation frequency, I had assumed that this resistance was due to mutations in their sterol biosynthesis genes. However, it now seemed possible that these surviving amoebae had acquired nystatin resistance (in the absence of a mutation), which remained only as long as they were maintained on the nystatin supplemented media. This would explain why this resistance was lost when these amoebae were taken off nystatin in the course of obtaining haploid derivatives. It would also explain the exuberant growth of the amoebae transferred from the azasterol-supplemented plates to the extra nystatin-supplemented ones (the plates that I did not toss out). Since azasterol induced the replacement of the wild-type sterol by the precursor sterol, a much higher percentage of these amoebae would survive the initial nystatin killing long enough to acquire NDNR.

This was an entirely new observation—one where nystatin (and not a mutation) seemed to induce amoebae to become resistant to its killing effect. Many questions still remain unanswered. What is the molecular basis of NDNR? Can NDNR occur in fungi or human cells? Does this phenomenon extend to amphotericin B? The one that baffled my supervisor was—what inspired me to transfer the amoebae grown on the azasterol-supplemented plates to the nystatin-supplemented ones? It seemed such a crazy thing to do! Both my 'failure' to obtain dominant mutants and the fact that I did not toss out the extra plates were integral to this serendipitous discovery of NDNR. I believe it was Samuel Goldwyn who said *"... the harder I work the luckier I get".*

Notes:

1. The research described here was published in Antimicrob. Agents Chemother. 27: 974-976, 1985. URL: https://journals.asm.org/doi/10.1128/AAC.27.6.974.
2. To read more about cannibalism in slime moulds, refer: Waddell D. R. 1982. A predatory slime mould. Nature 298, 464-466.
3. Source of the image used in the background of the article title: Slime Mould. Credits: Usman Bashir, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Dictyostelium_discoideum_43.jpg. License: CC-BY-SA.

D. P. Kasbekar is a retired scientist.

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Verbs Explained!

Author: Rohini Chintha

The kids stood absolutely still with their lemons and spoons. As soon as the whistle blew, they started racing ahead. A few lemons fell off the spoons. These were met by groans of disappointment from the participants and the crowd alike.

Mittu was nearing the finish line when Tatha cheered "Go on, Mittu." Mittu turned to look at Tatha, and PLOP! His lemon rolled off his spoon. Mittu was out.

On the way home, Tatha and Mittu walked for a while in silence. "I shouldn't have called out," said Tatha apologetically.

"I shouldn't have looked." Mittu laughed light-heartedly.

"Ah! Newton's laws." sighed Tatha.

"What?" Mittu looked up inquisitively.

"Newton's Laws of Motion," shrugged Tatha. "Three laws that explain all and any type of movement or motion…," he added after a pause.

"Any type of motion?" asked Mittu.

"Yes."

They had reached the park near home. Mittu looked at the children in the park. "Racing, running, swinging, jumping, falling, skipping, throwing a ball?"

"Yes."

Mittu looked at the road. "Bicycling and driving?"

"Yes."

Looking up at the sky, Mittu quizzed, "Birds flying? The rotation of the earth? The moon orbiting the earth? All verbs?"

Tatha nodded. "Yes."

"Wow!" Mittu looked stumped. "How?"

"After you freshen up," Tatha said, opening the gate to their house.

"See you in five!" Mittu raced inside. Tatha was sipping his coffee when Mittu rejoined him. "Now!" he said eagerly.

"In the lemon and spoon race," Tatha pointed out, "all of you were standing still at the beginning?"

"Nearly!"

"Let us assume you were all stationary, or at rest. The spoons in your mouths were at rest. And the lemons on those spoons were also at rest. None of these was moving?"

Mittu nodded.

"But when the whistle blew, all of you started moving towards the finish line. Your body changed from a state of rest to a state of motion?"

"Yes."

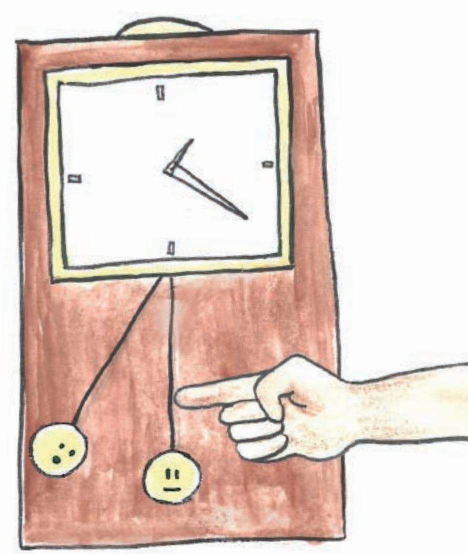
"You were holding the spoon firmly, almost as if it were attached to your body. So when you moved, the spoon moved with you?"

Mittu nodded, "And the lemon on the spoon too."

"And do you think the spoon and the lemon would have moved ahead in the race if you had not moved?"

"Of course not!" said Mittu looking puzzled.

"This is because anything at rest remains at rest, and anything in motion remains in motion unless a force acts on it. This tendency of a body to keep doing what it is doing is called **inertia**. When you were standing still, you needed some force to move forward. The same force also acted on the spoon and the lemon, and changed their state from rest to motion."



Mittu still seemed a bit confused.

Tatha continued, "Take swings for example. A swing at rest will continue to be at rest unless you push it. Pushing is the force you are using to change its state of rest. Similarly, a car at rest will remain at rest. When you start a car, the engine provides the force that will put it in motion. Or think of a pendulum clock. It will keep moving back and forth till you forcibly stop it or the clockwork gears break down."

Mittu took a few moments to think about this. Then asked, "But what about the kids who dropped their lemons right at the start?"

"Those kids sprang from a state of rest to a state of motion very quickly. In other words, they gained high speed in a few seconds of time, right?"

"Uh-huh".

*"Speed in a particular direction is called **velocity**. The rate of change of velocity with respect to time is called **acceleration**. Those kids experienced a big and sudden acceleration. Their bodies and the spoons in their mouths moved forward very quickly. Only the small surface of the lemon that was in contact with the spoon moved with the spoon. But the rest of the lemon stayed at rest. This caused the lemon to roll off the spoon."*

"Why didn't this happen to me?" Mittu asked.

"Because you changed your velocity more gradually, giving time for the motion to pass smoothly from your legs to the spoon to the whole lemon on the spoon."

"Then, why did my lemon drop when I turned towards you?" Mittu wondered.

"You tried to change the direction of its motion too suddenly. You, the spoon, and the lemon were all moving in a straight line. When you swerved to look at me, the force you applied to move your head moved the spoon in your mouth, and the lemon on it, sideways. This happened very quickly. Again, the part of the lemon that was not in contact with the spoon could not change its direction as quickly."

"Because of inertia?" Mittu asked.

"Yes. The inertia of moving in a straight line. So it rolled over the edge of the spoon and fell down."

"What about the kids whose lemons fell off their spoons when they stopped at the finish line?"

"The same reason. This time, the kids, the spoons they held in their mouths, and the lemons were all in motion. When their bodies came to a sudden rest at the finish line, the spoons in their mouths came to rest too. But because their velocity changed so quickly, the lemons continued moving forward and rolled off."

Mittu looked a bit puzzled.

"It's very much like swinging. When you jump off a fast-moving swing, your feet come to rest as soon as they touch the ground, but your upper body is still in motion." Tatha continued. "So, you tend to bend forward or take a few steps forward. If you did not do this, wouldn't you too fall like the lemon?"

"Yes!" Mittu exclaimed.

"This is Newton's First Law—everybody and everything continues to be in a state of rest or of uniform motion unless it is compelled by some external force to act otherwise."

*"**Uniform motion?**" Mittu asked.*

"When an object moves in one direction and covers equal distances in equal intervals of time. In other words, the object has constant velocity."

"Understood. What does the second law explain?" Mittu was eager.

"Well, to go back to your lemon and spoon race," Tatha gesticulated in the direction of the sports ground, "did you have great difficulty running with the spoon and lemon in your mouth? Were they heavy? Did you have to use a lot of force or physical strength to run forward with the lemon and spoon? Did you have to push hard to make your way ahead?"

"Don't be silly!" Mittu chuckled.

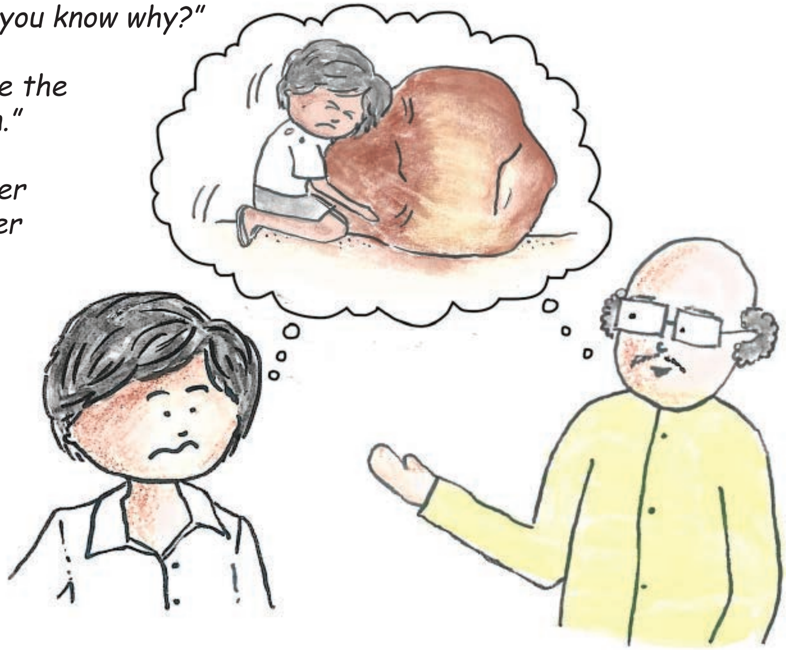
"What if you were carrying a huge paperweight instead?"

"It would have been a little more difficult," said Mittu thoughtfully.

"What if you were carrying a boulder?" Tatha quizzed.

"What are you driving at?" Mittu gazed at Tatha in confusion. "I would not have been able to lift the boulder, forget running with it. You know that."

"Exactly!" Tatha said calmly. "Do you know why?"



Mittu looked thoughtful. "Because the boulder is heavier than the lemon."

"Exactly!" Tatha said. "The greater the mass of an object, the greater the force needed to move it. When I say mass, I mean the amount of matter, molecules, or atoms present in an object."

"So if I grow taller and fatter, my mass will increase because I will have more cells and molecules in my body, right?" Mittu asked.

"Yes." Tatha agreed.

"And the more mass I have, the greater the force you will need to pull me up from this chair?" Mittu looked at Tatha.

"Yes. Also, the greater the force I will need to make an object move faster or slower," Tatha said. "For example, imagine I were pushing a swing with one child sitting on it. Then imagine that another child of about the same mass joins this one kid on the swing. Now, I would need to apply a much greater force to push the swing. I would also need to apply a much greater force to make a swing with two children reach the same height as a swing with one child on it."

"You will also need more force to slow down or stop a moving swing with more children on it, no?" Mittu added.

"That's right!" Tatha smiled. "This is Newton's second law. Force equals mass times acceleration. F=ma."

"Got it!" Mittu brightened.

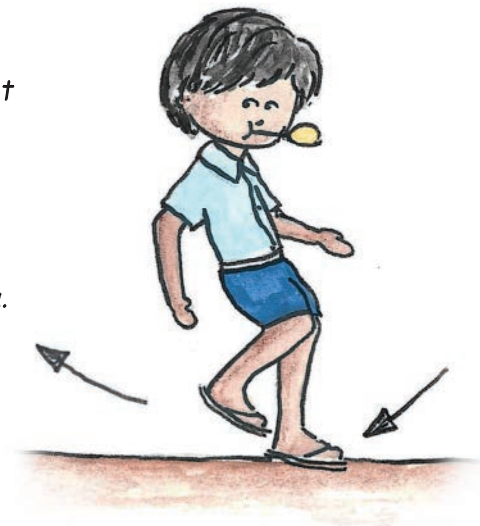
"And if you know the mass of an object and the amount of force acting on it, you can say how fast the object will pick up velocity." Tatha added.

"Cool!" Mittu exclaimed.

"Now for the third and last law of Motion," said Tatha.

"Ready!" Mittu was enthusiastic.

"Again, going back to the lemon and the spoon. When you started running, were your feet pushing on the ground backward or forward?" Tatha asked.



"Obviously backward, Tatha. If my feet were pushing on the ground in the forward direction, I would have been running backward," said Mittu rolling his eyes.

"Exactly. So you were pushing the ground backward and the ground was pushing you forward, right? The more force you apply in pushing the ground back, the more force the ground would exert on you to push you in the forward direction," said Tatha smiling.

"OMG! You are right! So for running in the forward direction, I have to push the ground backward. Then it is the ground that will push me forward?"

"Exactly. That is Newton's third law. Every action has an equal and opposite reaction. Let me give you another example. If a car crashed against a pillar, why does the car also get damaged?"

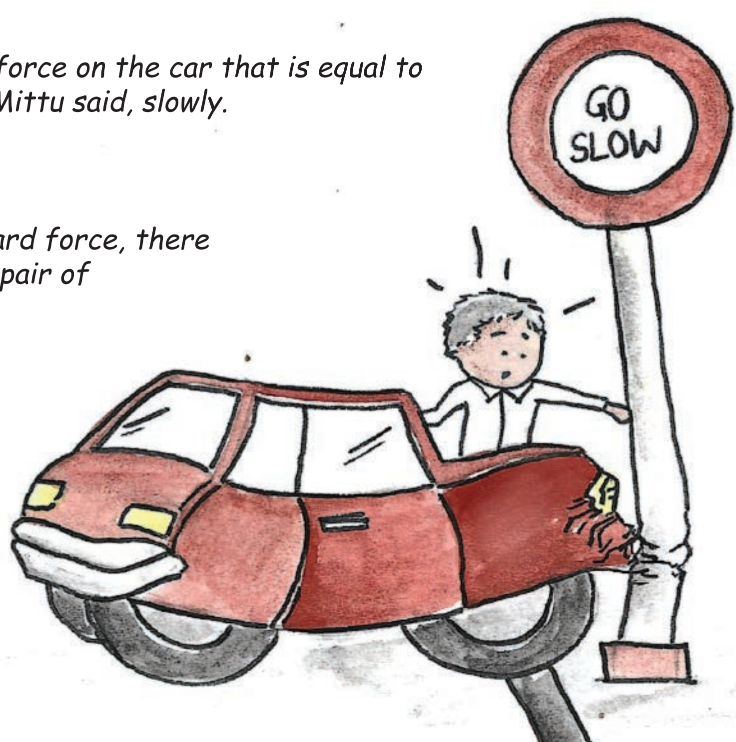
"Because the pillar applies a stopping force on the car that is equal to the force with which the car hit it?" Mittu said, slowly.

Tatha nodded.

"You mean to say that for every forward force, there is a reverse or opposite force? Like a pair of forces?" Mittu asked.

"Bravo!" Tatha exclaimed. "You have understood Newton's third law, Mittu. To every action force, there is an equal and opposite reaction force."

"Thanks for explaining the verbs!" Mittu winked. "Now to practice them," he said running out.



About the Author

Rohini Chintha is an Assistant Professor (C) at the Department of Genetics and Biotechnology, University College for Women, Hyderabad. She is passionate about writing for children, and believes that 'A Happy Childhood builds a Happy Society'. About 110 of her stories for children have been published in various magazines. To view her work, check out her website: www.popscicles.com.

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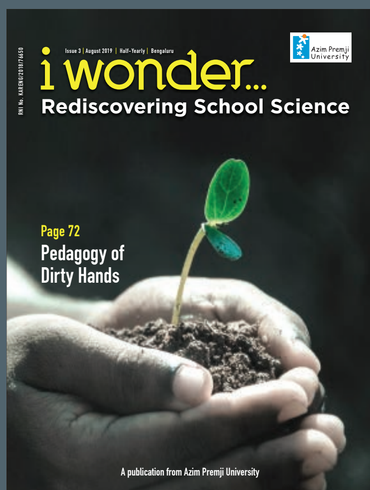

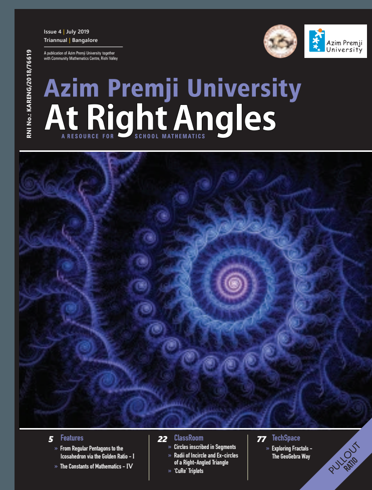

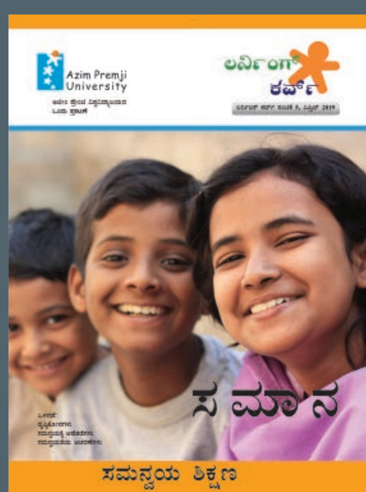

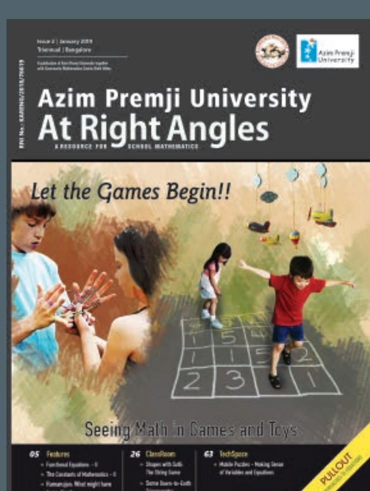

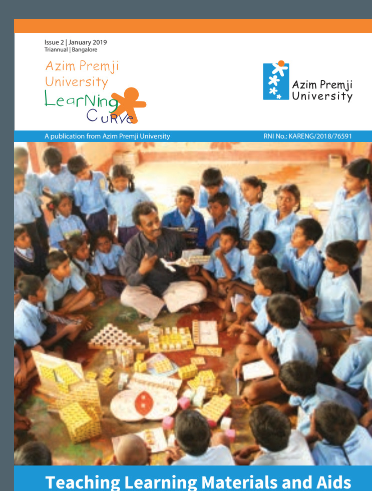

"Chlorine is a deadly poison gas employed on European battlefields in World War I. Sodium is a corrosive metal which burns upon contact with water. Together they make a placid and unpoisonous material, table salt. Why each of these substances has the properties it does is a subject called chemistry."

— Carl Sagan

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