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Azim Premji University

i wonder...

Rediscovering School Science

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Doing Science Without Labs

An Azim Premji University Publication

Chief Communications Officer and Managing Editor: Sudheesh Venkatesh.

Publications Team: Meera Prabhu, Shahanaz Begum, Lokram V G, and Sambit Mahapatra.

Translations Editors: Madhukara S Putty (Kannada) and Rajesh Utsahi (Hindi).

Illustrations and Artwork: Vidya Kamalesh.

Designers: MAP Systems, Upkar Chambers, 34/1, Rashtriya Vidyalaya Rd, Basavanagudi, Bengaluru, Karnataka.

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Email: publications@apu.edu.in | Website: www.azimpremjiuniversity.edu.in

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About Us: i wonder... is an Azim Premji University publication. Our main aim is to publish articles and classroom resources that support the teaching practice of science teachers at the middle stage (Grades VI-VIII) and Environmental Studies (EVS) teachers at the preparatory stage (Grades III-V). We present critical perspectives and pedagogical approaches that are aligned with the broader curricular goals and competencies that the National Curriculum Framework for School Education (NCF-SE) 2023 recommends for children at these stages of schooling. Our target readership consists of teachers from government schools and teacher educators from Azim Premji Foundation.

i wonder...
REDISCOVERING SCHOOL SCIENCE

About this issue:

Welcome to our Dec 2024 issue. This issue combines content planned for three issues. If any of these articles or detachable classroom resources support your classroom practice, tell us how. Experiences that can be of help to other teachers will be featured in our next issue.

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Editorial

This October, my colleagues (Radha Gopalan and Vijeta Raghuram) and I had the opportunity to visit nine government schools in Damoh and Bhopal. This was an opportunity to listen to the stories of many science teachers and teacher educators who were refusing to be passive. Refusing to let administration, bureaucracy, the lack of resources and time, the cynicism of their colleagues, negative perceptions of their work, the circumstances of their lives, their experiences as learners, and/or their fears as teachers stop them from taking control of their own teaching and learning. This refusal was in the value they saw in themselves and in the role that teachers play in society. In the transparency with which they shared their failures with their colleagues. In their willingness to try something new in their classrooms. Often, these stories were less about the heat of external rebellion and more about the quietness of inner resistance. They had an everyday quality to them. Every story was different. Yet, they were all stories of science teachers growing in their practice.

What supports this growth? I can think of two factors that may be common to science teachers across diverse contexts of practice. One of these may be the kind of questions we hold within ourselves. Questions like: *How do we engage our students' curiosity and interest in the concepts in their textbooks? How do we connect what they learn in class with their everyday experiences? How effectively can students use the skills they practice in the science classroom to address real world problems? Can the process of science open them to the possibilities that communities of practice offer? Can it help them appreciate how all that we know about our world today comes from the efforts of many people building on what we knew yesterday? Can science help our students think more clearly, feel more deeply, and act with more courage and care? Can it help them discover a sense of curiosity for and connection with the natural world that stays with them throughout their lives?* The other factor may be the ability to learn from the community we are part of. This community consists of teachers who share our questions and know why they matter to us. They are most likely to understand why these questions demand the patience and the confidence to take small steps in changing the way we relate to our students and the curriculum. They are the people who are most likely to learn from our struggles and our experience. And they are the people whose experiences and struggles we may learn the most from. This issue has many such experiences. I would like to highlight three. Naresh Kumar Sen shares how his decision to involve his students in writing biographies of scientists was inspired by the effectiveness with which they used elements of a project-centred approach in their real worlds. Anish Mokashi and Sreeja Velayudhan tell us how their decision to play a video of Usain Bolt's record-breaking sprint in class helped their students engage more actively with formal concepts in linear motion. And Shiv Pandey shares how his choice of questions led his students to think more creatively and critically about their experience of making and manipulating an inexpensive pinhole camera.

Do you teach science to students in the middle stage (Grades VI-VIII)? What factors support your growth as a teacher? What kind of questions drive it? What do other teachers contribute to it? How has your growth changed your classroom instruction? And how has it changed what your students learn? Share your experience with us.

Chitra Ravi
Editor

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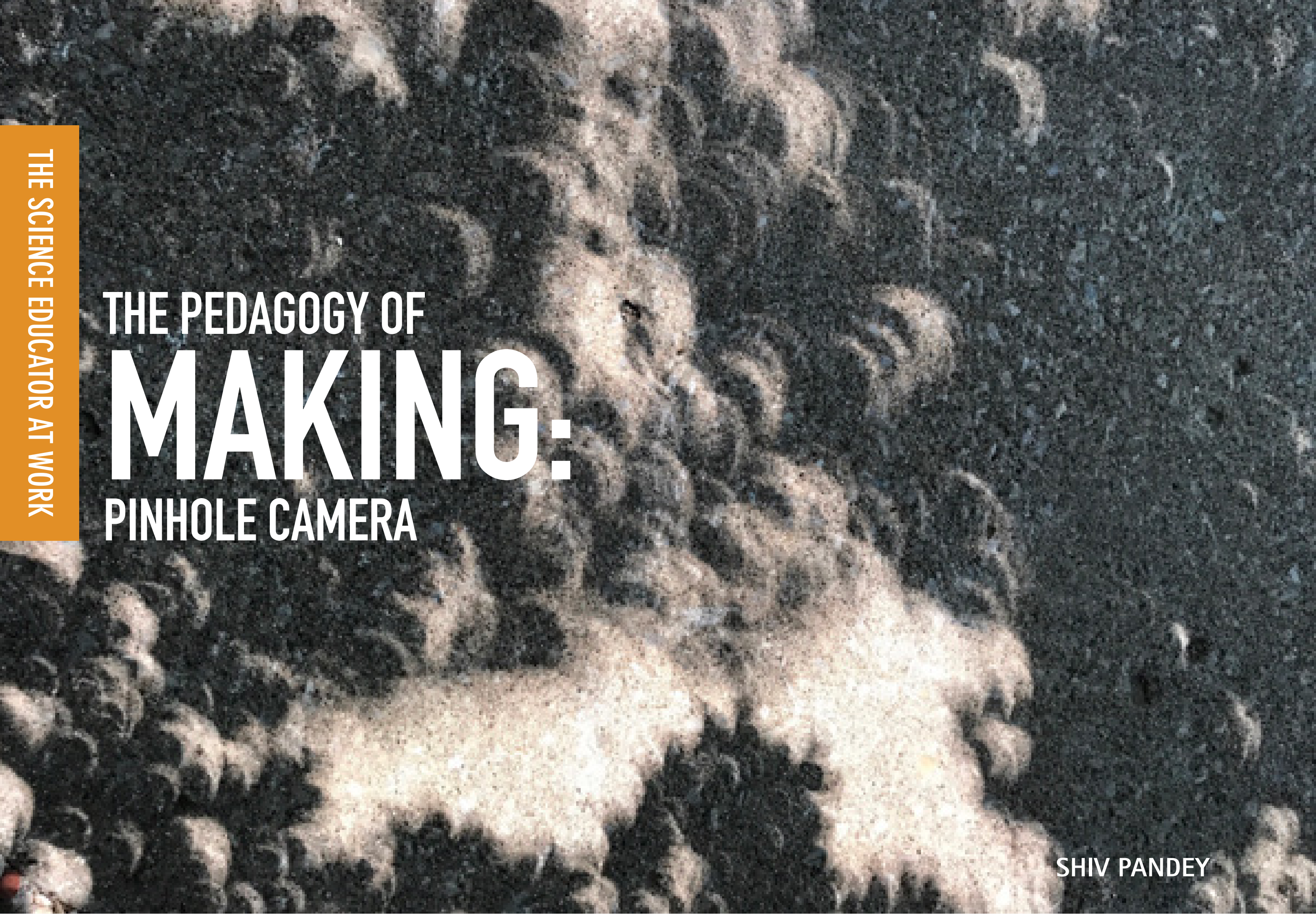

THE PEDAGOGY OF MAKING: PINHOLE CAMERA

SHIV PANDEY

What do children learn when they make models of simple scientific instruments themselves? Can making experiences be used to encourage deeper inquiry and discussion? What role does a teacher have in this process?

Inviting students to 'make' simple models of scientific instruments from scratch has many advantages. Constructing and analysing how and why these models work allows students to experience what it means to think like a scientist. Using inexpensive, local, and easily available materials to make these models strengthens their creativity, ability to improvise, and the ability to learn from failures. Understanding the role of different components of the model and playing with different variables deepen students' engagement with related concepts. Making experiences can also help students develop many important science skills, like the ability to manipulate or change a model to expose its properties, observe cause-and-effect relationships and correlational changes in different variables, and identify the limitations of their inferences. Students retain the knowledge and skills they gain from such making experiences for longer durations. Regular opportunities of this kind can help students develop into independent learners.

It is to encourage such making experiences in the classroom that science textbooks for the middle stage include step-by-step procedures for constructing instruments and models that support understanding of related curricular concepts. Often, teachers expect their students to read, understand, and follow these procedures on their own and as exactly as possible. While students may develop some technical proficiency and conceptual understanding from this mechanical repetition, they need to have the opportunity to use and develop their creative and critical thinking skills. To use the pedagogy of making most effectively in the classroom, teachers need to:

(a) Encourage students to modify the procedures shared in the textbook to match the materials and time available to them.

(b) Allow students to operate their models to understand their working principles.

(c) Ask students probing questions about their observations and findings to lead them towards new areas of inquiry.

Some textbook procedures can be quite complex, involving many steps and precautions. In such cases, students may depend on their teachers for step-by-step guidance and support. Even if they try to follow the procedure by themselves, it can take so much time, energy, and attention that students may be unable to focus on manipulating the different components and variables of the model. A creative science teacher can resolve this issue and bring their students' focus back towards the learning objectives of the session by simplifying the procedure and requirements for model making. One example of this can be seen in the procedure for constructing a pinhole camera included in the Grade VI curriculum (see **Box 1**).

Making a pinhole camera

I invited Grade VI students of an upper primary government school at Uttarkashi to make and manipulate their own pinhole cameras (see **Activity Sheet: Make your own Pinhole Camera**). This was the pedagogical approach I used:

Step 1: I started the activity by showing students a pinhole camera I had constructed using just a disposable paper cup and a piece of butter paper

Box 1. Pinhole cameras in the Grade VI curriculum:

A pinhole camera is an optical instrument that forms an image without using a mirror or a lens. In its most common form, it consists of a light-proof hollow box with a tiny aperture (pinhole) on one side and a translucent screen on the opposite side. When students turn the aperture side of the box towards an illuminated object, they will see a real but inverted image of the object projected on the screen (see **Fig. 1**).[1]

The construction of a pinhole camera is included in Chapter 8 ('Light, Shadows, and Reflections') of the Grade VI science textbook (NCERT, 2023-2024).[2] This chapter describes the property of light to travel in a straight line in a transparent medium. Called the rectilinear propagation of light, this property can be used to explain many real-world phenomena like eclipses and the formation of shadows. It now appears in Chapter 11 ('Light') of the Grade VII science textbook (NCERT, 2024-2025).[3]

While this property is often taught as a fact to be memorised by students, the National Curriculum Framework for School Education (NCF-SE) 2023 recommends that: "*...simply stating the rectilinear propagation of light is insufficient... To extend the example of rectilinear propagation of light, students can observe this through the...simple manipulation of cardboard sheets with small holes in front of a candle, or using a pinhole camera/ periscope made in the classroom*".[4, 5] A related learning outcome for Grade VI science is that: "*The learner constructs models using materials from surroundings and explains their working, e.g., pinhole camera, periscope, electric torch, etc*".[6]

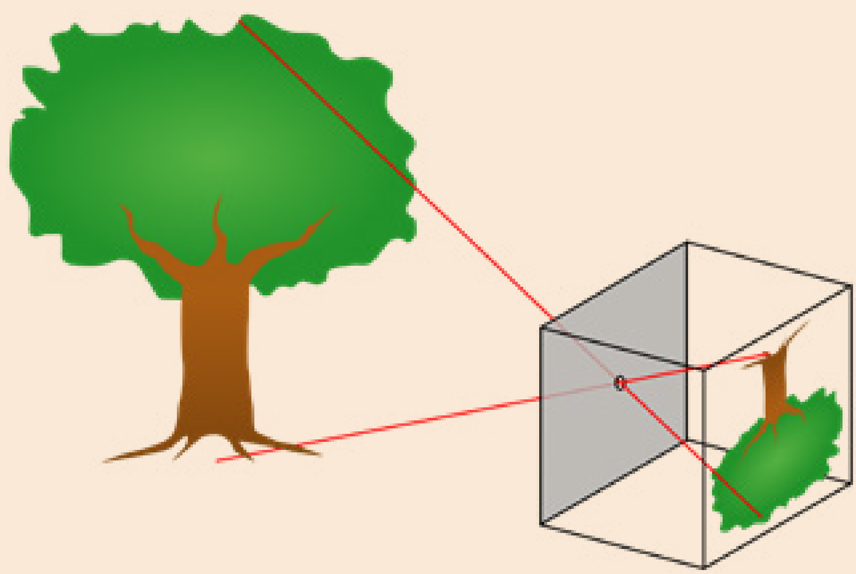

Fig. 1. Principle of a pinhole camera. Light from an illuminated object enters a dark box through a tiny hole and creates a real, inverted, and smaller image on the screen opposite the hole.

Credits: en:User:DrBob (original); en:User:Pbroks13 (redraw), Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Pinhole-camera.svg. License: Public Domain.

large enough to cover the open end of the cup. I had pierced the closed end of the cup with a pin to make a hole through which light from an illuminated object could enter the cup. The butter paper acted as a screen on which the image of the object is projected. I encouraged students to handle the camera themselves and see if they could guess the materials required to construct it. Once they had named the materials they could see, I lit a candle, turned the camera surface with the pinhole towards the flame, and asked students to observe the screen of the camera. Students shared that they could see an inverted image of the candle flame. I dismantled the camera and showed the students each of its parts. The main objective of this exercise was for students to understand that any opaque surface with a pinhole can be used to filter light and any translucent surface can be used as a screen to project the image of an illuminated object.

Step 2: When my students expressed the wish to construct their own cameras, I invited them to take building materials from a box kept on the teacher's table. This included paper cups, cutters, pieces of butter paper, glue, tape, etc. As students returned to their tables with these materials and began assembling their models, I walked around the class observing their work.

Many students found it difficult to attach the butter paper to the cup without wrinkling or tearing it. In such cases, I encouraged them to ask a friend for help. At first, students used a rubber band to secure the paper to the cup. But, we observed, that screens secured in this way showed wrinkling with repeated use. So I recommended that students use glue to permanently secure the ends of the butter paper to the cup. After all the students in the class had constructed their own cameras, I invited them to check if their models worked. I lit a candle on the teacher's table and students brought their cameras to the table to see the image formed on their screens.

Encouraging deeper inquiry and discussion

One of the first student cameras to be tested produced a blurred image. Without needing any instruction, the student who had constructed it began to adjust the distance of their camera from the candle—moving the camera first a bit closer, then a bit farther away from the flame. Through this process of minor adjustments, they were able to arrive at the distance at which their image was sharpest. Another student observed that changing the distance between the camera and the flame changed the size of the image too. Each of the other students tried this focusing activity for themselves. Through these experiments, they concluded that the closer the aperture of the camera is to an illuminated object, the sharper is its image on the screen.

Some students struggled more than others to get a clear image of the flame. I asked these students to compare their cameras with those of their classmates: Could they see any clear differences in construction? One of the differences we observed was in the size of the hole through which light enters. Some of my students had pierced the bottom of their cups with the tip of a ballpoint pen rather than a needle. This led students to conclude that the smaller the size of the hole in a pinhole camera, the sharper the image it produced. My next question was: What would I see on the screen of my camera if I made a smaller second hole (with a pin) near the larger first one (with the tip of a ballpoint pen)? Some of my students decided to try this out and were surprised to see two inverted images of the flame on their screens. This triggered the curiosity of other students, who immediately started poking multiple holes in the bottom of their own cups. They spent some very exciting moments comparing the patterns and orientations of the multiple images this produced on their screens.

To bring my students' attention back to the clarity of their images, I asked if it would change by darkening the room. Since the students were not sure of what effect this would have, I encouraged them to test it. When we closed the windows and switched off the one light bulb in the classroom, the images on their camera screens became a lot clearer. When I asked why this happened, some students suggested that darkening the room may have helped ensure that most of the light that entered the camera came from the flame. I pointed out that we had already ensured this by blackening the bottom and the sides of the cup. After some discussion, the students concluded that the less light from the environment the screen is exposed to, the sharper the image on it.

I asked my students if we could modify the design of the camera to reduce the amount of light from the environment that the screen is exposed to. One student suggested blackening the screen. I agreed that this would meet our aim. But, I asked, how would it affect the image of the flame on the screen? Seeing that my students did not know how to respond to this question, I asked if they could tell me why we were using butter paper for the screen. Could the screen be made from other material too? Since this too was met with silence, I asked students to suggest any other material that we could try using as a screen. My only condition was that the materials needed to be inexpensive and easy to find. As the students shared their suggestions, I listed them on the class board: Oiled paper, plain white paper, cloth, and polythene. I added blackened paper to this list and invited the class to try out each of these alternatives. Working in groups, the students constructed 5 different models of the camera. On testing these models, they discovered that images of the flame were visible on screens made of white butter paper and oil paper, but not on those made of polythene, white paper, and blackened oil paper. I asked if they could explain this observation. After some discussion, the students suggested that a blackened or opaque screen (like one made from white paper) blocked light from the candle from reaching our eyes. In contrast, a transparent screen (like one made from polythene) allowed the light to pass through without forming an image.

I brought the discussion back to the question we started with: Could we modify the design of the camera to reduce the light from the environment that the screen is exposed to? One of my students suggested covering the screen with something like a paper wall. Other students pointed out that the wall may help cut down light from the environment, but it would also obstruct our view of the image on the screen. Another student rolled a strip of black chart paper into a hollow pipe like structure and asked if we could use this to view the image on the screen. A third student backed the idea of a paper wall with one change: We cut out a small window through which we could view the screen. Discussion on both these modifications led to the decision to combine them. We blackened the outer surfaces of a second paper cup and cut out a small piece of paper from its bottom. The mouth of this cup was taped to that of the pinhole camera (see **Fig. 2**). When students tested the new model, they observed that the image produced by it in an undarkened room was as clear as the image produced by the older model in a darkened room.

Fig. 2. Children modifying the design of the pinhole camera.

At the end of the session, I encouraged my students to take their cameras back home and use them to see images of different illuminated objects, like trees, animals, other human beings, the Moon, etc.

Parting thoughts

Making experiences offer students the opportunity to learn science in the process of doing it. For example, teachers can connect student observations and experiences of making a pinhole camera with textbook concepts of rectilinear propagation of light, the classification of objects (into transparent, translucent, and opaque) based on how much light passes through them, image formation in different types of cameras, and the properties of these images. But, to do this, it may not be enough to ask students to mechanically follow complicated procedures from the school textbook. Instead, teachers need to use their own creativity to build simpler models (preferably with fewer and less expensive materials) that students can break down and reassemble by themselves without needing too much help or guidance. Teachers also play an important role in asking questions that encourage students to experiment with the materials, construction, and working of these models. These can offer students the chance to develop analytical, reasoning, and critical thinking skills. Such making experiences can go beyond offering connections to curricular concepts by helping students relate to the process of science through their creativity and curiosity.

Key takeaways

- Making simple models of scientific instruments allows students to engage with the scientific process, develop science skills, and retain knowledge of related concepts for longer.
- When textbook procedures for making models, like that of a pinhole camera, are complex and long, teachers may need to come up with procedures that have fewer steps and involve more easily available and less expensive materials.
- Giving students the opportunity to take apart a working model, examine its components, build and test their own models, and play with different parameters to refine their designs can help them develop analytical, reasoning and critical thinking skills.
- It is also important for teachers to ask students questions about the functioning of the model that encourages deeper inquiry, reflection, and discussion.
- Such making experiences can go beyond offering connections to curricular concepts by helping students relate to the process of science through their creativity and curiosity.

Notes:

1. Credits for the image used in the background of the article title: Pinhole Leaves, Shelly, Flickr. URL: https://www.flickr.com/photos/cat-sidh/36580062351/. License: CC BY-NC-SA 2.0 Generic Deed.
2. Many designs of pinhole cameras can be used to project an image of the Sun or an eclipse that is safe to view. This is because their construction and use allow the viewer to keep their back to the Sun. However, the design described in this article would require the viewer to face the Sun and look at it through the pinhole camera. This can harm their eyes. It may be important to discuss this with your students and remind them to never look at the Sun directly or through any equipment that is not specifically designed for this purpose. It may also be important to underline the fact that sunglasses, binoculars, telescopes, and this design of the pinhole camera do not offer proper protection against the Sun. You could ask your students how they would modify the design described in this article to make it safe to view the Sun.
3. This article includes one detachable classroom resource: **Activity Sheet: Make your own Pinhole Camera.**

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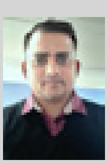
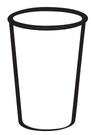


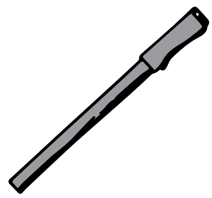
Shiv Pandey has completed an MSc in Zoology, an MPhil in Life Sciences, and a BEd. After teaching science for 12 years, he joined Azim Premji Foundation as a teacher educator. His current areas of work involve science module development, textbook review, science workshops, teacher training, providing classroom support to government school science teachers, and designing continuous and comprehensive evaluations. Shiv also teaches courses on 'Curricular material development' and 'Teacher professional development' at the Field Institute at Uttarkashi. He can be contacted at: shiv.pandey@azimpremjifoundation.org.

ACTIVITY SHEET I : MAKE YOUR OWN PINHOLE CAMERA

You will need:

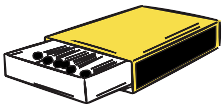


A disposable paper cup (ones that shops use for serving tea, coffee, or fruit juice)

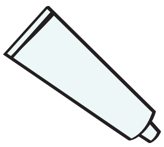


Black sketch pen

Needle



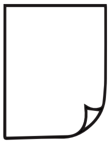
Matchbox



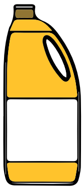
Glue

Candle

A pair of scissors



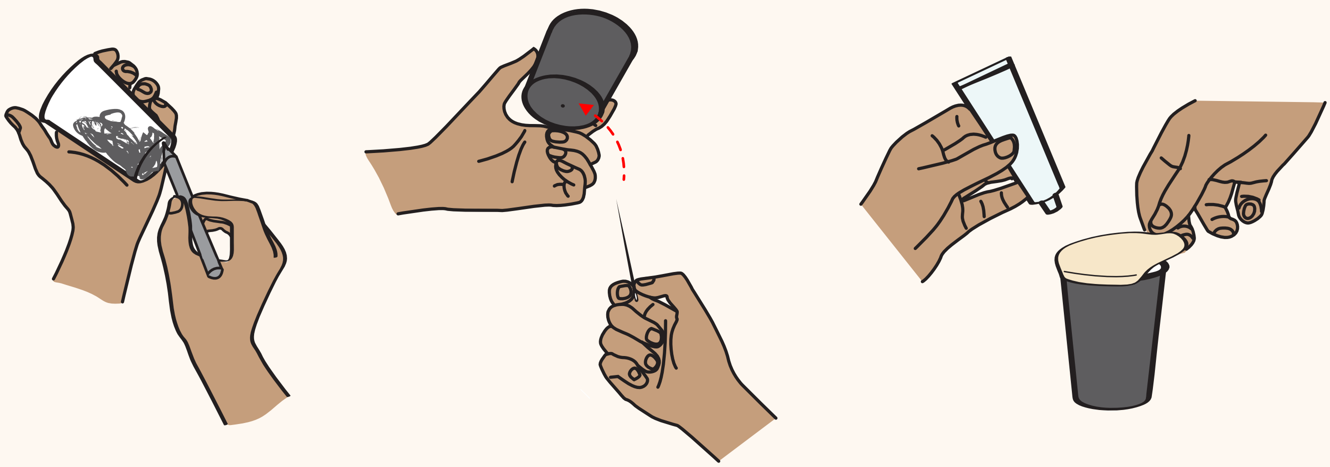
Butter paper or white paper



Vegetable oil

How to make:

- Use the paper cup as the body of your camera. Use the sketch pen to blacken its sides and bottom. This will help keep the cup dark inside.
- Use the needle to pierce the bottom of the cup once. This pinhole will act as the aperture for your camera.
- Use glue to close the open end of the cup with a piece of circular butter paper. The butter paper will act as the screen of your camera. If you do not have butter paper, you can use white paper—make it translucent by rubbing 1-2 drops of vegetable oil on it.



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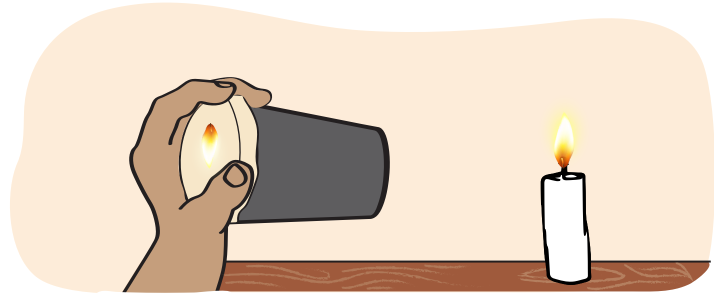
What to do:

Place a lighted candle on a flat table. Turn the pinhole end of your camera towards the flame. Observe the translucent screen.



Observe:

- What do you see on the screen? How is the image on the screen different from the actual flame?
- Move the camera closer and further away from the candle. How does the image on the screen change?
- At what distance is the image on the screen the same size as the flame of the candle? Measure this distance.
- At what distance is the image on the screen the sharpest? Measure this distance.
- Darken the room by drawing the curtains, closing the door, and switching off any other light sources. How does the image on the screen change?
- Use a pen to make the hole at the bottom of the cup bigger. How does the image on the screen change?
- Use the pin to make a second hole in the paper at the bottom of the cup. What do you see on the screen?

Discuss with your classmates:

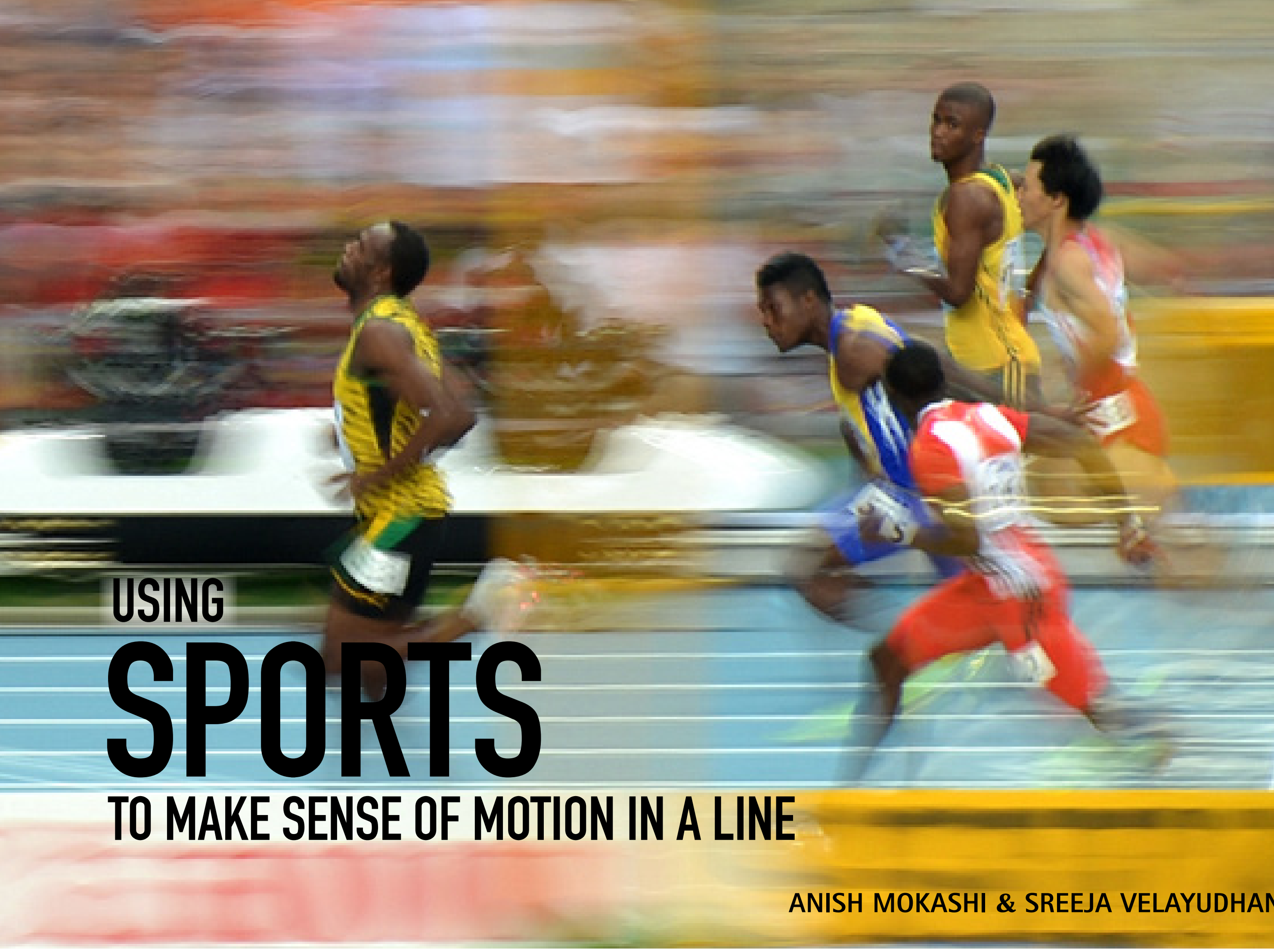
Q1. What factors help create the clearest image on the screen of your camera? Is the size of the clearest image equal to the size of the actual flame?

Q2. Why do you need translucent paper for the camera screen? Can you predict what would happen if you replaced this with a transparent polythene sheet or an opaque piece of card paper? How would you test your prediction?

Q3. What changes in the design of your camera will make the image sharper?

Q4. Is your pinhole camera different from the camera in a mobile phone? Share why.

Contributed by:
Shiv Pandey, who is a science teacher and teacher educator at Azim Premji Foundation. He can be contacted at: shiv.pandey@azimpremjifoundation.org.



USING SPORTS TO MAKE SENSE OF MOTION IN A LINE

ANISH MOKASHI & SREEJA VELAYUDHAN

Middle school students can find textbook chapters on linear motion dry and uninteresting. How do we use contexts from sports to engage student interest in these concepts and invite their active participation in exploring them? How do co-teaching experiences support such explorations?

A few years ago, the two of us were co-teaching science to Grade VIII students. It was close to the end of the academic year and we were discussing our teaching plan for the next year. Sreeja, who had been teaching in the school for several years, shared her experience that even students who otherwise liked to read found it difficult to connect with the science textbook. Moreover, they found textbook chapters on physics, like those on motion, especially dry and uninteresting.

We tried to address this challenge in teaching concepts related to motion in one line (see **Box 1**). Although we share our experience in a continuous manner, our attempt took two weeks (we had three classes per week of 40 minutes each). While we had a tentative plan for each class, responses and questions from our students greatly helped us fine-tune our plans according to their understanding of concepts. We discuss some of these student responses and share how they sometimes helped us take things forward. While looking at our notes and writing about this experience, we were able to reflect on our pedagogical approach. Perhaps this article could be seen as a suggested teaching sequence that other teachers can adapt and modify according to need and relevance (see **Teacher's Guide: Suggestions for Teaching Concepts Related to Linear Motion**).

Introducing Usain Bolt

In a book titled 'Infinite Powers', Steven Strogatz, the mathematician-writer, uses calculus to analyse the Jamaican athlete Usain Bolt's record-breaking 100-metre sprint in the 2008 Beijing Olympics.[4] While thinking about how to get our students interested in motion, we came across this excerpt from the book. Since many of our students liked sports, we thought this

Box 1. One-dimensional motion in the middle stage science curriculum:

According to the National Curriculum Framework for School Education (NCF-SE) 2023, science education at the middle stage is expected to help students develop the competency to describe: "*One-dimensional motion (uniform, non-uniform, horizontal, and vertical) using physical measurements (position, speed, and changes in speed) through mathematical and diagrammatic representations*".[1]

To meet this curricular goal, the concept of motion is first introduced in Chapter 5 ('Measurement of Length and Motion') of the Grade VI science textbook (NCERT, 2024–2025).[2] This chapter also discusses the measurement of length and its standard unit (metre). The concepts of time and speed are first introduced in Chapter 9 ('Motion and Time') of the Grade VII science textbook (NCERT, 2024-2025).[3]

was a context they would be able to connect with. For this reason, we started our exploration of motion by playing a video of Bolt's 100-metre sprint in the 2009 Berlin World Championships in Athletics.[5] It was in this event that Bolt set the current world record for sprinting.

The athletes in this sprint ran so impressively that watching them left all of us—children and adults—feeling amazed and excited. We watched the video a couple of times and were in awe of Bolt's feat. This is how we captured his feat on the class board:

100 metres → 9.58 seconds

A student remarked that this meant Bolt had taken less than a second to cover 10 metres. We asked why she thought so. She responded that if Bolt took a second to cover every 10 metres of the track, it was only a matter of adding up 1 second for each of these lengths and getting 10 seconds for the complete track. As she explained her reasoning, we drew a straight track on the board with 10-metre markings (see **Fig. 1**). Since Bolt took less than 10 seconds to finish the race, the student continued, he must have covered 10 metres in less than a second.

We let the students think about this for some time and rephrased her reasoning in terms of a direct proportion:

10 metres in 1 second

100 metres in ? seconds

To help the students develop a sense of distance, we wondered aloud how long 10 metres was. To relate this to a distance familiar to them, we asked the students to measure the distance from the chalkboard to the opposite wall with a metre stick. Two of the students volunteered to make this measurement. We suggested that they mark each metre with chalk. This distance turned out to be 7 metres. We took a few minutes to visualise Bolt going from the board to much beyond the wall in a second.

"Can we run like Usain Bolt?"

Feeling very inspired by Bolt's video, two of our students claimed that they too could run very fast. Their classmates caught on to their excitement and started encouraging them to race. We quickly discussed this idea amongst ourselves. Both of us felt that it could be an opportunity to deepen their sense of distance and to introduce them to the measurement of time. So we decided to go ahead with their plan.

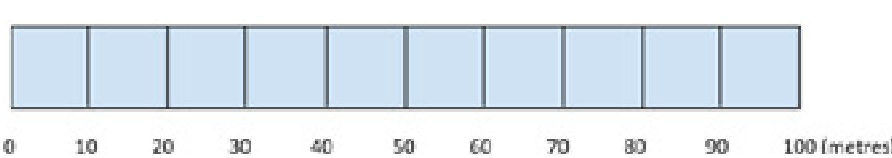


Fig. 1. A straight track with 10-metre markings.

Credits: Anish Mokashi & Sreeja Velayudhan. Licence: CC BY-NC-ND.

We gave the students a 5-metre metal measuring tape and asked them to measure the distance along the dirt road outside the school gate. Their measurement showed that we did not have enough space for a 100-metre race, but there was space for a 50-metre one. We wanted to compare the speeds of the two students with that of Bolt. So we asked our students to suppose that Bolt runs half the distance (50 metres) of the sprint in half the time (approximately 4.8 seconds or almost 5 seconds). We also asked the class to guess how much time their classmates might take to run 50 metres. Many of the students felt that their classmates would take double Bolt's time (or 10 seconds). Some teasingly said that they may take thrice that much time (or 15 seconds).

We invited our students to work out the details of the race. The students used a stick to mark a 'start' line and 'finish' line in the soil. One group of students stood at the start line and another at the finish line. We suggested that they use the stopwatch in one of our mobile phones to time the race. But, after that, we left it to them to discover the problems and precautions needed to make this measurement accurately. We only suggested things and pointed out issues as and when necessary, as too many instructions at the beginning would have been out of context for the students.

As expected, our students struggled with coordinating and recording the start and end times on the stopwatch. After some false starts by the runners and the students handling the stopwatch, we figured out a system that seemed to work better for us. One student decided to stand near the start line and another at the finish line. To start the race, the student at the start line would do a countdown from 10 to 0 in a loud voice and drop a handkerchief at the count of 0. At this cue, the student at the finish line would start the stopwatch. The two students practiced coordinating this sequence a few times before the actual race. The two runners ran the race with a lot of cheering from their classmates. It took one of them 8 seconds and the other 8.5 seconds to reach the finish line. Everyone applauded them.

Calculating speed

One of the expected learning outcomes for Grade VII science is that students learn to measure and calculate the speed of moving objects.[6] But we anticipated that our students were only familiar with the idea of speed in an everyday and qualitative sense. So we went back to the class and wrote this down on the board:

50 m → 8 seconds

What is your friend's speed?

Since none of the students responded to our question, we could see that they did not know how to calculate speed. So we asked them to compare their classmates' sprints with Bolt's. The students said it would have taken their classmates 16-17 s to finish the 100 m race. We said, *"Okay, could you tell us how much distance they would cover in one second?"* One of the students saw that this too was a problem of direct proportion and stated it on the board in these terms:

100 m in 16 s

?   m in 1 s

We used a calculator to answer this question and asked the student to replace the question mark on the board with 6.25 metres. At this point, we introduced the students to the idea that the distance covered by a moving object in unit time was called **speed** (we meant 'average speed'; however, we wanted to avoid introducing too many new terms to the students in one go). We reiterated this by writing the average speed of their fastest classmate on the board: 6.25 metres per second or 6.25 m/s. To relate this number to something tangible, we explained that this value meant that their classmate would not cross the length of the classroom (7 metres) in a second.

Since we wanted to discuss other details of Usain Bolt's sprint, we asked the students how much distance Bolt would cover in one second. One of the students had already reasoned out that it had to be more than 10 metres. The class was now able to calculate Bolt's speed using the same logic of direct proportion.

Thinking further about speed

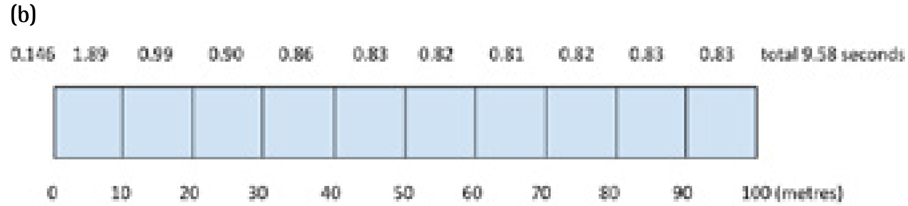
To help our students think further about how distance, time, and speed are related, we found the data for the time Bolt took to cover each 10 metre 'split' and wrote it down on the board (see **Fig. 2a**).[7] Then we wrote these values next to the track on the board (see **Fig. 2b**). We asked our students if they could guess what reaction time meant. Some of them wondered if it was the time an athlete takes to react to the sound of the pistol shot that signals the start of the race. We confirmed this and restated it as the time interval between the pistol being fired and the athlete beginning to run.

We asked the students to observe the numbers on the track. Did they see any patterns? A couple of students observed that the numbers suggested that Bolt had speeded up. When asked to explain why they thought so, the students pointed out that as the race progressed, Bolt covered the same distance (10 metres) in lesser and lesser time. Another student remarked that Bolt had speeded up for the first 70 metres, but had run at an almost constant speed beyond that. We watched the video again to see if we could notice him speeding up. We could see the amount of effort that all the runners made immediately after starting off and in the earlier half of the race.

(a)

Reaction Time	0-10 m	10-20 m	20-30 m	30-40 m	40-50 m	50-60 m	60-70 m	70-80 m	80-90 m	90-100 m	Total time
0.146 s	1.89 s	0.99 s	0.90 s	0.86 s	0.83 s	0.82 s	0.81 s	0.82 s	0.82 s	0.83 s	9.58 s

(b)



(c)

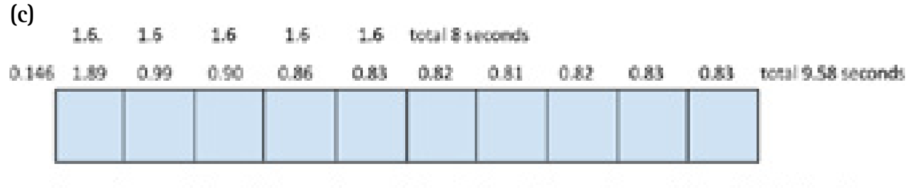


Fig. 2. Time taken for 10-metre splits. (a) Data for Bolt. **(b)** Data for Bolt written next to the track on board. **(c)** The average time taken by a student to complete these 10-metre splits, written above the data for Bolt.

Then, next to Usain Bolt's data, we wrote down the amount of time their classmates had taken to cover 10-metre splits (see **Fig. 2c**). We asked our students if they were okay with this. The entire class protested, pointing out that the data was not true. We did not have any of the 10-metre split times for their classmates. We had only measured the total time it took their racing classmates to reach the finish line.

At this point, we introduced the idea of **average speed** as the total distance covered by a moving object divided by the total time it takes to cover it. To emphasise this point, we explicitly rewrote the earlier calculations for the average speeds of their faster classmate and Usain Bolt as 50 metres divided by 8 seconds and 100 metres divided by 9.58 seconds respectively.

Connecting to everyday units

We now tried to connect the concepts of distance, time, and speed to the students' everyday understanding of these measurements. According to Google Maps, the distance from the school gate to the main road is 740 m. This was a distance that our students travelled every school day. We calculated Bolt's top speed: 10 metres/0.81 seconds = 12.3 m/s. Then asked how long it would take for Bolt to cover the distance between the main road and the school gate if he ran at his top speed:

10 m in 0.81 s

740 m in ? s

The students calculated that Bolt would cover this distance in a minute (about 60 seconds). We wrote this number on the board and used it to calculate the distance Bolt would travel in an hour: 740 x 60 = 44500 m = 44.5 kilometres. At this point, we introduced students to the idea that speed is commonly spoken about in units of kilometres per hour (kmph). Bolt's speed in these units would be 44.5 kmph. To help them relate to these new units, we compared Bolt's speed with that of the fastest animals and birds. For example, a cheetah's top speed is known to be 100 to 120 kmph. We noted that this is more than twice Usain Bolt's top speed. A student claimed that it was possible for them to run and catch up with a scooter moving at a constant speed of 20 kmph. We asked the class to use the logic we had just used to calculate the average speed of their faster classmate in kmph. In a few minutes, the students shared that it would be 6.25 x 60 x 60 metres per hour = 22.5 kmph. We ended the session by pointing out that by running at this speed, their classmate would indeed be able to catch up with a scooter moving at 20 kmph.

Summing up

We aimed to help our students connect textbook concepts of motion with their life experiences. We were fortunate to work in a school that allows teachers the freedom to come up with novel ways to do this. One of our ideas was to use Usain Bolt's sprint as an ice-breaker. But this context spoke to so many of our students that we found it helpful to stay with it throughout our exploration of motion. We also wonder if the field of sports may be rich with other such contexts that could be used to help students connect with concepts in science.

The process of addressing the challenge of engaging student interest in concepts related to motion was intense and time-consuming for us. Three things helped us in this process:

(a) The active participation of our students in each of the activities and discussions: We observed that students made different contributions to the class. Their contributions often sparked off their peers' thinking processes in ways that helped us sustain a dialogue with them.

(b) Our experience of co-teaching this topic: Like many teachers, we planned the activities for each class in advance and observed how our students responded to them. This meant that we often changed our plan in real time and moved on to connect things in future classes. Working together allowed us to share ideas and discuss problems with each other. It gave us the confidence to try out new and tentative ideas and offer on-the-spot responses to our students' questions and ideas. It was also helpful to get a peer's perspective on how one is interacting with students and how they are responding to the class.

(c) Documenting our lessons: We recorded our main observations from each class, took photographs of the blackboard, and jotted down points from our process of planning a sequence of successive classes. It helped that we maintained electronic files—we could locate our documentation, share it with each other, and see what themes emerged from them.

To meet the challenge of making science personally relatable and interesting to students, teachers need to have the space and time to learn how to iteratively develop effective and localised ways of engaging students in the subject matter of science. We feel that collaborating with a colleague may be one of the most readily available, accessible, and sustainable forms of support a teacher can get in strengthening their teaching practice.

SUGGESTIONS FOR TEACHING CONCEPTS RELATED TO LINEAR MOTION

> *If you don't deal with the epistemology of those subjects from the child's point of view then you run into trouble.*
>
> — Prof. Krishna Kumar.[1,2]

Prof. Krishna Kumar seems to suggest that it is important to involve students actively in building formal scientific concepts rather than present concepts merely as received knowledge. How do we do this? Linear motion is described in terms of the relationship between the concepts of distance, time, and speed. Students develop a qualitative sense of this relationship from everyday experiences such as walking, running, riding a bicycle, travelling in a bus or on a train etc. The concept of speed also enters their everyday vocabulary through popular culture, such as media and literature. By drawing on these and on familiar mathematical ideas, such as direct proportion, we can enter into a dialogue with our students. These conversations can be sustained through a sequence of activities and prompts to help students build a quantitative relationship between these concepts.

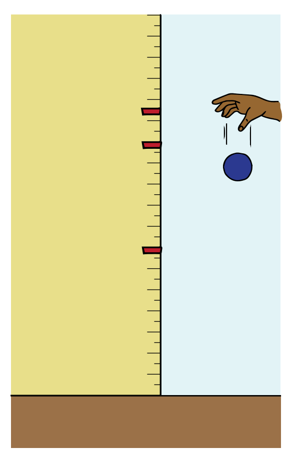
We have described the approach we took to teaching linear motion in the article titled 'Using Sports to Make Sense of Motion in a Line'. For teachers interested in our approach, this is the approximate sequence in which we took up discussions and activities:

1. Watch the video of Usain Bolt's 100 metre sprint.
2. Invite students to share what they noticed, felt, and thought while watching the video.
3. Connect metre (the unit of length) to distances students are familiar with.
4. Invite your students to measure the lengths of some objects in class. Allow them to use a metre scale or measuring tape if either is available.
5. Allow your students to race if even two of them volunteer to. Let your students measure out the distance for the race. Allow them to use a metre scale or measuring tape if either is available.
6. Challenge students (at least a pair of them) to synchronise the starting and ending of the race and their measurement of the time their peers take to run the race.
7. Use the concept of direct proportion to relate distance traveled and time taken. Arrive at the concept of average speed as distance traveled in one second.
8. Look at the times that Usain Bolt took to cover 10 metre splits in the race in order to help students notice how his speed changed during the race.
9. Connect speed in metres per second to the familiar unit of kilometres per hour.

Here are some additional suggestions that could be considered while teaching these concepts:

- We found it helpful to start with watching Usain Bolt's world-record setting 100 metre sprint as it engaged students' interest and attention. They seemed to feel personally involved in the race. The video is a little over two minutes. It shows the race from different angles and in slow motion. The sheer athleticism is captivating and students will very likely get quite drawn into watching the race and thinking about it. It might also help to play the video more than once so that students can watch it carefully and notice different aspects of the race. You can find the YouTube video here: https://youtu.be/HFLuduKmnW0. Or you could use the QR code for it (included to the right).

- Inviting comments from students and letting them speak about what they felt after watching the race and what they noticed in the video worked well for us as a way to initiate a classroom dialogue. Acknowledging students' ideas, summarising them on the chalkboard, and (if time permits) responding to some questions might also be helpful. It is quite possible that some of these points could help take the discussion further and connect to the formal concepts we intend to introduce in the class. We found it useful to be on the lookout for such opportunities. Often, students' ideas can be quite surprising. For example, we did not expect that students would want to race after watching the video. As teachers, we will have to take risks while relying on our pedagogical judgement to decide which ideas could be more suitable for further exploration.
- We would suggest having a race and weaving discussions around it so that students get something concrete to refer to in further class discussions. If your students do not express the wish to race themselves, suggest it to them. Being children, a few of them would definitely be willing to volunteer.
- For students to develop a better sense of the metre as a unit of length, discuss distances and lengths that are familiar to them from their everyday life at school or at home. This could include the length of their desk, classroom, or the playground. Involve them in actually measuring some of these distances with a scale or measuring tape. Giving this exercise enough time and care is important in ensuring that students acquire the skill of measuring lengths with reasonable accuracy. This understanding will also be important in interpreting the data from Usain Bolt's sprint.
- As we discuss in the article, helping students synchronize the start and end of the race and measure the time their peers took to run this distance was especially tricky. They needed continuous inputs to appreciate the care required to make accurate measurements. It may be best to have these conversations in class so that all your students are on the same page. But it may not be possible to avoid continuing these conversations while coordinating the race.
- Giving students a lot of instructions before they make their own measurements may not work. A more scaffolded approach would be to ask them to measure the time taken to complete one or two simpler tasks in the classroom. For example, they could roll a ball on the floor and measure the time it takes to reach a finish line they mark themselves. Or they could measure the time it takes for a ball to hit the floor when they drop it from a height of 2-3 metres. During these tasks, it may be useful to combine short instructions, measurements, and discussions in a graded manner. Discuss the precautions they need to take to time these tasks accurately. This experience can help them with the more complex task of measuring sprint times for the race.



- Discuss how Usain Bolt speeds up at the beginning of the race. You could also play the video again for students to observe this themselves. Then you could ask students if they have seen other examples of the speed of a moving object or person changing. If students do not share any examples immediately, you could ask them to observe the speed of vehicles when they come to a stop at a traffic signal or start off from it. Or the values displayed on the speedometer of a vehicle at different times during the course of a journey. Give them a couple of days to make these observations and invite them to share and discuss these in class.

- Rather than starting with a formal definition of speed, we took the approach of using direct proportion to arrive at the concept of average speed. For example, we asked: *"If a student ran 50 metres in 8 seconds, how many metres would they cover in one second?"*. We then gave the name 'average speed' to this number. We feel that this approach allowed students to relate to things better. Students might also understand the meaning of the units of speed (metres per second) in a more direct manner. We extended this logic to minutes and hours to get the distance covered in an hour in metres and then converted it to kilometres. Reasoning this way about conversion of units from metres per second to the more familiar kilometres per hour may also be a gentler way of introducing students to this process than just writing it down as a mathematical formula.

As teachers, you would know about the approach that might work best with your students. This approach would likely follow from the specific contexts of your students, the discussions that happen in your classes, and the ideas that emerge from these conversations. The suggestions shared here could be modified or adapted accordingly. We would like to hear about your experiences of trying out such ideas in your classrooms with your students. Please do write to us about what worked for you and how your students responded to your class. Thank you!

Notes:

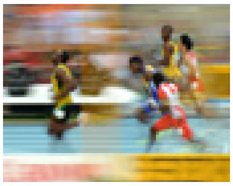
1. Some aspects of the epistemology ('theory of knowledge') of science are: The nature of science/scientific knowledge, the processes through which it is created, how it is contested and the way it evolves (which includes the social, philosophical, technological, and historical contexts of the work of scientists), the parameters to judge if something is scientifically valid/true or not (nature of evidence), and what can and cannot be said, deduced, or predicted based on a piece of scientific knowledge, etc.
2. Listen to Prof. Krishna Kumar's perspective here: 'In Conversation with Prof. Krishna Kumar', Doordarshan, 2005. URL: https://youtu.be/7kw41vIhxUg?feature=shared&t=245.

Contributed by:

Anish Mokashi, who works with the Physics and Teacher Education groups at Azim Premji University, Bengaluru. Anish can be contacted at: anish.mokashi@apu.edu.in.

Sreeja Velayudhan, who has been teaching Physics and Science at Poorna Learning Centre and Bidiru Learning Centre. Sreeja can be contacted at: sreeja@poorna.in.

Key takeaways



- Sports can provide engaging contexts for introducing students to curricular concepts around linear motion and connecting them with tangible experiences of distance, time, and speed.
- A teaching plan that changes to accommodate student responses is crucial in inviting students to share their ideas with each other and in encouraging their active participation in all the activities and discussions.
- Preparing for and facilitating such a pedagogical approach may require a lot of thought and time from teachers. Collaboration with other teachers can be one of the most readily available and sustainable forms of support that teachers can receive in such efforts.

Notes:

1. Credits for the image used in the background of the article title: Usain Bolt, Tobi 87, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/Usain_Bolt#/media/File:Leichtathletik_WM_2013_Moskau_100_m_Vorlauf.jpg. License: CC-BY-SA 3.0 Unported Deed.
2. For your students to actively participate in this pedagogical approach, they will need to be familiar with concepts like length measurement (Grade II mathematics), decimals to relate to non-integral values of time (Grade V mathematics), and direct proportion (Grade VII mathematics). They should also be able to round off numbers to get estimates.
3. If space for a 50-metre race is not available in and around your school, encourage your students to mark off a shorter distance and adapt the activity accordingly. If a 5-metre metal measuring tape is not available in your school, invite students to think of other easily available alternatives (like sticks or a spool of thread) that can be used to measure the distance for the race. You can also get your students to think about and discuss how these changes affect the accuracy of their measurements.
4. This article includes one detachable classroom resource: **Teacher's Guide: Suggestions for Teaching Concepts Related to Linear Motion**.

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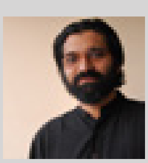
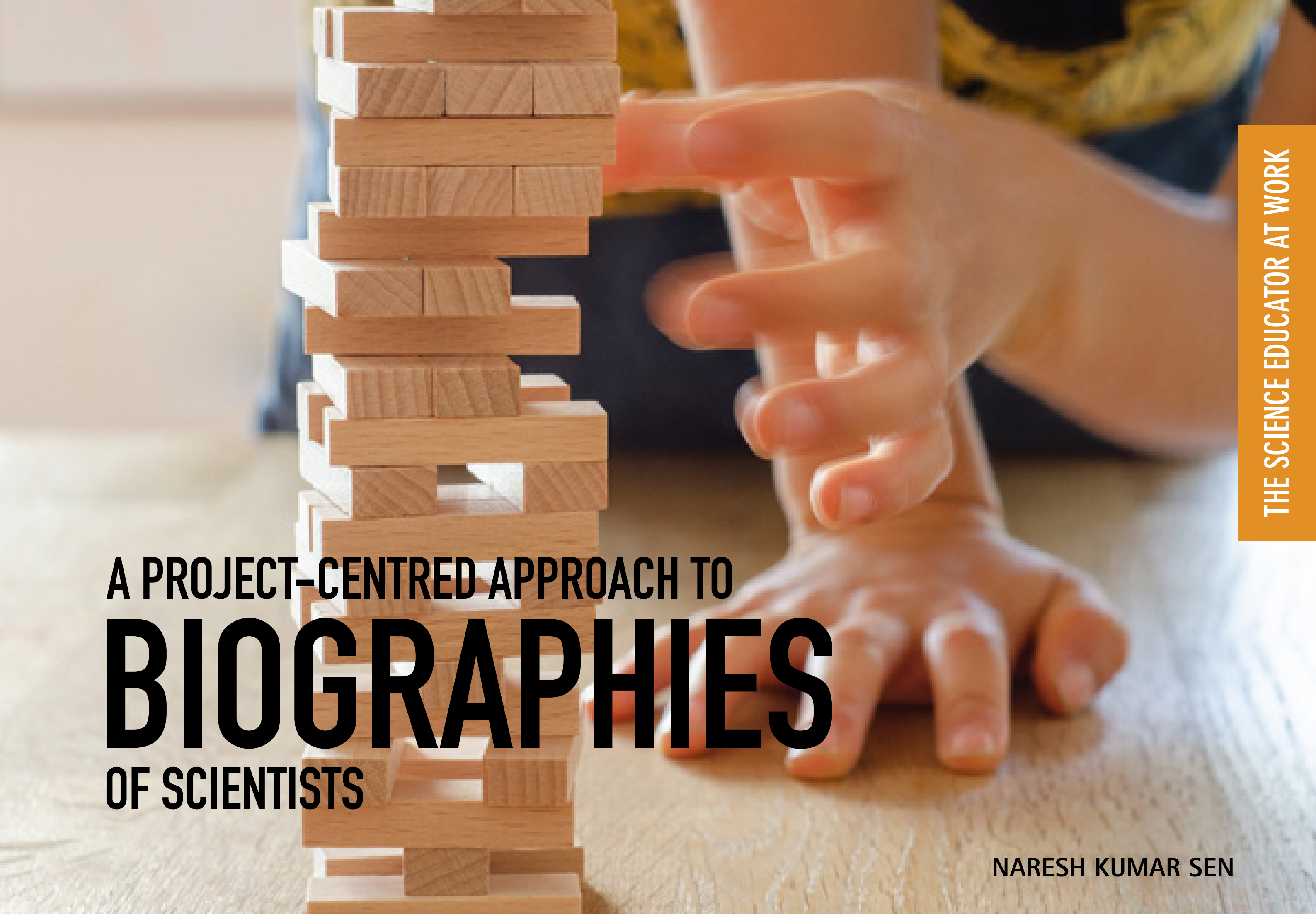


Anish Mokashi works with the Physics and Teacher Education groups at Azim Premji University, Bengaluru. His background is in experimental physics and he works in science education. Anish has previously taught undergraduate students at the Indian Institute of Science (IISc) Bengaluru; worked with Eklavya, Bhopal on science teacher education; and taught at Poorna Learning Centre, Bengaluru. He is interested in connecting doing and thinking in the context of learning science, students' ideas and meaning-making, cultures of teaching-learning, and the history of science. Anish can be contacted at: anish.mokashi@apu.edu.in.

Sreeja Velayudhan has been teaching Physics and Science at Poorna Learning Centre and Bidiru Learning Centre. She also co-founded a makerspace called Kreu. She loves to explore science via hands-on activities. Sreeja can be contacted at: sreeja@poorna.in.



A PROJECT-CENTRED APPROACH TO BIOGRAPHIES OF SCIENTISTS

NARESH KUMAR SEN

Biographies of scientists can be an effective and engaging way to introduce students to the process of discovery. How do we use a project-centred approach to meet this aim? What skills do students develop in such an approach? What do they learn about science?

The National Curriculum Framework for School Education (NCF-SE) 2023 suggests that: "…*examining the lives and works of scientists and the development of scientific knowledge is a way for students to engage with the nature and process of science and develop scientific values and dispositions*".[1] It is for this reason that middle school science textbooks include biographies of scientists. An expected learning outcome for Grade VIII science is: *"Children should discuss the stories of scientific discoveries and understand their importance"*.[2] But conversations with students and colleagues revealed that students are often asked to study these parts of the textbook by themselves. In some cases, teachers select details that are important from an examination point of view and write them down on the class board. Children are asked to copy these details in their notebooks and memorise them.

In the rural environment that I teach in, I have seen many instances where children take the initiative to work together as a group towards a common goal. Their goal could be as simple as planning a trip to a nearby place or playing a team sport. In each such instance, children come up with a plan to meet this goal, decide each person's role in the implementation of this plan, collect necessary information, and analyse it to make necessary decisions. These steps are part of the project-centred approach that the (NCF-SE) 2023 recommends for teaching school science: *"This approach allows learning within the classroom to continue outside the classroom and extend over a period of time. For example, observing the changes in the moon over a month to understand the phases of the moon. In this process, connections to daily life are also made. The project-centred approach allows students to develop artefacts/ products (charts, presentations, speeches)* *that reflect and communicate their emerging understanding. It also allows the integration of concepts across different curricular areas"*.[1] Since rural children use a project-centred approach so naturally and effectively in their everyday world, I decided to use it to introduce my Grade VIII students to the biographies of scientists.

My classroom process

Step 1: The Grade VIII textbook (NCERT, 2024-2025) includes biographies of eight scientists: Louis Pasteur, Alexander Fleming, Edward Jenner, Robert Koch, Ian Wilmut, Otto von Guericke, William Nicholson, and Benjamin Franklin. None of these scientists are from India. According to the NCF-SE 2023, one of the curricular goals of science education at the middle stage is to ensure that each student: *"Understands and appreciates the contribution of India through history and the present times to the overall field of science, including the disciplines that constitute it"*.[1] With this aim in mind, I prepared a list of Indians who have made important contributions to science. This included people like Sushruta, Charaka, Kanada, Aryabhatta, Bhaskaracharya, Varahamihira, Brahmagupta, Nagarjuna, Birbal Sahni, Har Gobind Khorana, Meghnad Saha, MS Swaminathan, Homi Jehangir Bhabha, Vikram Sarabhai, APJ Abdul Kalam, CV Raman, Srinivasa Ramanujan, Jagadish Chandra Bose, and Satyendra Nath Bose. Two of these people are featured in the Grade VI textbook (NCERT, 2024-2025).

Step 2: I stuck photos of these scientists on a piece of thick cardboard and displayed this in class. I gave my students 10 minutes to look at these photos and asked if they recognised any of them. The only scientist my students knew of (and slightly) was Abdul Kalam. Apart from his name, they knew that Kalam was a scientist and had been one of the presidents of India. I named each of the scientists on the display.

Step 3: With their consent, I named each student after one of the scientists on my list. Their task was to investigate the scientist assigned to them. At the end of the two weeks, they were expected to submit a biography of this scientist. The biography could include details like: (a) What do we know about this scientist's life and the challenges they faced, (b) What were their contributions to science, and (c) What have we learnt from their work or how have these contributions benefited us. I encouraged them to search for this information in books, newspapers, magazines, and on the Internet.

Step 4: I observed that my students applied themselves to this task with seriousness. In the days that followed, I heard them discuss their projects with each other, their siblings from higher grades, and the other teachers in school. Some of the students came up to me to share what they had learnt so far or to ask where they could get some more information. At the end of two weeks, each student submitted a piece of writing about the scientist assigned to them (see **Fig. 1**).

Step 5: To bring the students together as a group, I invited each of them to play the role of the scientist assigned to them and present what they had learnt about this scientist as a first-person account to the class. My students enjoyed this task. It allowed them to share their own work and hear about the scientists that their peers had researched.

Step 6: I wrapped up the project with a class discussion. I invited my students to share what they had learnt from their own work and that of their peers. This exercise gave them a chance to reflect upon and express their learning as a group.

Parting thoughts

Using a project-centred approach to introduce students to the lives and contributions of Indian scientists had many advantages. The individual tasks assigned to the students appealed to their inquisitive nature and interest in exploring new things by themselves. The process of writing biographies allowed them to develop skills like collecting information from different sources, analysing this information to understand it and reach valid

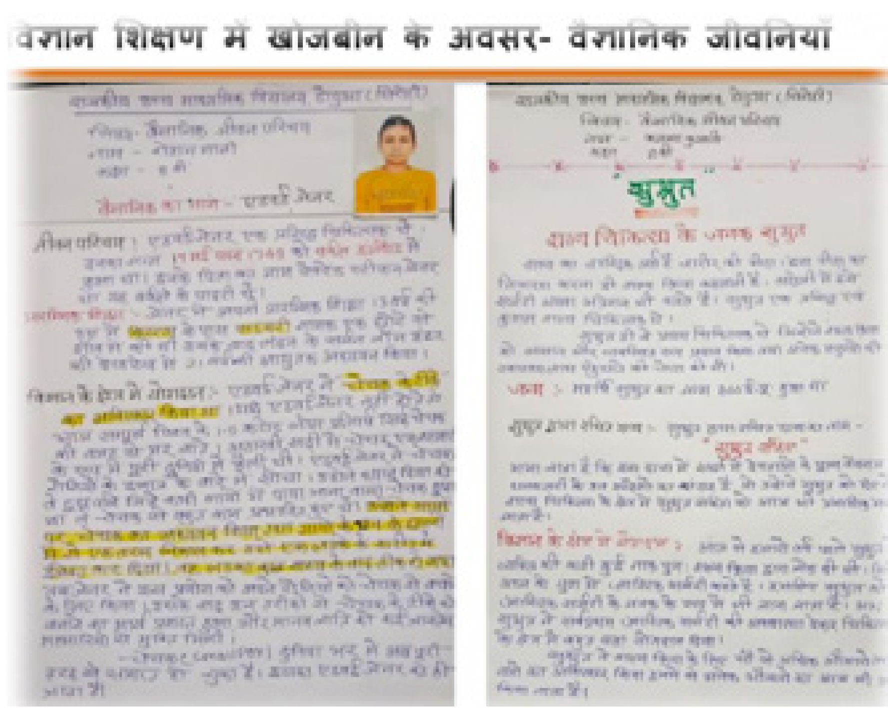


Fig. 1. Examples of student-authored biographies of scientists.

ACTIVITY SHEET I : WHO ARE THESE SCIENTISTS?

What to do:

The wall below has photos of six Indian scientists. Take a few minutes to look at them. How many of them can you identify?

(a)....................................

(b)....................................

(c)....................................

(d)....................................

(e)....................................

(f)....................................

Here are some clues to help you:

(a) Do you enjoy sucking on sugarcane stems? Did you know we imported sugarcane from other parts of the world till this scientist (1897-1984) developed varieties that were sweeter than native Indian varieties and better suited to grow in our country than imported varieties? She is sometimes called 'The first Indian woman botanist'. Chapter 2 ('Diversity in the Living World') of your Grade VI science textbook (NCERT, 2024-25) highlights her role in the Silent Valley Movement and in documenting Indian plant diversity.

(b) Chapter 7 ('Temperature and its Measurement') of your Grade VI science textbook (NCERT, 2024-25) introduces this scientist (1918-2001) as the 'Weather Woman of India'. She invented many instruments to make precise measurements of weather phenomena like humidity, rainfall, air pressure, and wind speed. This reduced our need to import scientific instruments from other countries. She also used one of her instruments to measure the thickness of the ozone layer. You read about ozone in Chapter 5 ('Physical and Chemical Changes') of your Grade VII science textbook (NCERT, 2024-25). Her measurements have helped us understand the importance of this layer in protecting life on Earth.

(c) In Chapter 8 ('A Treat for Mosquitoes') of your Grade V Environmental Science textbook (NCERT, 2024-2025), you read about how we can get malaria when we are bitten by a disease-causing mosquito. Chapter 2 ('Microorganisms: Friend and Foe') of your Grade VIII science textbook (NCERT, 2024-25) shares simple things you can do to prevent the spread of this disease. But what if you have malaria? This scientist (1917-2006) isolated many chemicals of medicinal value from plants native to India and used some of them to develop a drug to treat malaria.

(d) Some couples find it difficult to have children naturally. In Chapter 6 ('Reproduction in Animals') of your Grade VIII science textbook (NCERT, 2024-25), you read of how in-vitro fertilisation can help such couples have test-tube babies. This scientist (1946-) was among the first to try this process in India. She was also one of the two people who led the medical team that delivered one of India's first test-tube babies: Harsha Chawda.

(e) In Chapter 1 ('Crop Production and Management') of your Grade VIII science textbook (NCERT, 2024-25), you read of how important water is in growing food. Our farmers depend on the monsoons and groundwater for water. But we are using up groundwater very quickly and the monsoons can be late or not bring enough rainfall. This puts us at risk of droughts. Droughts can cause crops to fail and millions to die. This scientist (1956-) has developed seeds of wheat, rice, and mulberry that can grow in severe drought conditions.

(f) You may have learned from your parents, teachers, and Chapter 3 ('Mindful Eating: A Path to a Healthy Body') of your Grade VI science textbook (NCERT, 2024-25) about the importance of a balanced diet and how inadequate nutrition can cause diseases. But many children and adults cannot afford nutritious food. This scientist (1911-1998) studied the nutritional value of a commonly available, sweet, and inexpensive drink, called *Neera*, prepared from the sap of coconut palms. She showed that adding this drink to the diets of undernourished adolescents and pregnant women could improve their health.

Sources for images:

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Contributed by:
Vijeta Raghuram, who is a science communicator with a PhD from the Centre for Cellular and Molecular Biology (CCMB), Hyderabad. She can be contacted at: vijeta.raghuram@apu.edu.in.

conclusions, and communicating what they had learnt to their peers and teachers. The class presentations allowed my students to listen to and learn from their peers. These are important aspects of knowledge creation in science.

In the discussion that followed their presentations, the students shared how learning about the work of scientists like Sushruta, Louis Pasteur, Edward Jenner, Benjamin Franklin, and MS Swaminathan had shown them the usefulness of science in their real worlds. This observation extended into a discussion on the many ways in which the contributions of scientists from India and other parts of the world have not only helped save lives but also improved the quality of our lives. The students also shared how this project had challenged two of their most common beliefs: (a) Scientists are rarely Indian, and (b) Scientists had special abilities that made them very different from other people (in my students' words, they were "*smarter*" or "*more intelligent*" than "*ordinary*" people).[3] Through this project, my students learnt about some of the Indians who have made important contributions to science (see **Activity Sheet: Who are these Scientists?**). As they documented these lives in science and role-played them in class, they began to identify with the scientists assigned to them. For some time after the completion of this project, my students would call each other by the names of the scientists they had researched instead of their real names. Most importantly, they now looked at the biographies in their textbooks with spontaneous interest and curiosity rather than as material to be mechanically memorised for examinations.

Key takeaways

- Biographies of scientists can be an effective and engaging way of introducing students to the process of science.
- A project-centred approach that invites students to document and share key aspects of the life and work of scientists with their peers can help them develop skills like collecting, analysing, and communicating scientific knowledge.
- Focusing on scientists from other parts of the world as well as India allows students to examine some of their own beliefs about where scientists come from and who can be a scientist.
- The opportunity to relate to the people behind scientific discoveries and see how these discoveries have improved our lives can help students develop an interest in science and scientists that extends beyond examinations.

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1. Cooperation is key in the teaching and learning of science. The author thanks his institution head Sonu Mistry and his colleagues Tina Mistry and Saruparam for their constant support.
2. The editors thank Gajendra Pal Chouhan and Amol Anandrao Kate from Azim Premji Foundation for sharing this draft with us. We acknowledge Gajendra Pal's help in facilitating every stage of the review and design of this draft. We thank Rajesh Utsahi from Azim Premji University for sharing the English translation of the original draft (written in Hindi). We also thank Saurav Shome and Vinay Suram for their inputs on the project-centred approach described in this draft.

Notes:

1. Credits for the image used in the background of the article title: Constructing knowledge, Kathas_Fotos, Pixabay. URL: https://pixabay.com/photos/jengawooden-blocks-game-strategy-6380189/. License: CC0.
2. This article includes one detachable classroom resource: **Activity Sheet: Who are these Scientists?** The scientists in the sheet are: (a) Janaki Ammal, (b) Anna Mani, (c) Asima Chatterjee, (d) Indira Hinduja, (e) Paramjit Khurana, and (f) Kamala Sohonie. If you try this activity in your classroom, which scientists would you include and why? Write to tell us (at: iwonder@apu.edu.in).

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1. National Steering Committee for National Curriculum Frameworks. 'National Curriculum Framework for School Education 2023'. National Council of Educational Research and Training. URL: https://ncert.nic.in/pdf/NCFSE-2023-August_2023.pdf.
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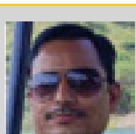

Naresh Kumar Sen works as a science teacher in the Government Higher Secondary School Dodua at Sirohi, Rajasthan. He has a BSc, a BEd, and 12 years of teaching experience.

'ALL THAT BREATHES': WHY RAPTORS MATTER

DEBORAH DUTTA

Can a film on rescuing sick and injured black kites draw students' attention to the raptors in their own neighbourhood? Can it help them appreciate the role of these carnivorous birds in maintaining healthy ecosystems? How do we use the film to highlight the interdependence of animals and humans?

"Time flows differently in this basement. Sometimes I feel that my heart will burst open one day while working here, and kites would fly out of it." Saud's wistful expression is a mixture of grief, love, and perseverance as his eyes meet the piercing gaze of a kite with a bandaged wing (see **Fig. 1**). For the past twenty years, Mohammad Saud and his brother Nadeem Shehzad have been nursing sick and injured birds of prey, mainly black kites, in a makeshift clinic at their home in Delhi, one of the most polluted metropolitan cities in the world. The Oscar-nominated documentary 'All that breathes' by Indian filmmaker Shaunak Sen is a powerful yet sensitive portrayal of their rescue efforts (see **Fig. 2**).

The film follows the seemingly ordinary activities of the brothers and their endearing assistant Salik Rehman as they traverse the choked arteries of the metropolis to find and rescue ailing birds (see **Box 1**). As it does so, we catch glimpses of the many animals that

Fig. 1. The black kite (*Milvus migrans*). Ask students: *Do you see this bird in your neighbourhood? What do you know about it? How would you describe its different features: Size, beaks, claws, and colour? What role do these birds have in a food web?*

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Box 1. Connections to the curriculum:

This resource can offer many ways of connecting what students learn about the living world in textbooks for Environmental Studies (EVS) in the preparatory stage (Grades III-V) and science in the middle stage (Grades VI-VIII) with their real worlds (see **Activity Sheet I: Kites in your Skies, Activity Sheet II: Meeting Other Raptors**, and **Teachers Guide: Activity Sheet I & II**). It can also offer a gentle and non-prescriptive way of meeting what the National Education Policy (NEP) 2020 describes as the aim of school education: "*The purpose of the education system is to develop good human beings capable of rational thought and action, **possessing compassion and empathy**, courage and resilience, scientific temper and creative imagination, **with sound ethical moorings and values***".[1] It could also be used to build what the National Curriculum Framework for School Education (NCF-SE) 2023 describes as a capacity for social engagement that includes affective aspects: *"Empathy and compassion are not only values or dispositions; these are capacities that are developed through deliberate practice"*.[1] Lastly, teachers could plan activities around this story that align with the following curricular goals listed in the NCF-SE 2023 for:

(A) The preparatory stage:

- CG-2: (The student) understands the interdependence in their environment through observation and experiences, developing the basis for appreciation of the idea of '*Vasudhaiva Kutumbakam*'. Specifically, it can help students develop the competency to: *"Connect changes in the environment and the lives of their family and community, as communicated by elders and through local stories (changes in occupation, food habits, resources, celebrations, communication)"*.
- CG-4: (The student) develops sensitivity towards the social and natural environment. Specifically, it can help students develop the competency to: *"Identify needs of plants, birds, and animals, and how they can be supported (water, soil, food, care)"*.[1]

(B) The middle stage: CG-3: Explores the living world in scientific terms. It can help students develop and exercise the following competencies:

- *"Describe the diversity of living things observed in the natural surroundings (insects, earthworms, snails, birds, mammals, reptiles, spiders, diverse plants, and fungi)"*.
- *"Analyse patterns of relationships between living organisms and their environments in terms of dependence on and response to each other"*.[1]

inhabit the city. Pigs wading through sewage canals. A tortoise navigating through the trash. Cows negotiating a path through flooded streets. Rats rummaging through garbage. Monkeys making their way through a maze of cables, wires, and construction sites.

The drone of flies is a constant part of the background sound. And we see kites hover prominently over landfills with massive piles of the city's waste (see **Fig. 3**). At one point in the film, Salik estimates that a kite eats about 10-15 grams of food daily. So, he continues, the 10,000 or so kites circling the landfill must be consuming roughly 100-150 kilograms of waste per day. Saud then compares the city to a stomach and creatures like the kites to the *"...bacteria that help in digestion"*.

Fig. 2. The release poster of the film (2022). The 93-minute-long film is directed by Shaunak Sen. Watch the trailer here: https://www.allthatbreathes.com/trailer. Watch the film on HBO Max (https://www.hbo.com/movies/all-that-breathes).

The entangled lives of these different species are a vivid reminder that no place is apart from Nature, no matter how indifferent cities are to these interrelationships. Seeing the city's marginalised (both the human and the 'more-than-human') and recognising the precariousness of their lives, one is reminded of the poem 'How to be a poet':

> *"There are no unsacred places;*
> *there are only sacred places*
> *and desecrated places."*
> —Wendell Berry.[2]

Saud and Nadeem recall childhood stories told to them by their mother, who lost her life to cancer. Animals and other creatures were the main protagonists of these stories and interconnections between species were

Fig. 3. An 80-acre landfill at Ghaziabad at sundown. Ask students: *How far is your home or school from a landfill? Have you visited a landfill or seen one while travelling? Can you think of ways in which you (and all of us) contribute to landfills? What role do black kites and other raptors have at landfills? And what role do waste-pickers have? Are these roles interconnected?*

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woven into them like a fundamental fact of life. However, these manifest forms of interdependence are not why the brothers engage in the largely thankless work of rescuing kites. Their relentless and restless efforts draw on something much more personal and powerful. Saud and Nadeem describe how they grew up watching kites. They found their first injured kite when they were in their teens and took it to a bird hospital nearby for treatment. But the hospital refused to admit a carnivorous bird. In the Muslim faith, it is believed that feeding kites can ease your worries as the raptor 'devours your anxieties'. The injured kite became the brothers' first patient. Other birds followed. Saud and Nadeem have treated around 20,000 kites in the last 15-20 years.

Dedication to this task does not come easy, however. Short of funds to support their work, we watch the brothers ask their main meat seller to reduce the price of the meat they buy for the birds. The meat seller refuses. Later, while mincing meat for the kites to feed on, Salik asks Saud if the kites will eat him too if he pretended to be dead. Saud jokingly asks him to try, while Nadeem pithily comments, *"Humans forget that they are also a piece of meat…".*

Fig. 4. A view of the polluted Delhi skies. Ask students: *Compare these skies with your own. How do you think the pollution in Delhi affects the health of its plants, animals, and humans? How polluted is the air near your home or school?*

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The documentary unfolds against the backdrop of growing unrest and anti-CAA (Citizenship Amendment Act) protests in the city.[3] Nadeem muses upon the fact that a misspelling of their father's name in government identification certifications could cost them their citizenship. Can such arbitrary criteria make the process of 'othering' so easy? Outside, the protests spark the fires of sectarian violence. Suppressed dread looms in the city. The air quality deteriorates to such alarming levels that birds plummet from the sky (see **Fig. 4**). Yet the brothers continue their work as if pulled by mysterious forces stretching out from kite-filled skies. Speaking of Saud's relationship with kites, Nadeem says: *"It is said that while performing classical music, if one truly sings a raga well, one experiences a kind of fleeting bliss. This bliss cannot be possessed or captured. For a brief moment, you just touch it… Saud can touch a similar relief when he is with kites"*. Sharing how he

ACTIVITY SHEET I : KITES IN YOUR SKIES

The bird on the poster of the film 'All that breathes' is a black kite. You may have seen these birds soaring above waste dump yards and landfills looking for food (dead animals) or swooping down to catch live fish, rodents, bats, and other small animals. But these are only one of the four kinds of kites seen in India:

Observe and discuss:

- Take a few minutes to observe the photographs of the different kinds of kites in flight. Can you spot any features that are common to them and different from other kinds of birds you see in your neighbourhood?

- Can you tell the four kinds of kites apart? What are some of the most important differences you can spot between them?

- To the left of the table below are some features of these birds. One or more of these features may be visible to you when you see them in your sky. How would you describe these features to your friends? Think, for example, of what can you see of the size, shape, and colour of each feature in their photographs.

What does this look like?	(a)	(b)	(c)	(d)
Head				
Eyes				
Beak				
Wings				
Tail				
Body				

- People who regularly observe birds (bird watchers) call these kites by certain names. These 'common' names can help us identify each kite by the way it looks. Can you match the common names of these birds with their photographs?

Photographs	Common Names
(a)	Brahminy Kite
(b)	Black-winged Kite
(c)	Black-eared Kite
(d)	Black Kite

- Can you think of a different common name for any of these kites? It could be in English or any other language. Choose a name that can help your friends identify the bird (even when it is in flight). Try a name that is not too long and not too hard to remember.

- Look for these birds in your own skies. Then record your observations in the table below.

	(a)	(b)	(c)	(d)
Have you seen this bird in your skies?				
When (which part of the day) have you seen this bird in the sky?				
How large is this bird? You could compare it with the size of a crow.				
How wide are its wings? You could compare it to the length of its body.				
How would you describe its flight to your friends?				
Have you seen this bird hunt or eat? What does it eat?				
How does it use its eyes, beak, and claws to hunt and eat?				
What other details did you observe about this bird?				

Sources for images:

Contributed by:
Chitra Ravi, who works at Azim Premji University, Bengaluru.

ACTIVITY SHEET II : MEET OTHER RAPTORS

Kites are raptors. Here are some things we know about raptors:

- They are diurnal birds that feed on other animals (their prey). Some hunt, catch, and kill their food. Others feed on dead animals. Some do both.
- The word 'raptor' comes from a Latin word that means 'to grasp or seize'. These birds have eight sharp claws (called talons), which they use to capture and secure their prey.
- Their hooked upper beaks allows them to tear into their prey.
- They have a strong sense of vision. They can see at least four times farther than we can. This helps them spot their prey even when they are soaring several thousand feet above the ground.
- Because of their looks and their feeding habits (they eat 'pests' or dead animals), people often think of these birds as unclean, fearsome, or disgusting.
- Their feeding habits help control the population of pests (like rats who eat up our crops and stored food) and clear up the bodies of dead animals (which when uncleared can cause the spread of disease).
- Droughts, our use of pesticides, and the loss of their habitats by human activity threaten the survival of these birds. Scientists treat a fall in their numbers as a warning about the health of the environment.

Kites are not the only raptors. Here are some other kinds seen in India:

(a) Indian Vultures:
Seen near open fields in villages and near garbage dumps in cities. Feed mostly on the bodies (carcasses) of dead animals, including cattle.

(b) Shikras:
Small birds that feed mostly on rats, mice, squirrels, other small birds, lizards, and insects in farmlands, cities, and forests.

(c) Indian Spotted Eagle:
Live in forests, wetlands, and grasslands. Very rarely seen in cities and towns. Feed mostly on small animals such as rats, frogs, lizards, small birds, and insects.

Observe:

Take a few minutes to look at the photographs of the different kinds of raptors. Then record your observations and findings in the table below.

Photographs	(a)	(b)	(c)
How would you describe its eyes?			
What is the colour of its beak? Is the beak thick or thin? How long is it? What is its shape? Does it look light or heavy?			
Can you see its feet? Are the talons long or short?			
Did you find any other features interesting?			
Have you seen this bird in your neighbourhood? If yes, where have you seen it? (For example, on an electric wire, flying high, sitting on a tree, on the ground, or the top of a building or hill)			
Does this bird have a local name? What do the elders in your community call it? What else do they know about it?			

Think about and discuss:

- A lot of birds are carnivorous. What makes the birds in this sheet different?
- Think about where these birds live and hunt. Can you guess how they are affected by changes in:
  (a) The amount of smoke and dust in the air?

  (b) How we manage our solid waste?

  (c) What we grow on our farms and how we take care of our farm animals?

  (d) The numbers and kinds of trees that grow near our homes and farms?
- Think about what these birds eat. What do you think would happen to them if their source of food disappears? Or if their food is poisoned by the chemicals we use to rid our fields and homes of pests (like insects, rats, and mice)? Or if these birds get injured and cannot hunt for food?
- Have you ever rescued or treated an injured animal? How did you take care of it? Where did you learn to take care of it? Did the animal survive? What did you do with it after it had recovered?

Sources for images:

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Contributed by:
Radha Gopalan, who is an environmental scientist with a PhD from the Indian Institute of Technology Bombay (IITB), Mumbai. After an 18-year career in environmental consulting, she taught Environmental Science at the Rishi Valley Education Centre, Andhra Pradesh. She is a Visiting Faculty at the School of Development, Azim Premji University, Bengaluru, and a member of the Kudali Intergenerational Learning Centre, Telangana.

Resource Review

ACTIVITY SHEETS I AND II

TEACHER'S GUIDE

- Activity Sheets I and II are designed as Environmental Science (EVS) projects for Grade III–V students. They can be connected to:
  - Unit 2 ('Life Around Us') of the Grade III EVS textbook (NCERT, 2024-2025). This unit invites teachers and students to enjoy observing the animals and plants around us: *"The more we watch them, the more we learn about their fascinating lives This curiosity drives us to explore further, discovering new and exciting things. Recognising and respecting the well-being of both plants and animals is essential for maintaining ecological balance and fostering a more compassionate society".*
  - Chapter 1 ('Super Senses') of the Grade V EVS textbook (NCERT, 2024-2025). In this chapter, children learn about the strong sense of sight that raptors have.
- Each activity can be done over 2-3 days. Each sheet has some tasks that can be done in the classroom and some that need to be done outside. Plan to allot three hours to the classroom tasks.
- For the classroom tasks:
  - Introduce the two activities by screening the film on a computer or mobile phone. If this is not possible, read the article titled 'All that Breathes: Why Raptors Matter' in this issue. Then briefly narrate the story of the kite 'carers' to your students.
  - Start each classroom session by giving students 5-10 minutes to observe the photographs of the four kinds of kites in Activity Sheet I and that of the other kinds of raptors in Activity Sheet II.
  - Share clear instructions for each activity. Remind students that they need to record their observations in the tables provided in each sheet.
  - Give students enough time to record their observations and answer the questions in each sheet. Facilitate a discussion based on students' observations and any questions they may have.
- For the tasks that can be done outside the class, encourage students to:
  - Work together if they live in the same neighbourhood.
  - Observe these birds carefully without disturbing or harming them. (You may want to draw your students' attention to the kinds of observations listed in the tables in the two sheets before assigning this task).
  - Talk to the elders in their community, listen carefully to what they tell them about these birds, and carefully record these details in their notebooks or activity sheets.
- Make a note of any student questions that have not been addressed during the class discussion. You could take these up later. Or assign them to your students to explore on their own and share their findings with the class.
- Encourage students to think about how interdependent all living beings are on each other and the environment that we are part of. By inviting students to observe their surroundings with attention and learn from the lived experience of their communities, we can help them develop care, empathy, and compassion even for beings that appear fearsome or disgusting to people.

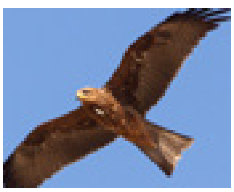
Contributed by:

Radha Gopalan, who is an environmental scientist with a PhD from the Indian Institute of Technology Bombay (IITB), Mumbai. After an 18-year career in environmental consulting, she taught Environmental Science at the Rishi Valley Education Centre, Andhra Pradesh. She is a Visiting Faculty at the School of Development, Azim Premji University, Bengaluru, and a member of the Kudali Intergenerational Learning Centre, Telangana.

views their work, Nadeem compares it to applying a band-aid to the huge gaping wound that is the city. He also confesses to wanting more from his life.

One feels vicarious relief when the brothers get formal approval to seek foreign funding to support their work and partake in the deep grief Saud feels when surrounded by the bodies of the birds they could not save. Showing how the brothers' spirits soar with hopes of expanding their work while wading through the murky waters of communal violence, pollution, and increasing bird mortality, the documentary does not search for a grand narrative or final judgement. Instead, it simply affirms the truth we can feel deep in our bones: *"Cheezon ki parvah isliye nahi kee jati kyunki unka desh, ya mazhab, ya politics aap jaisi hai. Zindagi khud ek tarah ki rishtedaari hai. Hum sab hawaa ke biraadari hain. Isliye hum pakshiyon ko chhod nahi sakte. (We don't care for things because they share our nation, religion, or politics. Life itself is a kind of kinship. We are all a community of air. That is why we cannot abandon the birds)".*

Key takeaways



- Through the story of three men rescuing and treating ailing and injured raptors in Delhi, the film 'All that Breathes' invites us to explore our interconnection with these carnivorous birds.
- It can be used to offer students at the preparatory stage a sensitive and empathetic introduction to the raptors in their own neighbourhood.
- By drawing attention to the role of raptors at landfills, the film can help students in the middle stage relate to the importance of these birds in maintaining healthy ecosystems.
- The film can also help students and teachers appreciate the diversity and interdependence of species.

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Notes:

1. Credits for the image used in the background of the article title: Black kite, Ron Knight, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Black_Kite_%28Milvus_migrans%29_%288079585185%29.jpg. License: CC-BY 2.0 Generic Deed.
2. This film review was first published in Ecological Matters (https://www.ecologicalcitizen.net/): https://www.ecologicalcitizen.net/pdfs/epub-092.pdf. The wording and structure of the version published here has been modified to align with our readership of middle school science and elementary school EVS teachers. These changes have been made with the author's permission.
3. To learn more about Saud, Nadeem, and Salik's work and contribute to it, visit: https://www.raptorrescue.org/.
4. To read more of Deborah Dutta's literary rambles, visit: https://linktr.ee/deborahdutta.
5. This article includes three detachable **Activity Sheet I: Kites in Your Skies, Activity Sheet II: Meet Other Raptors**, and **Teacher's Guide: Activity Sheets I & II**. The kites featured in Activity Sheet I are: (a) Black Kite, (b) Black-eared Kite, (c) Black-winged Kite, and (d) Brahminy Kite.

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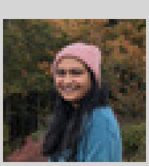

Deborah Dutta is currently a postdoctoral fellow at the University of Calgary, Canada, where she is exploring soil-based pedagogies to understand anti-colonial and transdisciplinary ways of 'knowing' from the sciences, mathematics, histories, and arts (see https://soilcamp.ca/). She has a PhD from the Homi Bhabha Centre for Science Education (HBCSE), Mumbai. Deborah enjoys collecting and sharing stories, seeds, and recipes.

WHY WAS PLUTO A PLANET FOR 76 YEARS?

MADHUKARA PUTTY & CHITRA RAVI

Until 2006, we thought of Pluto as the ninth planet in the solar system. Many of us learnt this 'fact' from our school textbooks. But our students learn that the solar system has only eight planets. Why did scientists believe Pluto was a planet for so long? Was this belief supported by any evidence?

Chapter 12 ('Beyond Earth') of the Grade VI science textbook (NCERT, 2024-2025) introduces students to the concept of a planet as being: *"...a large, nearly spherical object that revolves around the Sun"*. In the same chapter, students learn about the eight planets in the solar system. They also learn how an object that scientists believed to be the ninth planet of the solar system for nearly 76 years is now seen as a dwarf planet. According to the textbook, this change in Pluto's status happened when in 2006, *"the International Astronomical Union (IAU)... redefined the requirements of an object to be called a planet"*.[1] This brief description may leave curious students and teachers with questions like: What led scientists to believe Pluto was a planet? Was this belief supported by any evidence? The answer to this question is linked to the story of its discovery (see **Box 1**).

The search begins

By the early 19th century, the first seven planets of the solar system had been discovered.[2] But astronomers observed that the actual path (orbit) that Uranus took around the Sun did not match their predictions. What could be causing this difference? In 1841, the British astronomer John Couch Adams proposed that Uranus may be pulled from its predicted path around the Sun by another, yet to be discovered, planet in the solar system.[3]

In 1846, the French astronomer Urbain Le Verrier used mathematical calculations to predict the likely position of such a planet. He sent these details to the German astronomer Johann Gottfried Galle. On the night he received Verrier's letter, Galle and his student Heinrich Louis d'Arrest were able to locate this planet within a degree of its predicted position. This planet was named Neptune.[3]

Box 1. Connections to the curriculum:

Discussions around this story can help teachers meet two of the nine curricular goals that the National Curriculum Framework for School Education (NCF-SE) 2023 recommends for the middle stage (see **Teacher's Guide: Pluto in the Classroom**):

- CG-6: *"Explores the nature and processes of science through engaging with the evolution of scientific knowledge and conducting scientific inquiry"*. Specifically, it can help students develop the competency to: *"Illustrate how scientific knowledge and ideas have changed over time (description of motion of objects and planets, number of planets) and identify the scientific values that are inherent and common across the evolution of scientific knowledge (scientific temper, science as a collective endeavour…)"*.
- CG-9: *"Develops awareness of the most current discoveries, ideas, and frontiers in all areas of scientific knowledge in order to appreciate that Science is ever evolving and that there are still many unanswered questions"*.[4]

But observations of Neptune and calculations of its mass did not fully explain Uranus' deviations from its predicted orbit. In fact, Neptune's path around the Sun was also slightly different from what astronomers had predicted for it. Could these differences be caused by the presence of another object? In 1902, the wealthy American astronomer Percival Lowell proposed that this object was the ninth planet of the solar system. He called it 'Planet X' ('X' here is the English alphabet, not the Roman numeral).[5]

Lowell's Planet X

Born in 1855, Lowell was the son of a wealthy businessman. In 1876, he graduated from Harvard College, with a distinction in mathematics. In 1893, Lowell read a description of 'canals' on the surface of Mars in the book *'La planète Mars'* written by the French astronomer Camille Flammarion. His determination to explore these canals led Lowell to a career in astronomy.[6, 7] Within a year, he had used his personal wealth and influence to establish the Lowell Observatory at Flagstaff, Arizona, USA. It was here, in 1906, that he started a search for Planet X.

In the first phase of this search, Lowell, like Verrier, used mathematical calculations to identify the most likely position of the new planet. Astronomers at the Lowell Observatory used its 42-inch telescope to photograph these specific regions of the sky on different days. Lowell used a hand magnifier to painstakingly examine every inch of these photographic glass plates (see **Box 2**). By 1910, Lowell's team had taken close to 200 photographs and recorded the positions of thousands of stars. But had found no evidence for Planet X.

Lowell decided to change his approach. First, he hired a team of 'human computers'. Human computers were people, often women, who performed complex mathematical calculations. Led by the American astronomer Elizabeth Williams, this team's work allowed Lowell to more accurately predict regions of the sky where Planet X was likely to be found. Second, Lowell borrowed a 9-inch telescope from Sproul Observatory, Pennsylvania. He

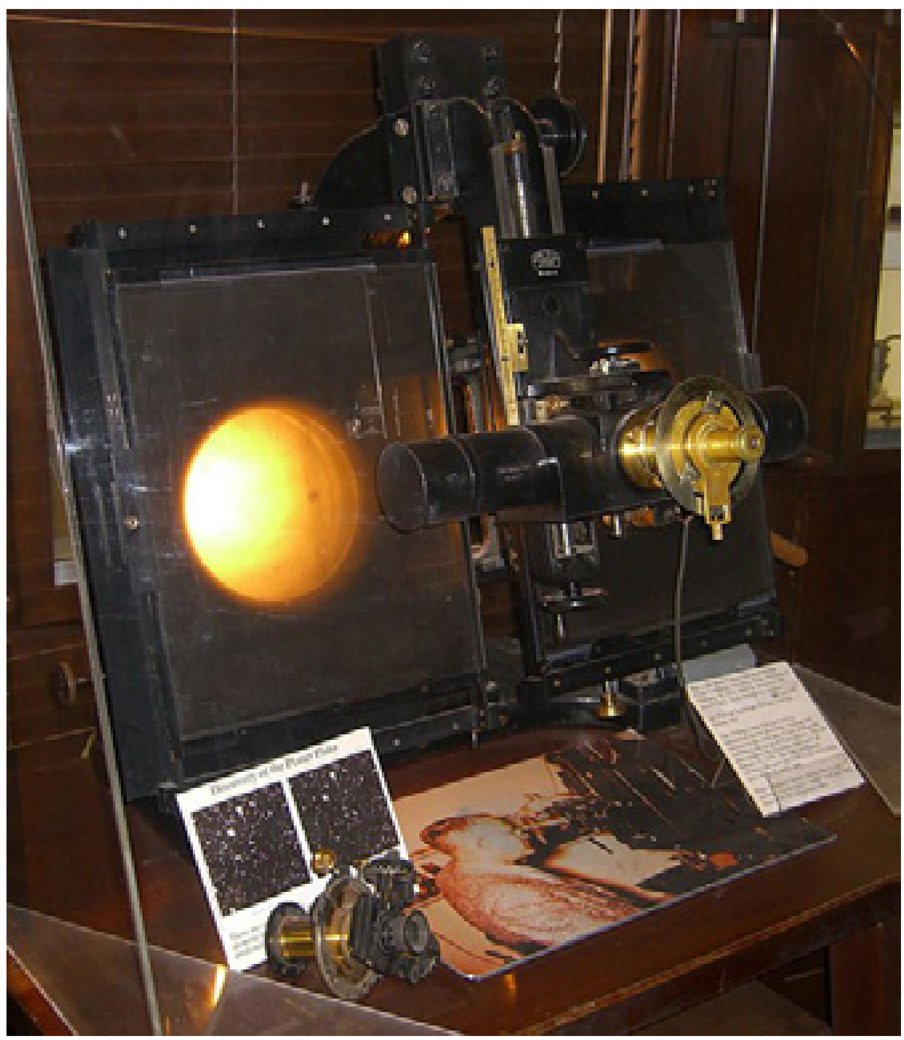

Fig. 1. A blink comparator. Lowell and Tombaugh sat in front of this instrument for hours, comparing photographs of the night sky for movements of Lowell's Planet X.

Box 2. What was Lowell looking for?

Lowell was examining photos of the night sky on different days to spot objects that had changed their position. Let us assume that he found such an object. How would he know it was a planet and not a star? Stars move too. The answer lies in the fact that our ability to spot distant objects in the sky depends on the the tools we use. Lowell may have counted on the possibility that the telescopes he was using to search for Planet X were powerful enough to capture the movement of another planet in our solar system. Even one he believed to be farther away from all the planets we knew of at the time. But these instruments were not powerful enough to capture the movement of stars, which are much farther away from us.

believed that the smaller telescope would be better suited to observing finer details of the night sky. Lastly, Lowell bought a specialized stereo microscope, popularly called a 'blink comparator' (see **Fig. 1**). This instrument allowed him to examine and compare two photographic plates one after the other in short order. This process was popularly called 'blinking' (see **Box 3**).

Box 3. What is a blink comparator?

How would you compare two images of the night sky to see if any objects in them had moved? You could do this by looking at each object in the first image and checking its position in the second image. This would likely be a slow process. Imagine you were doing this every day for months at a stretch with many images (like that of the night sky) and each image had many small and similar-looking objects! It would quickly get tiring. A blink comparator allows you to flip between two images very, very quickly. Our short-term memory of the two images allows us to spot differences between them much more easily.[8]

Early versions of this instrument could hold 6-inch x 7-inch plates. But Lowell's team found that viewing 14-inch x 17-inch plates would be better suited to their purpose. The American astronomer Carl Lampland, who was part of this team, modified the blink comparator to include slip frames that allowed Lowell to compare a quarter of the larger plates at a time.[5]

Lowell used this combined mathematical and observational approach to scan the night sky for Planet X till his sudden death from a stroke in 1916.[7] His wife contested his decision to leave most of his million-dollar estate to the observatory. This led to a long legal battle, during which the Lowell Observatory's search for Planet X was put on hold. In 1927, the litigation was resolved in the observatory's favour and the search for Planet X resumed.[7, 9] In 1929, the American astronomer Dr Vesto Slipher, the acting director of the observatory, assigned the task of finding Planet X to a 23-year-old man called Clyde Tombaugh.

Enter Tombaugh

Tombaugh was the son of a farmer. Born in the year Lowell started his search for Planet X, Tombaugh graduated from high school in 1925. He was unable to afford a college education. In 1924, Tombaugh read a magazine article titled 'The Drift of Jupiter's Markings' written by the amateur astronomer Latimer J Wilson. Fascinated by Wilson's drawings of the markings on the surface of Jupiter, Tombaugh wanted to see these features himself. So, in 1926, at the age of 20, Tombaugh built his first telescope with discarded car parts and farm machinery. Not satisfied with it, he spent the next two years honing the skill of building telescopes, grinding his own mirrors and lenses for them. In 1928, Tombaugh built a telescope that allowed him to observe markings on the surface of Jupiter and Mars (see **Fig. 2**). To control temperature and air flow, Tombaugh operated this telescope from a 24 feet long, 8 feet deep, and 7 feet wide pit that he dug himself. He sent detailed drawings of his observations to the Lowell Observatory.[10, 11] Impressed with his keen observation skills, Slipher offered Tombaugh a position with a three-month trial period.

At the observatory, Tombaugh began a systematic survey of the night sky. Learning from Lowell's efforts, Tombaugh would fit a 14-inch x 17-inch photographic plate in a powerful 13-inch telescopic camera and take long exposures of the night sky (see **Box 4**). He focused on observing regions where Lowell had predicted Planet X's presence. Often, he would need three hours to take one photo. He would then fix a fresh plate in the camera, focus on an adjacent region of the sky, and take another photo. Every few days, he would revisit the same regions of the sky and photograph them. In the day, he would develop the plates and use the blink comparator to compare photos of the same region.[5] Like Lowell, he would examine each inch of these photos for any tiny dot that had changed position. This was a tedious task and demanded extreme concentration. Every half hour, Tombaugh would take a short break by walking away from the comparator. The stakes were too high to afford any lapse in concentration.

By January 1930, Tombaugh had spent thousands of hours on the blink comparator and had scanned the positions of 15 lakh stars. He had observed many dots that had moved, but at speeds that suggested they were too close to Earth to be Planet X. Finally, on February 18, 1930, Tombaugh noticed a tiny object that was in different positions in the plates taken on January 23 and January 29. The image was too sharp to be that of a comet. Its speed was too slow to be that of an asteroid or space debris, but suggested that it was far enough from Earth to be beyond Neptune.[10, 12] This was just as Lowell had predicted.

Announcing the discovery of Planet X

When Tombaugh reported this observation to Slipher, the entire team at the Lowell Observatory became

Fig. 2. Clyde Tombaugh with his homemade 9-inch telescope. He ground the mirrors for it himself. He also built his own mount with part of the crankshaft from his father's 1910 Buick (a car model) and discarded parts of a cream separator (used on his family's farm). This was the telescope that allowed him to observe markings on the surface or Jupiter and Mars.

Box 4. Why did Tombaugh use long exposures?

Because he was taking photographs of the night sky. By choosing long exposures, Tombaugh was ensuring that the aperture of the camera remained open for as long as possible, letting in as much light as possible in an otherwise dim environment. This kind of exposure may also have been better suited to contrasting static objects with moving ones, although it may have caused moving objects to look blurred.

involved in checking if this object met Lowell's predictions for Planet X. Based on Lowell's calculations, the mass of this object would be seven times that of Earth and it would be at a mean distance of 43 astronomical units (AU) from the Sun. This is how Chapter 12 of the Grade VI textbook introduces this unit of distance: *"The distance of the Sun from the Earth is about 150 million km. A useful unit for expressing distances within the solar system is 'astronomical unit' (au) which is approximately the distance between the Sun and the Earth".*[1] Tombaugh took more images of the same region of the sky with his 13-inch telescope and the 24-inch telescope that Lowell had used to observe Mars. Based on his observations, Tombaugh estimated the mass of this object to be roughly the same as that of Earth. Lampland tried to a get a clearer image of the object by photographing it with the 42-inch telescope that Lowell had used in the first phase of his search. But its images remained faint and did not have the disc-like appearance that other planets had.[13] To determine its path around the Sun, Tombaugh and Lampland recorded its position every day till May 26. Since no one at the Lowell Observatory had any experience calculating planet orbitals, Slipher asked astronomers from other observatories for help in this task.[5]

Finally, on March 12, 1930, Slipher sent a telegram with details of this discovery to the Harvard College Observatory. Based on the evidence the team at the Lowell Observatory had so carefully collected, the discovery was announced on March 13. This would have been Lowell's 75th birthday. As news of this discovery spread, the Lowell Observatory received more than a thousand suggestions for names. The most popular choices were Minerva, Persephone, and Cronus.[9, 10] The name 'Pluto' (the Roman God of the underworld) was suggested by a 11-year-old called Venetia Phair. Her grandfather, Falconer Madan, loved the name and shared it with the Lowell Observatory through an astronomer friend.[14] When a vote was taken, this name received 150 nominations. The Lowell Observatory got this name approved by both the American Astronomical Society and the Royal Astronomical Society. By May 1, 1930, Planet X was officially known as Pluto.

PLUTO IN THE CLASSROOM

Chapter 1 ('The Wonderful World of Science') of the Grade VI science textbook (NCERT, 2024-2025) invites students to see science as: *"...a way of thinking, observing, and doing things to understand the world we live in and to uncover the secrets of the universe".* The story of the discovery of Pluto offers a concrete example of this process. Discussions around this story can help teachers meet two of the nine curricular goals that the National Curriculum Framework for School Education (NCF-SE) 2023 recommends for the middle stage:

1) CG-6: *"Explore the nature and processes of science through engaging with the evolution of scientific knowledge and conducting scientific inquiry".* Specifically, it can help students develop the competency to: *"Illustrate how scientific knowledge and ideas have changed over time (description of motion of objects and planets, number of planets) and identify the scientific values that are inherent and common across the evolution of scientific knowledge (scientific temper, science as a collective endeavour...)".*
2) CG-9: *"Develop awareness of the most current discoveries, ideas, and frontiers in all areas of scientific knowledge in order to appreciate that Science is ever evolving and that there are still many unanswered questions".*

In addition to the aspects highlighted in these curricular goals, I would like to briefly touch upon two more:

3) Students often think of experiments as being the only or the most important approach that scientists use to investigate the natural world. Is this reinforced by the fact that many science textbooks focus on experiments? Or because many of us call all hands-on experiences in the classroom 'experiments' rather than 'activities'? The story of the discovery of Pluto may illustrate how experiments may not always be possible to do in fields like astronomy. It could also introduce students to the role that speculation, mathematical calculations, and careful observation play in developing scientific knowledge. **Prompt for students:** If your students show interest in this aspect of science, you could encourage them to think of and discuss examples where using an experiment to answer a question in science may be unnecessary, insufficient, or even unethical.
4) The story of the discovery of Pluto illustrates how our perception of the natural world is linked to and aided by the tools we use to explore it. We would know very little about Pluto (as well as Uranus and Neptune) without the powerful telescopes that are part of this story. It may also be important to point out to students that the efforts of many generations of people were involved in designing, building, and refining these tools. **Prompt for students:** If your students show interest in this aspect of science, you could:
    a) Encourage them to think of and discuss an example of at least one tool that allows them to observe, measure, or analyse some phenomenon in their immediate world in more detail and with more accuracy. You could use some of these questions for the discussion: *What aspects of your world would be invisible, inaudible, or unclear to you if you did not have this tool? Are there things you could not have known for yourself without this tool?*
    b) You could also download the **Planet Discovery Activity** on blink comparators designed by Dr Erica from Rosie Research: https://bit.ly/3VJgm2S. Invite your students to try it out. Page 4 of this activity displays images of the actual slides that Tombaugh compared to discover Pluto. If your students are unable to spot Pluto on these slides, show them what Tombaugh spotted by displaying this image on your mobile phone: https://www.planetary.org/space-images/the-pluto-discovery-plates. You could use this question for the discussion: *How important is it to have tools that make an investigation less time consuming? What kind of explorations would require such tools?*

The fact that Pluto is no longer considered a planet is linked to all these aspects of the nature of science. Because it is so far away from us (34 times the distance between us and the Sun), it is very difficult to observe. We have seen how Tombaugh and Lampland used a range of telescopes of increasing resolution to photograph it. But their images remained dim and unclear. As our tools to observe Pluto have become more refined, our knowledge of it has changed, and our definition of a planet has become clearer. For example, the first planet-like image of Pluto came in the 1990s, after the launch of the Hubble Space Telescope. The more astronomers observed this object, the smaller it appeared. By 2006, its mass was estimated as being 0.2% that of the Earth. These changes in our understanding have led to its reclassification as a dwarf planet. Returning to Chapter 1 of the Grade VI science textbook, this aspect of the story can be used as an example of how: *"Science is like a giant and unending jigsaw puzzle... Sometimes, we find that a piece of this puzzle has been put in the wrong place and needs to be moved. New discoveries often change our understanding of the world".* **Prompt for students:** If your students show interest in this aspect of science, you could encourage them to think of 1-2 statements about any aspects of their own world that are well-supported by evidence. These statements could be very simple in nature. For example, students could say that the bell for their lunch break always rings at 12 pm. Or that a certain kind of tree in their neighbourhood only starts flowering in a certain month of the year. Write these statements on the board. Ask them to share evidence to support these statements. You could then ask: *What if you found new evidence? For example, Buransh or Rhododendron, the state tree of Uttarakhand, is known to flower in March and April. But it was seen to bloom in January this year. How would you respond to new evidence of this kind? Would you dismiss it? Or would you be open to revising your earlier statement? What factors would help you choose your response?* Use this discussion to share how 'facts' in science are reliable, yet open to revision.


(a)

Another reason this story may be important to tell in the science classroom is to ask students two questions that they may not ask you themselves, but are likely to think about a lot. Especially when they need to finish a lot of homework, prepare for examinations, or struggle with understanding a particularly abstract or complex concept in their textbook. The two questions are: *Why does science matter? Why do we study it?* This is how Chapter 1 of the Grade VI science textbook responds to these questions: *"As human beings, we have always been curious about our surroundings. We start exploring our surroundings and asking questions right from our childhood...science is all about joyful exploration. Enjoy your scientific journey, keep exploring and never stop wondering about the amazing mysteries of the universe and asking questions."* But many students may struggle to find opportunities to connect this curiosity and sense of joy with what they see in their textbooks. Some of our ways of teaching science may also play a role in this disconnection. In contrast, stories of discovery, like that of Pluto, can offer students many opportunities to relate to science as an exciting and creative pursuit rather than as a dry and uninteresting subject. Here are some aspects of this story that hooked our interest:

- Neptune was discovered within a degree of the position Verrier had predicted for it. And Galle spotted it on the same night that he received Verrier's prediction! **Prompt for students:** If your students show interest in this aspect of the story, invite them to imagine what influence the speed of this discovery may have had on Lowell's resolve to search for Planet X. Remind them that Lowell started his search for Pluto in 1906 and continued to search for it till his death ten years later. He used an approach that combined mathematical calculations (like Verrier) with observations of the night sky (like Galle). Yet, Lowell found no evidence for Pluto in his lifetime. You could use some of these questions for a discussion: *What does this tell us about the process of seeking answers* *for questions in science? What do you think may have helped Galle and Verrier? Was the search for Pluto harder to start with?*

- To refine his search for Planet X, Lowell needed the answer to two questions: Where in the night sky would he be most likely to find such an object? And how big an object should he be looking for in photographs of the night sky? Making these predictions required some very complex mathematical calculations. Astronomers today could use some very advanced computers to do this. But this was at a time when even calculators (like the arithmometer) were only able to handle much simpler calculations. So, Lowell hired a team of 'human' computers! These were people who made complex, long, and often tedious calculations by hand. These calculations were particularly important in astronomy and navigation. About 50% of human computers were women. Many men saw this as a dull unglamorous job. It required long hours of precise work that was rarely acknowledged. Many astronomers could pay women computers half of what they paid the men. Lowell's team of human computers was headed by Elizabeth Langdon Williams. She was among the earliest women to graduate (with a degree in physics) from the Massachusetts Institute of Technology (MIT), US. Both Lowell and Tombaugh used Williams' calculations in their search for Pluto. **Prompt for students:** If your students show interest in this aspect, you could ask them to search for more details about Williams. Or to come up with a list of other such women whose calculations contributed to important discoveries in science. Depending on their interest and the resources available to you, this could become a year-long project. It may be helpful to keep in mind that there are very few records of the contributions women made to science during this period. Searching for material and even the names of scientists who were women may be particularly difficult. If neither of these ideas are possible to explore in your context, you could use some of these questions for a class discussion: *How was Williams' contribution to the discovery of Pluto different from Verrier's contribution to the discovery of Neptune? Why do you think Williams' role in this story is rarely spoken about? Do you think the girls in your class have a better chance (than Williams) of becoming and being known as scientists?* Even as science teachers, this may be the first time some of us may be participating in or facilitating such a discussion. You may find the freely available recording of an i wonder...webinar (Feb 2024) titled 'Dorothy Andersen: An Unsung Hero' (https://www.youtube.com/watch?v=GkKhdz8Wbe8) helpful in preparing for your role in the discussion.

(b)

- Lowell used his personal wealth to build the Lowell Observatory (it was one of a kind at the time) and willed most of his estate to it! We can guess how important this aspect is from the fact that the search for Pluto was put on hold for a 11-year period when the observatory did not have access to Lowell's wealth. **Prompt for students:** If your students show interest in this aspect, you could ask them how this may be related to the nature of Lowell's search. You could use some of these questions for a discussion: *Can you think of some things an astronomer would need to answer such a question? Do all questions in science need this kind of financial support? Can you think of 1-2 questions that can be explored with simple, inexpensive, and easily available materials?* You could also connect it to the next aspect included in this list!

- Tombaugh was so determined to observe markings on the surface of Jupiter that he built his own telescopes from scratch. He ground his own mirrors and lenses for it. And used discarded automobile parts and farm equipment to build its mount. He had no formal training in any of this! **Prompt for students:** If your students have had the opportunity to 'make' a scientific model or instrument themselves, you could invite them to share their experience. Here are some questions you could use for this discussion: *What did you make? What kind of help did you need from your classmates and/or teacher? What did* *you use this instrument for? What did you learn from this experience? Did you enjoy it?* To offer students more of these opportunities, you could refer to the articles titled:

a) 'The Pedagogy of Making: Pinhole Camera' in this issue of i wonder… (Dec 2024). In this article, Shiv Pandey (a teacher) shares his experience of inviting students to construct their own pinhole cameras.

b) 'Doing Science without Labs' in this issue of i wonder… (Dec 2024). In this article, Satish Bhaskar (a teacher educator) shares his observations of how offering a space for '*jugaad* from junk' can encourage students to experiment with constructing new things using discarded objects.

c) 'Daytime Astronomy with Self-constructed Equipment' in the previous issue of i wonder… (Jun 2023). In this article, Prajval Shastri (an astronomer) shares how students can construct their own magic mirrors and mounted solar ball projectors to observe celestial objects in the daytime sky.

- Dr Slipher saw some of Tombaugh's drawings of Jupiter and offered him a chance to work as an astronomer at the Lowell Observatory. Tombaugh had completed only a high school degree at the time! **Prompt for students:** If your students show interest in this aspect, encourage them to record their observations of any object or feature in their immediate world by drawing it. Invite them to choose a subject that is related to something they are studying in science. You could use this question as a prompt: *What about this object or feature would be interesting to discuss in the science class?* Display their drawings in the class. Give each drawing a number. Allow your students enough time to view this display. Ask them to guess what object or feature is captured in each drawing. Then invite each student to present the subject of their drawing to the class. At the end of each sharing, ask how many students had guessed the subject of the drawing correctly. You could use some these questions for a discussion: *What would you need to see in a drawing to make a more accurate guess about its subject? Did any of the drawings help you see something that you had not noticed before? How easy or difficult did you find it to record your observations as drawings? Did it have any effect on what you observed or the way you observed it? How important do you think drawings are in science? What scientist-like skills could Dr Slipher have seen in Tombaugh's drawings?*

- Tombaugh first observed Pluto in February, 1930. This was the evidence that the Lowell Observatory had been seeking for about 24 years. The most immediate effect it had was that the entire staff at the observatory became involved in verifying this observation. They announced this discovery only about a month later! **Prompt for students:** If your students show interest in this aspect, ask them to imagine: *If you were in Tombaugh's shoes or on that team, what would that month have seemed like? Why was it so important to verify this observation? What do you think this process of verification involved? What if the team at the Lowell Observatory had reported this observation as soon as Tombaugh made it and it turned out to be wrong? We have seen that science is open to revision. How is this different from the kind of revision we spoke about?*

We wrote this story specifically for school teachers preparing to introduce their students to the solar system. While Pluto was seen as a planet for only 76 years, it has made a mark on many of us. It is likely that your students will question how matter-of-factly their textbook addresses this 'demotion.' We hope our telling of this story allows you to answer their questions without taking away from the wonder that this example of science as a human endeavour can inspire. We also invite you to choose parts of this story and ways of retelling it that you think will be most engaging to your students.

Curious about the images in this Guide? Here are some details:

Figure (a): Lowell using the 24-inch telescope at Lowell Observatory to observe the sky. Later, Tombaugh used this telescope to photograph Pluto. Both would likely sit in this position for hours. Credits: Lowell Observatory, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:Percival_Lowell_observing_Venus_from_the_Lowell_Observatory_in_1914.jpg. License: Public Domain.
Figure (b): Perhaps the only photograph we have of Elizabeth Langdon Williams. What about the other women on her team? Who were they? Credits: Lowell Observatory, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Elizabeth_Langdon_Williams.jpg. License: Public Domain.

Contributed by:
Chitra Ravi, who works at Azim Premji University, Bengaluru.

Key takeaways

- The presence of a ninth planet in the solar system was proposed when observations of Neptune could not explain differences between the predicted and observed orbitals of Uranus.
- The astronomer Percival Lowell started the search for this planet, which he called Planet X, in 1906 at the Lowell Observatory, Arizona, USA. Between 1906 and 1916, Lowell and his team developed a combined mathematical and observational approach to search for this planet in the night sky. They also refined the tools (telescopes and blink comparator) they used for this search.
- In 1929, Vesto Slipher from the Lowell Observatory resumed the search for this planet and assigned this task to Clyde Tombaugh, a gifted telescope builder and an amateur astronomer. In February 1930, using Lowell's methods and his tools, Tombaugh discovered an object that was planet-like in its movement and far enough from Earth to be beyond Neptune.
- In March 1930, the discovery of this planet was announced. The name 'Pluto' was suggested by a eleven-year-old called Venetia Phair.

Acknowledgments: The authors thank Hridaykant Dewan for emphasizing the need to present this story not as a collection of historical facts, but as a window to the process of science and scientific thinking. We thank Radha Gopalan for drawing our attention to excerpts related to the 'concept of a planet' and 'AU as a unit to measure distances in space' from the Grade VI science textbook (NCERT, 2024-2025).

Notes:

1. Credits for the image used in the background of the article title: Pluto, NASA, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:Pluto-01_Stern_03_Pluto_Color_TXT.jpg. License: CC-BY.
2. This article has one detachable classroom resource: **Teacher's Guide: Pluto in the Classroom**.

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Madhukara Putty works at Azim Premji University, Bengaluru. He can be contacted at: madhukara.putty@apu.edu.in.

Chitra Ravi works at Azim Premji University, Bengaluru. She can be contacted at: chitra.ravi@apu.edu.in.

DOING SCIENCE WITHOUT LABS

SATISH BHASKAR

Science labs can ignite curiosity in science, offer students the opportunity to develop their creativity and imagination, and give them a sense of what it means to think like a scientist. But some schools may not have the resources to set up labs. How can teachers in such schools create spaces that allow 'learning by doing'?

Often, our students learn science by memorizing textbook terms and definitions for exams. They may score well in these examinations, but not connect with these concepts outside the classroom. This is because science is not a bundle of information to be memorized. It is a living and dynamic process. Unless students **do** science, they may not understand this process or experience the fun of working like a scientist. According to the National Curriculum Framework for School Education (NCF-SE) 2023: "*The most important part of learning science is actually 'doing science' through hands-on experiential learning. 'Doing science' can range from trial and error, using materials around them, or using basic scientific instruments (measuring instruments), and laboratory apparatus. In this process, students gain conceptual understanding and develop capacities through manipulating, designing, and building experiments and demonstrations*". But how can students do science in schools with no labs? I share three ways in which teachers can address this challenge. These ideas are based on my experience of working for four years with students in upper primary government schools in Champawat, Uttarakhand.

A) Creative corner

This is ideal for students of Grade III and upwards. At this stage, the main aim of teaching is to nurture curiosity in children about the world around them. Put together a variety of easily available and inexpensive materials in a box and place the box on a table in the middle of the classroom (see **Table I**).

Share copies of books with ideas for simple experiments, preferably presented as pictures (see **Box 1**). Demonstrate some of these experiments in class. Invite your students to use the materials in the box and try out new things for themselves (see **Fig. 1**). Encourage group work and peer discussion.

S. No.	Material	Use	Quantity
1	Big empty box	To store all the materials	1
2	Table	To place the box of materials on. If unavailable, you can keep the box of materials in any corner of the class.	1
3	Mats	For children to sit on.	1
4	Small cardboard boxes	Place these in class. Invite students to write their questions on slips of paper and drop them into these boxes. Shake the box before asking students to take out a slip and read it aloud in class. Encourage students to respond to the question.	5
5	Nails	To display student work on the walls of the classroom. This should be done with the help of the teacher.	13
6	Fevicol/Glue stick	As adhesives in construction.	1-2
7	Ice cream sticks	To construct many things, like a whistle.	50
8	Old newspapers	To make paper mache figures and shapes.	1 kg
9	Drinking straws	To make sound and rotating toys.	1 pack
10	Balloons	To make toys and for simple experiments.	1 pack
11	Spool of thread	To make string telephones.	1 per student
12	Coffee cups	To make string telephones.	2 per student
13	Old bulbs	To make convex lenses.	4
14	Old CDs	To make CD hovercrafts.	5
15	Light emitting diodes	To light bulbs with potato batteries.	10
16	Copper wires	To light bulbs with potato batteries.	1 foot
17	Zinc strips	To light bulbs with potato batteries.	5

Table I. A list of materials that can be used to set up a creative corner.

Box 1. Recommended books for the creative corner:

1. Arvind Gupta. 'Apane Haath Ganit'. URL: https://www.arvindguptatoys.com/arvindgupta/h-apne-hath-ganit.pdf
2. Arvind Gupta. 'Little Science: Kabaad se Jugaad'. Published by Eklavya. URL: https://www.arvindguptatoys.com/arvindgupta/kabad-jugad-ag.pdf.
3. Arvind Gupta. 'Vigyan ka Maza'. Published by Pratham. URL: https://www.arvindguptatoys.com/arvindgupta/vigyan-maza-pratham.pdf.
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5. Arvind Gupta. 'The Toy Bag'. Published by Eklavya. URL: https://www.arvindguptatoys.com/arvindgupta/Toy_bag.pdf.
6. Arvind Gupta. 'Best of Arvind Gupta: Science Skills and Thrills'. Published by Rubin DCruz, Director, Kerala State Institute of Children's Literature. URL: https://www.arvindguptatoys.com/arvindgupta/skillsthrills.pdf.

Fig. 1. Children at work in a creative corner.

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B) Science corner

This is ideal for students in the middle stage (Grades VI-VIII). Make a list of materials required for the experiments listed in the textbooks for these grades. Collect as many of these materials as possible. Divide them into separate piles, with each pile being specific to experiments for a certain grade level. Put the materials from each pile into a transparent box, like the kind used to sell toffees in bulk. Label the boxes to indicate the appropriate grade level. This will make it easier for students to look for what they need. Rather than looking for a separate room to set up a lab, find a corner in your classroom which allows students the freedom to do these experiments (see **Fig. 2**). Preferably choose a location that can be used for this purpose for a long time. You can set up your lab by moving a table from the class to this corner.

Introduce the corner and its purpose to students. Making the best use of the science corner may need a change in your teaching methods. Rather than insisting that students memorize important principles, offer them the opportunity to reach these conclusions by doing their own experiments and learning through observation, discussion, and reflection. Encourage your students to bring material from the science corner to their tables to set up their experiments. Allow them to choose if they want to work by themselves, in pairs, or in small groups. Ensure that children are given the maximum opportunity to work with these materials, ask questions, discuss with peers, and learn for themselves. Ask questions that help them think more deeply about what they are doing and seeing.

Use the last few minutes of class to help students put back any unused material in the labelled boxes. Ask your students to record and share their experiences of the experiments they do. Encourage them to present some of their work as posters. Display these posters on the walls of the classroom. These can inspire your students, give them more confidence in their ability to think for themselves, and encourage more creativity.

C) *Jugaad* from junk

This is ideal for students in middle school and upwards. I am using the word '*jugaad*' to refer to innovation and the word 'junk' to refer to the many things that are discarded from our homes and schools. Choose a room in the school that your students can visit without hesitation. In one corner of the room, stock tools and materials like screwdrivers, hammers, springs, pulleys, radio making kits, old mobile phones, discarded radio and television sets, old wires, fused bulbs, old cells, etc. Encourage students to add to this stock any discarded materials from their homes and neighborhoods that are of interest to them.

It is important that this space be seen as an opportunity to nurture students' natural curiosity and help them take their bookish knowledge forward based on their own experiences. Allow them the freedom to touch and disassemble junk as well as build and experiment with the assembly of their own models. Working with discarded materials will give students the confidence to manipulate materials in different ways, even if some of the models they build do not work. In addition to inspiring the spirit of innovation, such a space can help expand environmental awareness as students begin to discover for themselves the many ways in which 'waste' can be reused.

Fig. 2. An example of a science corner in a school with no lab.

Parting thoughts

Teachers play a vital role in such 'lab' spaces:

(a) Students are drawn to these spaces by their curiosity. Teachers can inspire this by creating a learning environment where students ask a lot of questions about what they see and do in class. Rather than provide answers, encourage students to find these out for themselves.

(b) Students learn through practical experiences. Teachers can encourage this kind of learning by offering many opportunities for construction and experimentation. Allowing your students to observe and understand the concepts and mechanisms underlying their models and experiments gives them a natural sense of what it means to be a scientist.

(c) Students learn by communicating what they think and do. Teachers can invite them to present their work to their peers or the other children in school. Morning assemblies can be useful spaces for such presentations. For example, I saw two middle grade students show how they had made a drone from junk. Since it was fitted with a light motor, this model could fly to some height above the ground. In another instance, I saw two Grade V students demonstrate how they had constructed a scooter model with a paper cup. I have often seen younger children being given the chance to perform stories from their textbooks with puppets they had made themselves. Giving your students such opportunities can often increase their confidence in their own creativity.

While the teachers I worked with did not always find it easy to create and maintain such 'lab' spaces, the presence of such spaces in their schools have had many advantages. Initially, children would use the materials provided to them, wait to work with their teachers, and would need their teachers to be present for the entire process of experimentation or construction. But this changed over time. Students started bringing broken equipment from their own homes in the hope of investigating them or reusing their parts. They began to express interest in working on their own projects, like building a whistle or kaleidoscope (a tube with coloured glass pieces that displays colorful scenes when rotated). Sometimes, students would come up with ideas for projects that were not possible to do with the materials available to them. If this happened frequently, their teacher and I would plan a meeting with the students. These meetings were arranged after regular school hours. We would start each meeting by discussing what students wanted to make and what they would need for it. Their teacher and I would list the materials they needed on the black board and highlight materials that were unavailable in school. We would then explore and suggest sources from which these materials could be procured with minimal or no cost. Through these experiences, we discovered that most materials needed to make new things could be found in old things. This exercise encouraged students to think more creatively about materials in their own environment. Making such creative spaces in school led to changes outside science too. For example, young children often wanted to write their names on the models they had constructed. Students who did not know how to write asked their teachers for help. After a few months of observing how their teachers wrote their names, these students started doing so themselves (see **Fig. 3**). Many teachers noticed the eagerness with which children sought out these spaces as soon as they arrived at school. Other teachers reported more regular attendance from children who routinely absented themselves from school. Many of these children expressed a sense of anticipation and excitement for what they would get to do in these creative spaces. Some teachers spoke of how the freedom given to children to choose and do things on their own helped them cultivate a sense of responsibility. Overall, such 'lab' spaces can open countless opportunities for student learning—what you do with it is a matter of choice.

Fig. 3. Children felt a sense of ownership for their creations and were keen to write their names on their models.

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Key takeaways

- Unless students 'do' science, they may not understand its process or experience the fun of thinking and working like a scientist.
- Science teachers from schools with no labs can use inexpensive, locally available, or discarded materials to create and maintain grade-appropriate experiential learning spaces for their students. Rather than use an entire room, such spaces can be built in a corner of the classroom.
- To make the most effective use of such spaces, science teachers may need to try teaching methods that inspire curiosity and encourage practical experience. They may also need to give their students the opportunity to present their work to their peers and other children in school.

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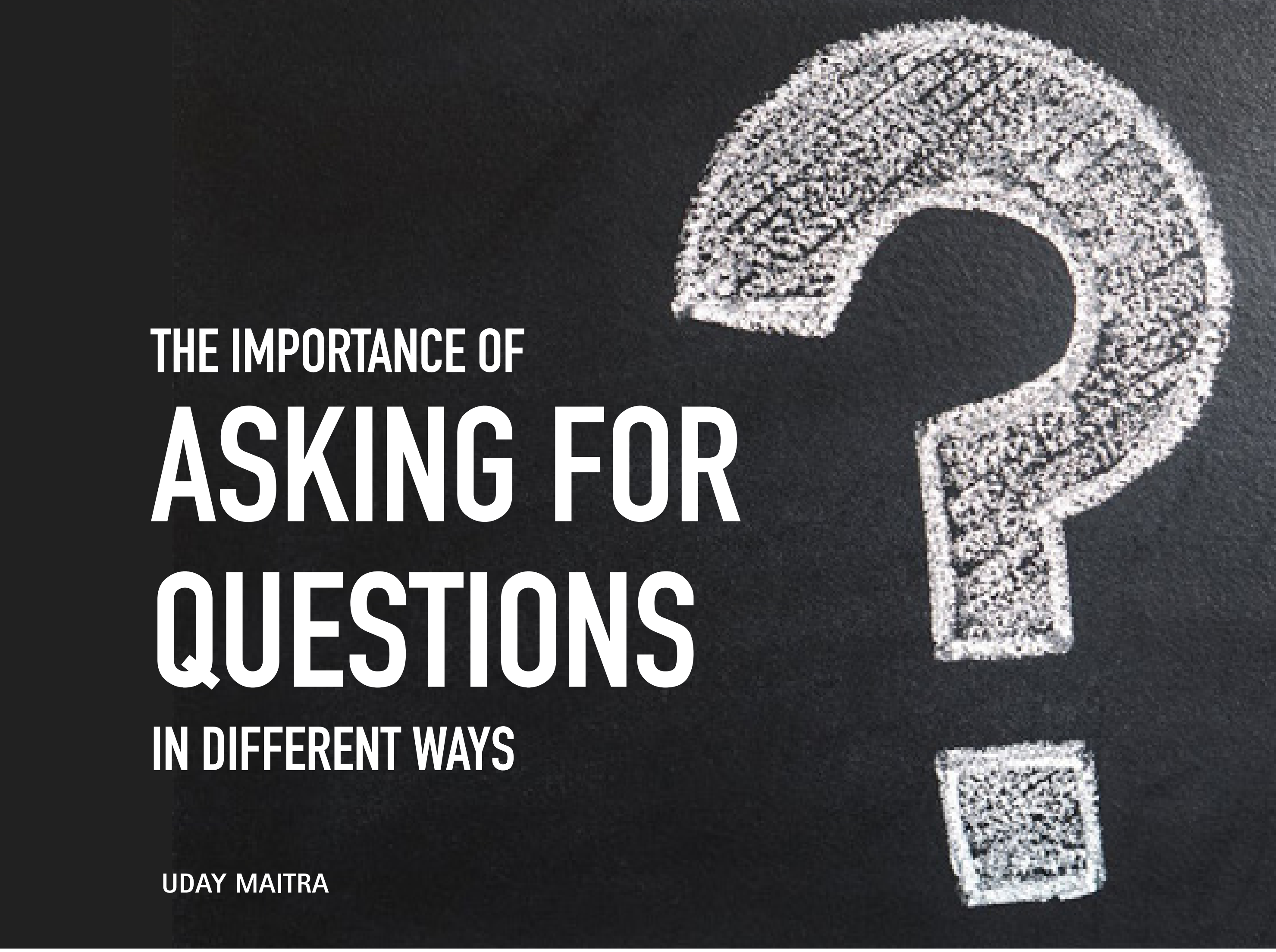
Notes: Credits for the image used in the background of the article title: Hands-on Learning Spaces, Satish Bhaskar. License: CC-BY-NC.

Satish Bhaskar works as a science resource person at Azim Premji Foundation. He joined the District Institute at Champawat, Uttarakhand, in 2014 and moved to the District Institute at Damoh, Madhya Pradesh, in 2022. Satish has a Masters in Biochemistry and a Bachelors in Education. He is passionate about encouraging creativity and innovation in science. He can be contacted at: satish.bhaskar@azimpremjifoundation.org.



THE IMPORTANCE OF ASKING FOR QUESTIONS IN DIFFERENT WAYS

UDAY MAITRA

Asking questions about the natural world is an important aspect of learning to think like a scientist. But our approach to classroom instruction and assessments is often designed to get students to answer our questions. How do we encourage our students to ask questions instead?

"The question is a central aspect of both learning and knowledge creation. Yet students often seem to value more the answer than the question… I think quite the opposite. The quest to answer a question is where the learning takes place, not the answer itself."—Richard Zare, Professor of Chemistry at Stanford University, USA.[1]

Our students spend a large fraction of their study time preparing to answer questions that appear in examinations. Does this time-consuming exercise lead to a better understanding of science? The simple answer is no! While it is almost obligatory to do well in examinations, it is more important for students to understand the subject well. This does not happen by just learning to answer examination questions. In fact, students should ask more questions than they answer.

The American physicist Isidor Isaac Rabi once shared: *"My mother made me a scientist without ever intending to. Every other Jewish mother in Brooklyn would ask her child after school: So? Did you learn anything today? But not my mother. "Izzy," she would say, "did you ask a good question today?" "That difference—asking good questions—made me become a scientist".*[2] Rabi received the Nobel Prize in Physics in 1944 for his discovery of Nuclear Magnetic Resonance (NMR). This non-invasive analytical technique has important applications in many fields, including chemistry, biology, and medicine.

The role of the science teacher

The National Curriculum Framework for School Education (NCF-SE) 2023 suggests that: "*The role of the Teacher in aligning pedagogy and assessment with how students learn Science is critical. Teachers must build an environment that* ***promotes natural curiosity, encourages questions,*** *gives maximum possible opportunities for hands-on activities, and gives ample* *space to discuss ideas*".[4] It recommends that teachers use pedagogical processes that simulate *"the process of science, such as asking questions"* and assess students for their ability to *"ask questions"* about the phenomena they observe.

I share three strategies that teachers can use at any level of science education. I use them in the course I teach at the Indian Institute of Science (IISc), Bengaluru, to encourage students to ask questions. They have also allowed me to assess my students' creative abilities.

I do not give routine homework to my students. Instead, every 2-3 weeks, I ask them to submit a single page of writing that includes a science question and its probable answer. Probable, because the answer to the question may not even be known. My conditions are that the question cannot be from any textbook or examination. Also, ideally, its answer should not be obvious from a reading of their textbook. Over the years, many students have told me that they enjoyed this type of homework, since it made them read and, most importantly, think. From a teacher's point of view, this approach has an additional advantage. Every student comes up with a different question since this task offers little scope for copying homework from one another.

I have attempted a variation of this in my assessments. In addition to standard questions, I include one with an image relevant to the topics covered in the assessment. The image can be a plot or a photograph. I ask students to share any two science questions one may ask by looking at the image (see **Activity Sheet: Asking Scientific Questions** and the related **Teacher's Guide**).

A third 'trick' that I frequently employ is to provide students with a question and its answer. I tell them that the answer may be correct, partially correct, or completely wrong. The student's task is to 'evaluate' the accuracy of the answer and assign marks to it. I also ask them to share reasons to support their evaluation. I assign marks to them by assessing the accuracy of their evaluation and reasoning. My students liked this form of assessment too, since it allowed them to use their judgment in a creative way.

Key takeaways

- Many of our assessments for students test their ability to answer our questions rather than ask their own questions.
- Learning to ask scientific questions about the natural world is an important aspect of thinking like a scientist. It allows students to go beyond the information in their textbooks and exercise their creativity.
- This article shares three tried-and-tested ways in which teachers can use assessments to help students develop and practice the skill to ask scientific questions.

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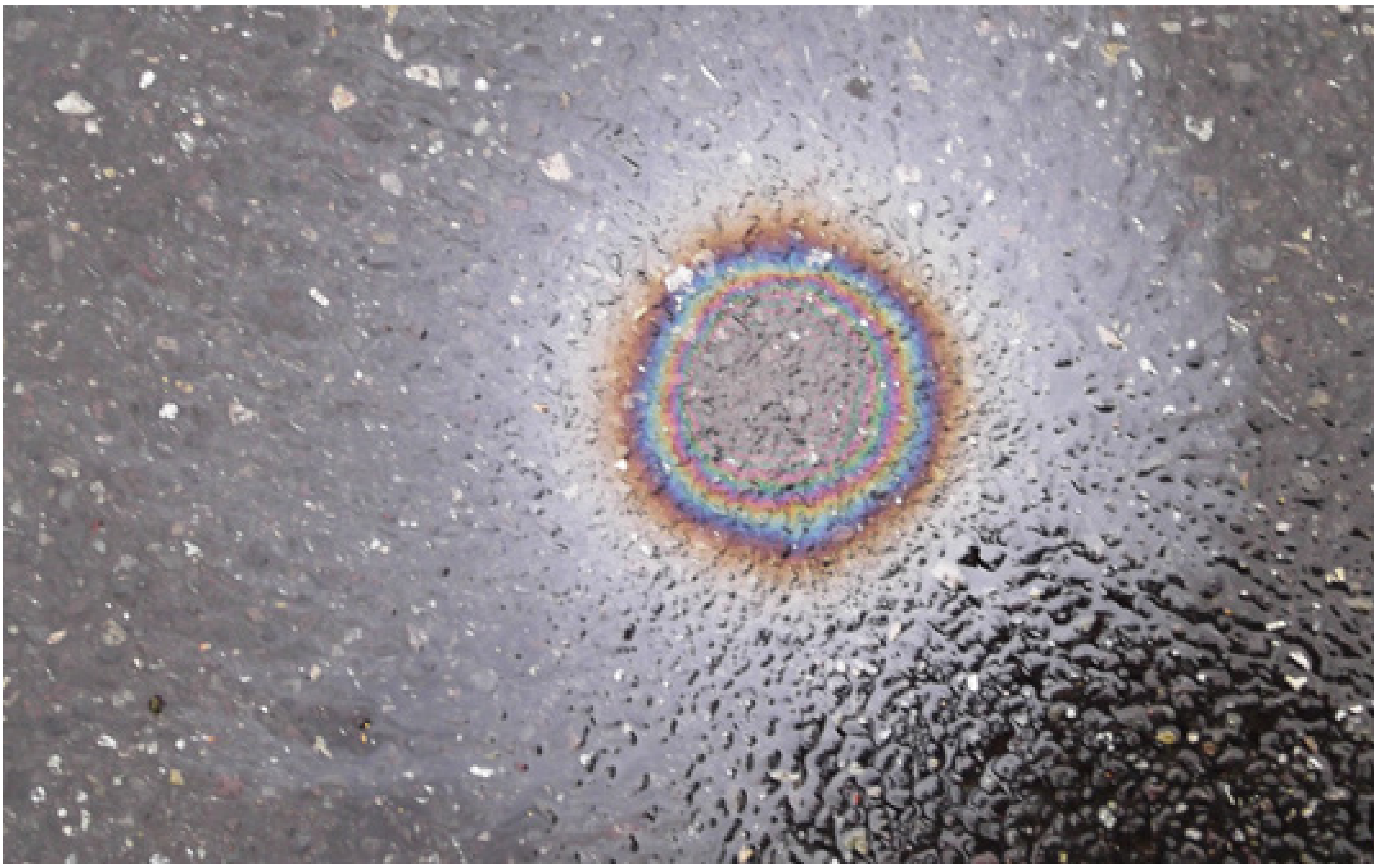
Notes:

1. Credits for the image used in the background of the article title: Questions, Pixabay. URL: https://www.pexels.com/photo/question-mark-on-chalkboard-356079/. License: CC0.
2. This article includes two detachable classroom resources: '**Activity Sheet: Asking Scientific Questions**' and a related '**Teacher's Guide**'.

ACTIVITY SHEET : ASKING SCIENTIFIC QUESTIONS

Aim:

You may have spent a lot of time remembering the answers to science questions in your textbook, class, or examinations. This can sometimes feel hard and boring. But did you know that **asking questions** about the natural world is a key part of what scientists do? This can be a lot of fun. Try it out for yourself.



Observe and record:

Take 5-10 minutes to look at the photograph above.

- What do you see in the photograph? How would you describe it to a friend who has not seen it? Try to describe as many details as you can. Point out anything about the photograph that is beautiful or interesting.

- Can you guess what you are seeing in the photograph? Have you seen something like this in your natural world? If yes, describe when and where you have seen it.

Think about and discuss:

A. Take a few minutes to think of three questions you think scientists are likely to ask about the phenomenon in the photograph. Write them down one below the other. Be as simple and direct as possible. Try and choose questions that:

- Are about a specific aspect of the phenomenon.
- Are not from a textbook or exam.
- You do not know the correct answer for yet.
- Are likely to make you (and your friends) **think**.
- You think will tell you something important about the phenomenon.

	Your questions
Q1	
Q2	
Q3	

B. Why do you think scientists are likely to ask these kinds of questions? What makes them different from other kinds of questions?

C. To the left of the Table below are some characteristics of scientific questions. To the right, are columns for your three questions: Q1, Q2, and Q3. Take a few minutes to fill the boxes to the right with a 'Yes', 'No', or 'Maybe'.

Characteristics	Q1	Q2	Q3
Can you guess the answer to your question? Your guess must be of the kind you think is likely to be accurate, but can be proven wrong. Try expressing this as an If...Then... statement.			
Can you test your answer by observations, measurements, and/or an experiment? This is your method. Try and choose a method that is most likely to show you if your guess is incorrect.			
If you tested your guess with the same method and under the same conditions on a different day, would you be likely to get the same result?			
Is your guess based on evidence that your friends can check for themselves? Are they likely to get the same answer if they tried your method under the same conditions?			

D. Did any of your questions get a 'Yes' in all three rows of the Table above? This is most likely to be a scientific question. Write this down below. If you got 3-4 yeses for more than one question, choose one that is most interesting to you. If none of your questions were of this kind, take a few minutes to think again. Can you come up with a more scientific question about the phenomenon in the photograph? (Remember: It takes practice to think like a scientist).

E. Can you think of a simple way of finding the answer to your question? Try and choose a method that:

- Can be done with simple, inexpensive materials, preferably ones you already have.
- Does not take too long to do.
- Is not too complicated.
- Is most likely to give you a clear answer to your question.

F. Discuss what you learnt about scientific questions with your friends.

- What parts of this exercise did you find easy? What parts did you find hard?
- What does your question tell you about the phenomenon in the photograph? For example, does it tell you something about the cause of the phenomenon? Or does it allow you to compare the effects of two factors on it?
- Many questions in science are one of three kinds: *What is this (phenomenon)? How does this work? How did it come to be this way?* Which kind is your question?
- Why is it important to ask scientific questions? Why do you think your question matters?

Source of the image used in this sheet:

i wonder... Rediscovering school science

Contributed by:
Chitra Ravi, who works at Azim Premji University, Bengaluru.

Your Notes

ASKING SCIENTIFIC QUESTIONS

1. This activity is designed to give students the opportunity to:
    - Construct scientific questions based on their own observations of real-world phenomena.
    - Refine their questions by thinking of how a scientist would try to answer them and test the validity of their answers.
    - Explore why scientific questions matter.
2. Adapted versions of this activity can be used for Grades VI, VII, VIII. Chapter 1 ('The Wonderful World of Science') of the Grade VI science textbook (NCERT, 2024-2025) asks students: "*How can we try to find answers to our questions on our own?*". You could use the exercise in this sheet as an extension to the three activities included in this chapter. But if you think your students may need more practice with this, you could invite them to attempt only Part A) of the **Think about and discuss** section. Rather than list 3 questions, encourage them to write all the questions they can think of. Grade VII students could be invited to try Parts A, B, and C of the sheet. Grade VIII students can work on the entire exercise.
3. Plan to allot 3 classes for the entire activity and assign homework after the first two classes.
4. The photograph displayed in the sheet is of the rainbow effect created by oil on water. I chose this prompt because it is something that children are likely to have seen in their real worlds. That it produces the colours they associate with rainbows in the sky often fascinates children and naturally inspires many questions.
    - You could use a different photograph. Or start the exercise by playing a video, bringing an actual object into the classroom, or giving a simple demonstration. If you use living organisms or combustible materials, it is important to take precautions to ensure that your prompt and your class are not at risk of being harmed during the exercise.
    - Your prompt could be related to a concept or topic you just finished teaching or plan to start teaching. I have sometimes started this exercise with something my students asked me a lot of questions about.
    - Preferably choose a prompt that is not specific to the science classroom. Bring the everyday world into the classroom. Doing this exercise with a prompt that children see as being ordinary and familiar in their everyday world can be particularly interesting. It can open them to the wonder of looking at such things with the freshness, attention, and curiosity that is at the heart of all discovery in science.
5. Start the first class by sharing the activity sheet with your students. Tell them that you will be displaying a prompt for them to observe (and handle). Invite them to observe it keenly and think of three questions. Then give students 5-10 minutes to look at and engage with the prompt. Emphasize the need to do this quietly and without distracting others.
    - If the prompt is not a living organism or something that could harm your students if poorly handled, allow them to touch and manipulate the prompt without feeling as if they are being assessed.
    - If the prompt is a living organism, share the need to observe it without stressing or harming it. If it is something that could harm them if poorly handled, share precautions that may be necessary for them to take. In these cases, allow your students to observe the prompt at close quarters only under your supervision.
6. Give students at least 20 minutes to fill out the **Observe and record** section of the Activity Sheet. Then invite them to share their observations. Write these down on the board. Where

necessary, ask students more questions to make these observations as accurate and specific as possible.

7. Assign parts A and B from the **Think about and discuss** sections as homework. Very briefly, tell your students what they are expected to do. Answer any questions they may have about the task without using examples specific to the prompt.
8. Start the second class by asking students to take 5 minutes to look through their questions and make any changes to them. Invite them to share their responses to part B: What kinds of questions do they think scientists are likely to ask? Do such questions have any common characteristics? You could take a student's help in recording their answers on the board. Take 10 minutes to discuss these responses.
9. Draw the table in part C from the **Think about and discuss** section on the board. Discuss what the four characteristics mean. It is possible that your students may have guessed some of these characteristics themselves. Highlight such connections in class. Encourage students to ask questions and clarify their doubts, but try to not give them examples that relate directly to the prompt that you use for this activity. Then assign parts C, D & E from the **Think about and discuss** section as homework.
10. Start the third class by inviting 1-2 students to share their work. Give each student 5 minutes for their presentation. Encourage the other students to respond to the presentation with questions and suggestions before offering your own. Draw attention to the four criteria listed in part E of the **Think about and discuss** section. Where necessary, ask students to think of a different material or a simpler process.
11. Ask students to submit their responses to the **Activity Sheet**. Then open the class to discussions around the exercise. Use the questions in part F as prompts for the discussion. Close the class by reminding students that asking scientific questions is an important part of what scientists do. But asking such questions requires practice. Encourage them to keep practicing.
12. If you think your students have enjoyed the exercise, you could suggest that they keep a small notebook to record any scientific questions they think of. Or you could invite students to write their questions on slips of paper and drop these into an empty box. Once a week, you could start your class by choosing a slip from the box and reading out its question. Rather than answering the question, discuss it with your students. Some of these prompts can help:
    - Is this a scientific question? How do we know?
    - Can this be refined to become a scientific question?
    - How would you find an answer for it?

Contributed by:
Chitra Ravi, who works at Azim Premji University, Bengaluru

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Uday Maitra is an Honorary Professor and INSA Senior Scientist in the Department of Organic Chemistry at the Indian Institute of Science (IISc), Bengaluru. He can be contacted at: maitra@iisc.ac.in.

PERSPECTIVES

THE NCF-SE IN CLASSROOM INSTRUCTION

RAKESH TEWARY & VINAY SURAM

How can practicing school science teachers integrate the abstract and broad aims of education described in the NEP 2020 with what they teach in class? What role does the NCF-SE have in guiding teachers in their design of instructional and assessment strategies?

Drawing from the vision of society in the Constitution of India, the NEP 2020 states that the vision and purpose of: *"...the education system is to develop good human beings capable of rational thought and action, possessing compassion and empathy, courage and resilience, scientific temper, and creative imagination, with sound ethical moorings and values. It aims at producing engaged, productive, and contributing citizens for building an equitable, inclusive, and plural society as envisaged by our Constitution"*.[1] While extremely relevant, this vision of education may appear quite abstract to school science teachers in the context of their classroom instruction. It may raise questions like: How can the topics included in the school science syllabus help fulfil this purpose? How can this vision guide a science teacher's approach to classroom instruction?

It is in response to such questions that the National Curriculum Framework for School Education (NCF-SE) 2023 offers the Learning Standards Framework (see **Fig. 1**). This framework is aimed at guiding teachers in the process of designing and facilitating learning experiences that convert the abstract overall aims of education into concrete classroom practices.

Learning standards for science at the middle stage

(a) Curricular aims for school science: According to the NCF-SE, the aim of science education at the school level is to: "*...develop an understanding of the natural and physical world through systematic inquiry. Learning science also builds process skills such as observation, analysis, and inference. This in turn enables the meaningful participation of individuals in society and the world of work with scientific temper, critical and evidence-based thinking, asking relevant questions, analysing practices and norms,*

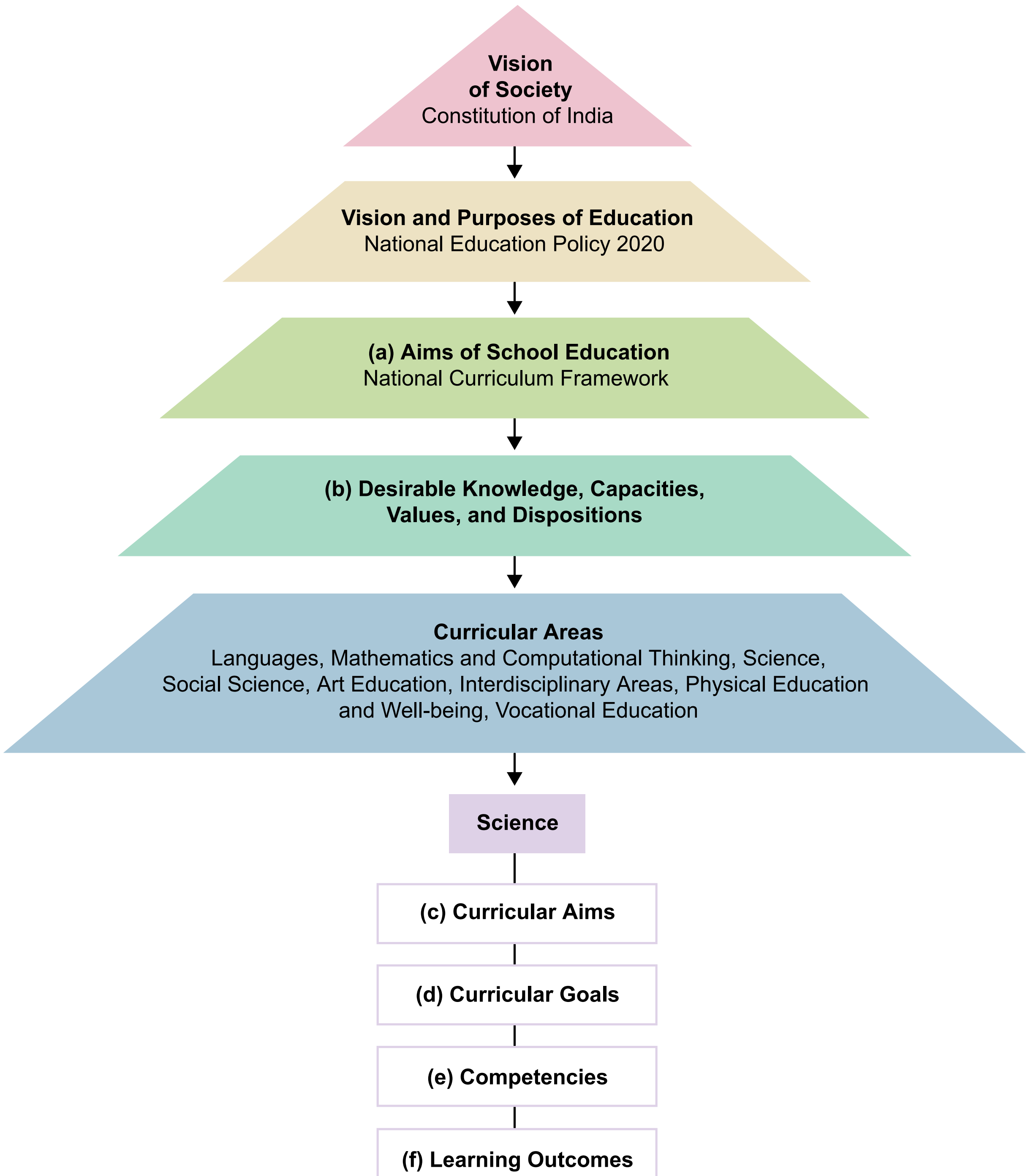

Fig. 1. Components of the Learning Standards Framework in the NCF-SE. (a) Aims of school education: Shaped by the vision for education in the NEP 2020, this section of the NCF-SE suggests that school education must support rational thought and independent thinking, health and well-being, democratic and community participation, economic participation, and cultural participation. These five aims are expressed as educational vision statements that give broad direction to all deliberate efforts (including curriculum development, institutional arrangements, funding and financing, and people's capacities) in school education. **(b) Knowledge, capacities, values, and dispositions:** This section of the NCF-SE outlines relevant and appropriate knowledge, capacities, values, and dispositions that students must develop to meet the aims of school education. **(c) Curricular Aims:** This section of the NCF-SE connects the aims of school education to aims specific to each of eight curricular areas. **(d) Curricular goals:** This section of the NCF-SE shares statements that guide stage-specific (foundational, preparatory, middle, and secondary) curricular arrangements necessary to meet the curricular aims. **(e) Competencies:** This section of the NCF-SE shares a set of learning achievements that students are expected to attain towards meeting each curricular goal. **(f) Learning Outcomes:** While the competencies listed in the NCF-SE are intended to guide student achievements in the middle stage, learning outcomes are interim grade-wise markers of each competency. Teachers can use these to plan their content, pedagogy, and assessments. They can also use them to observe and track student learning as well as respond to their needs on a continual basis.

Credits: Adapted from the NCF-SE 2023, NCERT.

and acting for necessary change".[2] This emphasizes the need for science to be introduced to school students not just as a body of factual knowledge, but also as the means to construct and use such knowledge. Elaborating on their use of this knowledge, the NCF-SE states that: "*Good education in science, including the development of a mindset of inquiry and research in students, is critical in addressing the challenges that India and the world face today, such as climate change, improving healthcare, technological advancement and use for sustainable development, creation of just and equitable livelihoods, and living in harmony with nature. This would help students to gain an understanding of how science and scientific research can address the central challenges faced by our society*".[2]

(b) Curricular goals for science at the middle stage: According to the NCF-SE, the science curriculum for Grades VI-VIII must allow students to:

- CG-1: Explore the world of matter and its constituents, properties, and behaviour.
- CG-2: Explore the physical world in scientific and mathematical terms.
- CG-3: Explore the living world in scientific terms.
- CG-4: Understand the components of health, hygiene, and wellbeing.
- CG-5: Understand the interface of Science, Technology, and Society.
- CG-6: Explore the nature and processes of science through engaging with the evolution of scientific knowledge and conducting scientific inquiry.
- CG-7: Communicate questions, observations, and conclusions related to science.
- CG-8: Understand and appreciate the contribution of India through history and the present times to the overall field of science, including the disciplines that constitute it.
- CG-9: Develop awareness of the most current discoveries, ideas, and frontiers in all areas of scientific knowledge in order to appreciate that science is ever evolving and that there are still many unanswered questions.[2]

(c) Competencies for each curricular goal: The NCF-SE breaks down each curricular goal into a set of competencies to be achieved (see **Table I**). Together, they show teachers how to meet a related curricular goal. Science teachers can use them to map student progression in conceptual understanding and process capacities. Competencies are also helpful in laying out boundaries for conceptual discussion at each stage of learning.

(d) Learning outcomes for each competency: Each competency in the learning standards for school science can be broken down into more granular milestones (see **Table II**).

These interim markers can be used to arrive at a progression of grade-specific learning outcomes (see **Table III**).

Learning outcomes and classroom practice

The attainment of grade-specific learning outcomes is not restricted to mere reciprocation of factual knowledge. It involves the development of the process skills required to achieve a certain competency. It is from this perspective that learning outcomes can guide the classroom practice of science teachers in multiple ways:

- Learning outcomes can help a science teacher choose the focus of classroom instruction and scope of discussion for each year of middle school. Each learning outcome is also carefully constructed to help teachers choose appropriate pedagogical practices to achieve it. For example, the expectation that a learner is able to measure any change in the position of an object points to the need for an instructional strategy that gives students a hands-on experience of making such measurements themselves. Teachers can choose from a variety of context-specific pedagogical practices to achieve this outcome. For example, they could invite learners to measure the length of a running track in the school grounds, the distance covered by a marble rolled on the floor, or the number of steps needed to reach home from school. Similarly, for students to be able to measure time, teachers could ask students to

Curricular Goal (CG)	Desired Competencies
CG-2: Explore the physical world in scientific and mathematical terms.	C-2.1: Describes one-dimensional motion (uniform, non-uniform, horizontal, and vertical) using physical measurements (position, speed, and changes in speed) through mathematical and diagrammatic representations.
	C-2.2 Describes how electricity works through manipulating different elements in simple circuits and demonstrates the heating and magnetic effects of electricity.
	C-2.3 Describes the properties of a magnet (natural and artificial; Earth as a magnet).
	C-2.4 Demonstrates rectilinear propagation of light from different sources (natural, artificial, and reflecting surfaces), verifies the laws of reflection through manipulation of light sources and objects and the use of apparatus and artefacts (such as plane and curved mirrors, pinhole camera, kaleidoscope, and periscope).
	C-2.5 Observes and identifies celestial objects (stars, planets, natural and artificial satellites, constellations, and comets) in the night sky using a simple telescope and images/photographs, and explains their role in navigation, calendars, and other phenomena (phases of the moon, eclipse, and life on earth).

Table I. The set of competencies students need to develop to achieve CG-2.[2]

Desired Competency	Interim Markers of Achievement
C-2.1: Describes one-dimensional motion (uniform, non-uniform, horizontal, and vertical) using physical measurements (position, speed, and changes in speed) through mathematical and diagrammatic representations.	Identify and measure the physical quantities (position with respect to a reference and time) required to describe motion.
	Use appropriate instruments and units to measure these quantities (for example, measure change in the position and time of moving objects and use these to calculate speed).
	Trace the journey of the various units used to measure these quantities (for example, explore locally used units and progress from such units to the SI units used today).
	Collect data and represent it in various formats (for example, collect position-time data and represent it in pictorial format or a tabular column).
	Draw inferences from the data (for example, use it to infer if an object is at rest, how fast it is moving, if it is moving at a constant speed, whether it shows uniform or non-uniform motion, etc.).
	Use mathematical expressions to calculate, explain, and predict the motion of an object.
	Apply relevant concepts to make models of instruments to measure length or a fixed duration of time (like a sand clock or a seconds pendulum).

Table II. Potential interim markers in achieving C-2.1.

Grade	Grade-specific Learning Outcomes
VI	Describe the position of an object in relation to a reference and record changes in its position; learn how distances have been traditionally measured in the learner's context and the basis of these measurements; explore standard instruments and units to measure distance; handle and construct models of different instruments to measure length; and extend the discussion on distance to other quantities required to describe motion.
VII	Measure time; handle and construct instruments and units to measure time; collect the position-time data of different objects in motion and present it as a graph; calculate (average) speed and arrive at its mathematical formula.
VIII	Infer if the motion of an object is uniform or non-uniform by reducing time intervals; predict the position of the object mathematically; and use this knowledge appropriately in different contexts.

Table III. An example of the progression of grade-specific learning outcomes.

measure the time it takes to walk from home to school.

- Learning outcomes can also guide teachers in designing assessments to determine what knowledge and process skills students have learned. For example, teachers could ask learners to design a strategy to measure the height of the school building. Responses to this task could be used to assess if the learner is able to extend the idea of measuring distances discussed in the classroom to real-world contexts. Teachers could also design assessment tasks that provide information of students' attainment of more than one learning outcome (see **Box 1**). Extending the assessment of learning outcomes across each grade to the end of the middle stage would provide information on the attainment of a competency. Similarly, information regarding the attainment of a set of competencies would indicate if a certain curricular goal has been achieved.

To make effective use of the learning standards framework in their classroom practice, teachers need to have an overall idea of each topic (of 'motion' for example) in the middle school curriculum, capacities students need to develop at the end of this stage, and how the attainment of outcomes

Box 1. An example of an assessment to measure the attainment of multiple learning outcomes related to motion:

Consider giving students the following assessment task: *Who walks the fastest in your family? Support your answer with a valid argument.*

A student working on this task is expected to record the position-time data of different family members and calculate their speeds using the related mathematical expression. They are also expected to come up with a design to approach this task. While both these requirements may seem simple, students will need to demonstrate both factual knowledge of related concepts and certain process skills to achieve them. For example, they will need to determine the time it takes for each family member to walk a certain distance. Teachers can assess:

- How students fix the optimum distance for this exercise.
- How they mark the fixed distance (which would involve proper handling of instruments).
- How they arrive at a format to record their observations after finalizing the number of quantities to be measured and the number of trials.
- How they compare the calculated values of speed for each family member to determine which member walks the fastest.
- If they represent their conclusion in an understandable manner.

This could be further extended to ask students to determine if their family members showed uniform or non-uniform motion during the task. To do this, students would need to measure position-time data along the walking track they have marked for the task.

needs to progress across stages. For example, learning to collect and use data to infer changes in the motion of an object in the middle stage would help students learn how to represent this data graphically at later stages.

Parting thoughts

The NCF-SE provides a structured approach for science teachers to design and facilitate classroom processes that help achieve the overall aims of education. We have shared how this framework could be applied to 'Motion in one dimension' to ensure that students not only understand key concepts, but also develop the skills and knowledge necessary to apply them effectively. But this framework can be used to teach any other topic in science. Not only does it outline clearly defined curricular goals for science at the middle stage, it offers guidance on the process of organizing content across grades in a logical sequence, integrating competencies, emphasizing their real-world applications, and aligning teaching strategies and assessments with overall learning standards. By establishing connections between the abstract larger aims of education and the granular learning outcomes for each topic in the middle school science curriculum, the NCF-SE also emphasizes the necessity of looking at aims and outcomes in continuity and simultaneity.

Key takeaways

- The NCF-SE provides a framework that supports teachers in developing instructional strategies that break down complex scientific concepts into manageable learning goals. By connecting each step with broader educational objectives, teachers can create a classroom environment that fosters deep understanding and continuous learning.
- Using the example of 'motion in one dimension', the article illustrates how teachers can guide students from mastering basic measurements to more advanced skills like data analysis. This structured progression offers a clear step-by-step approach to help students grasp complex topics by aligning each learning stage with specific educational goals.
- Teachers are encouraged to design assessments that go beyond simple recall to focus on evaluating process skills like planning and data analysis. These assessments need to be thoughtfully crafted to ensure that students meet their grade-specific learning outcomes while also providing insights into their grasp of concepts and practical skills.

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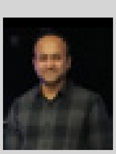
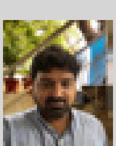


Rakesh Tewary has been with Azim Premji Foundation since May 2009, bringing grassroot experience as a science resource person, including hands-on work with government school science teachers. Currently, he leads field efforts in education, health, and livelihoods in Jharkhand. He can be reached at: rakesh.tewary@azimpremjifoundation.org.



Vinay Suram works as a resource person at Azim Premji Foundation, Bengaluru. In this role, he collaborates with government school teachers to make science education more hands-on and engaging for students. He also develops instructional modules to simplify complex scientific concepts and allow teachers to bring these concepts to life in their classrooms. Vinay has a master's degree in physics from Indian Institute of Technology Roorkee (IIT Roorkee), Uttarakhand. He is interested in the history and philosophy of science and in exploring approaches to improve science education. You can reach him at: vinay.suram@azimpremjifoundation.org.

OBSERVING NEIGHBOURHOOD BIRDS: THE MEDITATING HERON

HEMAL NAIK

Storytelling can be an effective and engaging way of teaching scientific concepts. Can we use this story of a farmer and a heron to invite students to observe birds in their neighbourhood with more attention? How do we use it to explore local connections between biodiversity and livelihoods?

I am a farmer. I live in Bumthang Valley, in the heart of Bhutan. Bumthang valley is known for its scenic views and vast green forests. One could sit here for hours admiring the beauty of its mountains, river, birds, and endless spark of life.

I go fishing regularly. The fish I catch supports my livelihood. I choose quiet spots by the river, away from other anglers. This helps me get a good catch. I am also able to enjoy the natural surroundings in silence.

My favourite fishing spot is five kilometres from my village, south of the temple at the village square. I follow a path that leads into the forest and then opens out to the riverbed. Then I walk for about three kilometres along the riverbed.

I know this spot by the pattern of its rocks. They make comfortable perches. I choose to sit on one that lies in the shade of a giant Ficus tree: My friend and protector from the sun and rain.

I am seldom alone when I fish. I share this spot with a stranger who fishes on the other side of the river. It is a heron.

Whenever I come here, it is here as well. This may be a coincidence. We are aware of each other, but go about our own business. I never try to interact with or feed it. It has never approached me.

I have seen the heron countless times. It stands for hours by the river, without moving. Without changing its position (see **Fig. 1**). Waiting for fish. Perhaps conserving its energy. In my head, I call it 'The Meditating Heron.' One day, I will tell my kids about it.

I admire its fishing routine. I can tell when it spots the movement of fish in the water. It becomes very alert and moves with precision towards its prey. Sometimes, it is very quick. I wonder how it appears to the fish it is after. Imagine a pair of giant chopsticks moving towards you at full speed!

Fig. 1. Can you spot the meditating heron?
Credits: Hemal Naik. License: Copyright owned by Hemal Naik. Used here with his permission.

At other times, I see it creeping in slow motion towards a particular spot in the river. Trying to get close enough to it without startling any fish that might be there. Once it is close enough, it moves quickly, using its beak to latch onto its thrashing prey.

But the heron is not always successful. Sometimes, it misses its mark and the fish escape. At other times, it does not spot any fish. It is not the only one to struggle. I too am finding it hard to get a good catch. The glaciers in the mountains are melting too rapidly. The flow of the river is getting much stronger than it has ever been. The fishing upstream has increased. The areas around the riverbank are changing.

Often, we wait for hours for fish to appear. I watch how calmly and patiently the heron waits. I try to do the same.

Box 1. Connections to the curriculum:

This story can offer many ways of connecting what students learn about the living world in textbooks for Environmental Studies (EVS) in the preparatory stage (Grades III-V) and science in the middle stage (Grades VI-VIII) with their real worlds (see **Activity Sheet I: Observe Fishing Birds, Activity Sheet II: Document Changes in Neighbourhood Birds**, **Teacher's Guide: Activity Sheets I & II**, **Activity Sheet III: Invite Birds to a Bird Bath**, and **Teacher's Guide: Activity Sheet III**). It can also offer a gentle and non-prescriptive way of meeting what the National Education Policy (NEP) 2020 describes as the aim of school education: "*The purpose of the education system is to develop good human beings capable of rational thought and action, **possessing compassion and empathy**, courage and resilience, scientific temper and creative imagination, **with sound ethical moorings and values***".[1] Teachers could use it to build what the National Curriculum Framework for School Education (NCF-SE) 2023 describes as a capacity for social engagement, including its affective aspects: *"Empathy and compassion are not only values or dispositions; these are capacities that are developed through deliberate practice"*.[1] Specifically, activities and discussions around this story can be used to meet the following curricular goals listed in the NCF-SE 2023 for:

(A) The preparatory stage:

- CG-2: (The student) understands the interdependence in their environment through observation and experiences, developing the basis for appreciation of the idea of '*Vasudhaiva Kutumbakam*'. Specifically, it can help students develop the competency to: *"Connect changes in the environment and the lives of their family and community, as communicated by elders and through local stories (changes in occupation, food habits, resources, celebrations, communication)"*.
- CG-4: (The student) develops sensitivity towards the social and natural environment. Specifically, it can help students develop the competency to: *"Identify needs of plants, birds, and animals, and how they can be supported (water, soil, food, care)"*.[1]

(B) The middle stage: CG-3: Explores the living world in scientific terms. It can help students develop and exercise the following competencies:

- *"Describe the diversity of living things observed in the natural surroundings (insects, earthworms, snails, birds, mammals, reptiles, spiders, diverse plants, and fungi)"*.
- *"Analyse patterns of relationships between living organisms and their environments in terms of dependence on and response to each other"*.[1]

I wonder if the heron has other fishing spots (see **Box 1**).

Eight years later...

After following the same routine for some years, I move on to other things. I start a business and get married. I have two kids: Tashi and Nuba. I tell my kids about my fishing days. They are eager to see my fishing spot.

One day, I decide to revisit my favourite spot. I take Tashi and Nuba along.

My old friends—the rocks and the Ficus—are still there. Unchanged and welcoming. But something does not seem right. I do not see the heron.

We return home and I do not give it much thought.

I start visiting my spot again. Many days pass by. But I still do not see the heron. I wonder if the winter finally got to him.

One day, my kids and I walk into a bookstore in the city of Thimpu. The store has a section of books on wildlife. I am curious about my missing companion.

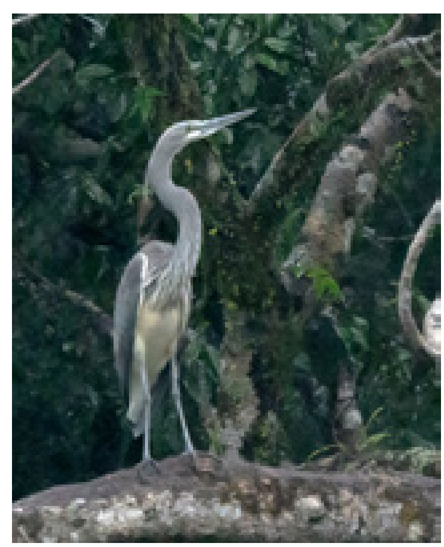


Fig. 2. The white-bellied heron (*Ardea insignis*) at Namdapha National Park, Changlang, Arunachal Pradesh, India.

Credits: Rajkimar99, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:WHITE-BELLIED-HERON.jpg. License: CC BY-SA 4.0 International Deed.

In all these years, it has never occurred to me to read about it. I have seen it basking in the sun by the river many times. I know how it looks in summer and in winter. I remember how magnificent it looks in flight. And it's cool composure during its hours of meditation by the river.

I search for it in a book called 'Birds of Bhutan'. But I do not find it there. The book talks about the purple heron, the grey heron, egrets, the pond heron, and the night heron, but not the one I call the meditating heron.

I wonder if the bird is in some other section. I carefully search the index. There is a reference to an entry on rare species on page 339. I turn to this page and there it is! Finally! The milk-white belly and throat with grey upper parts. I read on... the habitat description and notes on behaviour match perfectly (see **Fig. 2**). They call it the 'white-bellied heron' or 'imperial heron'. Its scientific name is *Ardea insignis*.[2, 3]

I show Tashi and Nuba the photo of the bird in the book. I tell them this is the fishing companion I have always talked about. This is the first time I have been able to show them how the bird looks.

Nuba points out the * symbol near the entry of the bird. This leads us to a footnote:

* Last record of species in 2000s. Possibly extinct due to habitat loss and poaching.

Key takeaways

- This is the story of a farmer who supports his livelihood by fishing. He observes and begins to relate to a heron who shares his fishing spot. It could be used in class to invite students to think about other species in their environment and how they relate to them.
- The farmer in the story shares his observations of the features and feeding habits of the heron. Encouraging students to observe birds in their own neighbourhood can give them the opportunity to discover and appreciate the diversity of the living world for themselves.
- The farmer in the story shares how human activity impacts his and the heron's ability to catch fish. We also learn how this heron species is disappearing from our world. This can be used to draw students into a discussion on the interdependence of species and the different kinds of roles we can play in the lives of the other humans and species in our environment.

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Notes:

1. Credits for the image used in the background of the article title: The Meditating Heron, Hemal Naik. License: Copyright owned by Hemal Naik. Used here with his permission.
2. This story was first published on Medium: https://hemalnaik.medium.com/the-meditating-heron-white-bellied-heron-an-emissary-from-the-past-6100aa1cb2a7. The wording and structure of the version included in i wonder... has been modified to align with our readership of middle school science and elementary school EVS teachers. These changes have been made with the author's permission.
3. To read more of Hemal Naik's writings, visit: https://hemalnaik.medium.com/.
4. This article includes five detachable classroom resources: **Activity Sheet I: Observe Fishing Birds, Activity Sheet II: Document Changes in Neighbourhood Birds, Activity Sheet III: Invite Birds to a Bird Bath, Teacher's Guide: Activity Sheets I & II,** and **Teacher's Guide: Activity Sheet III.**

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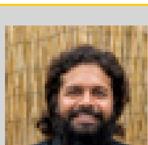


Hemal Naik works at the intersection of engineering, ecology, and art. He enjoys traveling, writing, and exploring wildlife, especially in the Himalayas. Hemal is currently using drones to study the mating behaviour of blackbucks in India. He can be contacted at: hnaik@ab.mpg.de.

Life in Your Backyard

ACTIVITY SHEET I : OBSERVE FISHING BIRDS

Azim Premji University

Aim:

- Explore the 'diversity of life' by learning about different kinds of fishing birds and their feeding habits.
- Think about how the kind of human activities that affect one kind of heron in a different part of the world (out there) can affect other kinds of herons and fishing birds in your own neighbourhood.

(a)

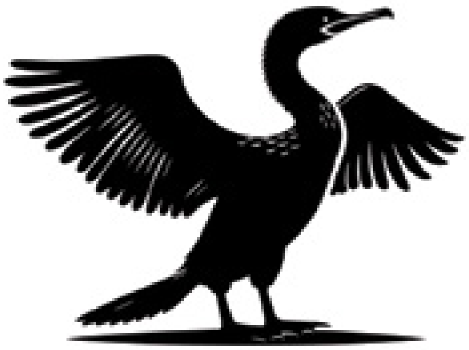
(b)

(c)

(d)

(e)

(f)



(g)

(h)

What to do:

In 'The Meditating Heron', a farmer describes the fishing routine of his companion, a white-bellied heron. Listen to your teacher read this part of the story out to you.

Observe:

Page 1 of this activity has images of six of the different kinds of fishing birds seen in India. Look at these images carefully. What do the beaks of these birds look like? What do their feet look like?

Think about:

A. Have you seen any of these kinds of birds in your neighbourhood? What do you call them? Can you think of 1-2 things about these birds that will help your friends identify them?

Which of them are seen in your neighbourhood?	What do you call them?	Think of 1-2 things about the way they look that stand out for you?	Have you seen them fishing? (Y/N)

B. Different kinds of fishing birds use different fishing strategies. The way they look can often give us important clues about the way they fish. Columns 1 and 2 of the table below list and describe some strategies that fishing birds use. Can you guess which of these fishing strategies the birds on Page 1 are most likely to use? Fill out your guesses in Column 3.

Strategy	What you will see the bird doing	Image numbers
DIVING	Dive towards the water. Catch fish with its beaks or claws.	
SKIMMING	Fly very quickly over the water. Keep its beak open in flight and catch fish from the surface.	
SCOOPING	Wade through shallow water or mud. Scoop fish up with its beak.	
AMBUSHING	Stand still in water or close to it. Creep up to and snatch up unsuspecting prey with a quick movement of its beak.	

C. Look at the images of the different kinds of fishing birds again. Think of what you heard about the fishing strategy of the farmer's companion. Which of the bird images on Page 1 is most like the 'meditating' heron? Why do you think so?

Discuss:

Watch the short 4-minute video that your teacher plays for you.

- Was your guess in Question C correct? If not, what did you miss?
- If you see any kind of heron in your real world, will you be able to identify it by the way it looks and fishes for food?
- If you see a neighbourhood bird catching fish, will you be able to tell if it is a diver, skimmer, scooper, or an ambusher?
- The farmer's 'meditating' heron is seen in India too. Here too, they are disappearing. Human activity plays an important role in its disappearance. The video shares some examples of such activities. Do you see any of these kinds of human activity in your neighbourhood? What effects do you think such activities have on the herons in your neighbourhood? Do you think they can affect other kinds of fishing birds too?

Contributed by:
Chitra Ravi, who works at Azim Premji University, Bengaluru.

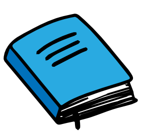
ACTIVITY SHEET II : DOCUMENT CHANGES IN NEIGHBOURHOOD BIRDS

In 'The Meditating Heron', a farmer from Bhutan wants to introduce his children to a heron who had been his fishing companion for a long time. The bird is no longer at its usual spot. The farmer also learns that birds of its kind are disappearing from his neighbourhood. Human activity plays an important role in this disappearance. Do you know the birds in your neighbourhood well enough to notice when they start disappearing?

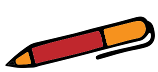
Aim:

- Discover some of your neighbourhood birds from the observations you, your friends, and elders from your community have made of them.
- Find out how the numbers and kinds of birds in your neighbourhood have been changing over the years.
- Think about the relationship between birds and us (humans).

You will need:



An observation notebook



A pen/pencil

What to do:

1. In class: Your teacher will divide you into groups. Use **Table I** to make a list of all the different kinds of birds you see around you almost every day. Record any details that will help your classmates and teacher identify the bird. Here are some things to think of:
   - Do you know the common names of these birds? These names could be in any language. If you do not know their names, describe them. For example, tell your friends what you know about their size, colour, beaks, or the sounds they make.
   - If you can, make a note of where you often see them. For example, do they usually perch on trees, electric wires, near water, or on the ground?
   - Have you seen them eating? What do they eat?
2. At home: Talk to your parents, grandparents, and other elders in your community. Find out what they can tell you about the birds in your neighbourhood. Listen carefully to what they share and make a note of it in your notebook. Here are some questions to ask:
   - What kinds of birds did they see when they were young? Do they see them now?
   - Do they see a change in the number of birds over the years? What do they think may be the reason for this change?
   - What can they tell you about what different birds eat and where they nest?

- If you live in a farming community, have your elders seen any changes in the way farming was done earlier and now? For example, are there changes in the kinds of crops grown then and now?
- What are some of the other changes they see in the area? For example, are there changes in the buildings, roads, water bodies, kinds and numbers of trees and other plants?

Listen and share:

Your teacher will invite each group to share their observations with the class:

- When other groups present their work, listen carefully. Do they talk about a bird you have seen too? Have they observed the same details as your group has? Make a note of anything new or different you learn from their presentations and any questions you may have.
- When it is your group's turn to present, focus on birds or features that none of your classmates have spoken about. If your classmates ask any questions that you do not know the answer to just yet, write them down. This may be something to observe the next time you see the bird the question is about.

Think about and discuss:

a) How many different kinds of birds do you think you have in our neighbourhood?

b) How have the number and kinds of birds in your neighbourhood changed over the years? What role have we (humans) played in this change?

c) What role do birds have in our lives?

i wonder... Rediscovering school science

Contributed by:

Radha Gopalan, who is an environmental scientist with a PhD from the Indian Institute of Technology Bombay (IITB), Mumbai. After an 18-year career in environmental consulting, she taught Environmental Science at the Rishi Valley Education Centre, Andhra Pradesh. She is a Visiting Faculty at the School of Development, Azim Premji University, Bengaluru and a member of the Kudali Intergenerational Learning Centre, Telangana.

Table I: Describe the birds in your neighbourhood.

Name of the bird (Common English name/Local name)	Description of the bird*	Description of the beak**	Where you see them #	What they eat

* Size (sparrow size, crow size, smaller or bigger than sparrow or crow), colours, call of the bird, and whether they are single or in groups.

** Colour, thickness (thin, thick), and length (short, long, curved, straight).

On the ground, on a tree, on electric wires, near a water body, or on houses.

Life in Your Backyard

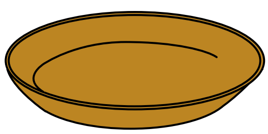
ACTIVITY SHEET III : INVITE BIRDS TO A BIRD BATH

In the story of the 'The Meditating Heron', a farmer from Bhutan introduces us to a heron in his neighbourhood as his fishing companion. The farmer gets to know this bird so well because he sees it every time he visits his favourite fishing spot. You could meet many birds in your neighbourhood by setting up a bird bath.

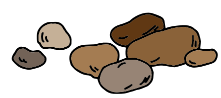
Aim:

- Set up a bird bath to invite neighbourhood birds to your school.
- Observe the neighbourhood birds that visit your bird bath.

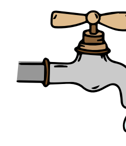
You will need:



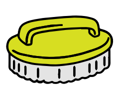
A shallow mud plate/bowl or an old plastic bowl with a thick rim (for your guests to perch on)



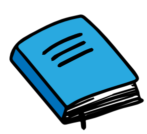
A few stones/pebbles (again, for your guests to perch on)



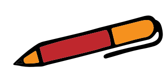
A source of clean water



A scrubber (to clean the bird bath)



An observation notebook



A pen/pencil

What to do:

1. With your teacher's help, set up at least two bird baths in school. Choose different locations for them. It may be best to have them at locations where you are able to easily observe your bird guests every time you enter and leave the school.
2. Place the bowls at the selected locations. Fill them with fresh water. If the bowls do not have a wide rim, place some stones or pebbles inside so birds have something to perch on.
3. Check each bird bath at least once a day to make sure it is filled with water. You may need to check this more often on hot dry days.
4. Take turns to clean each bird bath at least once a week. You may need to do this more frequently if the water is dirty.
5. Take 5 minutes to observe birds to the bird bath at least three times a day: When you arrive in school, at meal-time, and just before you leave for home.

Observe and record:

- Do you know the names of any of the birds you see? If yes, write them down. These names could be in any language.
- How do the birds look? Record these details in **Table I**. Or you could draw the bird in your notebook.
- If you hear any of the birds calling or singing, describe that sound. Or try and learn to imitate their call.
- How do the birds behave? Do they take turns in using the water? Do any of the birds use the baths to bathe? Do any of them use it to drink water?
- Other animals may visit your bird bath. Record your observations of them too.
- Remember to make all your observations from a distance.

Think about:

- Why do you think birds visit a bird bath?
- Why is it important to describe your bird guests in detail? What does it help you learn?
- Go through your observations and record the following findings:
  a) Which birds come every day?
  b) Which birds come only at certain times of the day?
  c) Which birds come only at certain times of the year (you will be able to answer this question only after one year of observations)?

Discuss:

1. Why do you think your teacher is inviting you to make all your observations of the bird bath from a distance?
2. Do you see any patterns in your observations? For example, do any of the birds visit the bath at specific times of the day? Can you think of an explanation for these patterns? Where might these birds be at other times?
3. What do you think will happen when several birds come to the bird bath at the same time? Think of a reason for your prediction. Compare this with your actual observations of how birds behave at the bird bath. Is it different from what you had predicted? Discuss possible explanations for this difference.
4. Share 1-2 of:
   - The observations that were most exciting for you.
   - The new things that you learnt from this activity.
   - The things you thought about birds that changed because of these observations.

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Radha Gopalan, who is an environmental scientist with a PhD from the Indian Institute of Technology Bombay (IITB), Mumbai. After an 18-year career in environmental consulting, she taught Environmental Science at the Rishi Valley Education Centre, Andhra Pradesh. She is a Visiting Faculty at the School of Development, Azim Premji University, Bengaluru and a member of the Kudali Intergenerational Learning Centre, Telangana.

Table I: Describe the birds that visit your bird bath.

Date: ____________________ Location (if there is more than one bird bath): ____________________

Time: ____________________

Name of the bird (Common English name/ Local name)	Description of the bird				Behaviour of birds**		
	Size*	Colour (feathers and wings)	Any other features that stand out	Bird call (what does it sound like)	Bathes, drinks, or does both?	Waits its turn (Y/N)	Any other observation
Any other visitors?***							

* How big is the bird? You could compare its size to that of a sparrow or a crow. For example, is it bigger or smaller than a sparrow?

** Does the bird wait its turn in using the water? Does it bathe, drink water, or do both? Did you notice anything else about the way it behaves?

*** Describe their size, features, and colour if you do not know their name.

ACTIVITIES I & II

Azim Premji University

1) Activities I & II can help meet the following learning outcomes:
   - For science at the middle stage (Grades VI-VIII): The learner can identify and classify living organisms based on their observable features, can conduct simple investigations to seek answers to queries, and makes efforts to protect the environment (by spreading awareness on the need to protect plants and animals).
   - For EVS at the preparatory stage (Grades III-V): The learner can identify simple features (like movement, eating habits, and sounds) of birds in their immediate surroundings, group birds according to similarities and differences using different senses, predict patterns, and show sensitivity towards plants and animals.

2) One of the goals (CG-3) in the National Curriculum Framework for School Education (NCF-SE) 2023 for science in the middle stage is for students to have the opportunity to explore the living world in scientific terms. Activities I & II are designed to help meet this goal and two of its related competencies:
   - Describe the diversity of living things (including birds) observed in the natural surroundings.
   - Analyse patterns of relationships between living organisms and their environments in terms of dependence on and response to each other.

3) In Activity I:
   - Start the activity by narrating the story of 'The Meditating Heron'. You may want to read the parts that describe the features of the bird and its fishing routine again if students request it.
   - The kinds of birds in **Sheet I** are: (a) Kingfishers, (b) Grebes, (c) Skimmers, (d) Herons, (e) Sea Eagles, (f) Pelicans, (g) Cormorants, and (h) Spoonbills.
   - In **part B** of the **Think about** section: Kingfishers, Grebes, Sea eagles, and Cormorants are divers. Skimmers are named for skimming. Pelicans and Spoonbills are scoopers. Herons are ambushers.
   - Encourage students to attempt the questions in the **Discuss** section after you show them a short 4-minute YouTube video (by Roundglass Sustain) on your mobile phone. Titled 'How Namdapha's Most Statuesque Bird is Quietly Disappearing', this video is available in English here: https://www.youtube.com/watch?v=s-H5zn4xCDw. If students prefer, you could play it in Hindi instead: https://www.youtube.com/watch?v=eTPr31KbHeE&t=0s.

4) In Activity II:
   - Encourage students to listen carefully to the stories and information their elders share. Ask them to record these details in their notebooks.
   - Also, encourage them to listen carefully to presentations by the other groups in class.

5) Facilitate the discussion in both activities by encouraging students to think about and share the effects we (humans) have on birds in our neighbourhoods. End the session by posing these questions: Do human activities always have harmful impacts on birds? Can they think of some activities that don't? Do they know of efforts in their locality that help protect birds or their habitats? Let students take at least a couple of days to think about these questions. If you see a lot of interest in these questions, you could invite them to share their responses in a class discussion.

TEACHER'S GUIDE

Contributed by:
Chitra Ravi, who works at Azim Premji University, Bengaluru.

ACTIVITY III

1. This activity is designed as an extension of *'Activity 4: Prepare a birdbath—offer water to birds in the hot summer months'* described in the Grade III EVS textbook (NCERT, 2024-2025, pg. 96-97). It can also be connected to 'Chapter 7: Water A Precious Gift' in Unit 3 of the Grade III EVS textbook (NCERT, 2024-2025).
2. It is designed to build and deepen students' affective skills of empathy and care for all living beings around us. The National Curriculum Framework (NCF-SE) 2023 suggests that: *"Empathy and compassion are not only values or dispositions; these are capacities that are developed through deliberate practice".*
3. This activity may be carried out by students as a year-long activity.
4. Start this activity by reading out the story 'The Meditating Heron' to the students. Then introduce the idea of setting up bird baths in school. Invite students to bring used or old shallow mud or plastic containers that are about 10-15 cm deep. Tell them that the containers can be of 2-3 different volumes.
5. Once you set up the baths, work with your students to set up a duty roster for maintaining them. Ensure that students take turns to clean the baths and refill the water in them. Doing these tasks collaboratively helps students build a sense of ownership and responsibility. These are important attributes in caring for others.
6. Share clear instructions for the tasks. Emphasize the instruction that students must observe non-human visitors to the bird bath without feeding or interacting with them. This will help them build skills of observing with attention and sharing space (and resources) with other living beings.
7. Clarify to the students that they should record their observations systematically and regularly in the format provided in **Table I**.
8. Encourage your students to observe visitors to the bird bath for at least 10-15 minutes, three times a day: When they enter the school, during their meal-break, and before they leave school. Encourage them to record their observations as soon as possible after each such session.
9. Plan a session for at least 30 minutes per week.
    - Depending on their class strength and the time available for discussion, divide students into pairs or small groups of 3-4. Facilitate the exercise of peer sharing and discussion. Clarify that students in each pair or group must take turns to share their observations and explanations. Encourage them to listen carefully to each other.
    - Once a month, use this session to invite students to share their responses to questions in the **'Think about'** and **'Discuss'** sections.
10. Make a note of any student questions that have not been addressed during these discussions. You could take these up at a later point. Or you may consider assigning it to students to explore on their own and share their findings with the class.
11. Encourage students to set up bird baths at home and maintain a journal of their observations for as many years as they can. As they do this, they will begin to recognise and infer patterns and rhythms over time. This can help your students become more aware and

sensitive to changes in their environment. This may build their capacity to respond in meaningful ways to many other changes around them.

12. Encourage students to think of the role their observations of birds play in their ability to care for these animals and be empathetic to their needs. By inviting students to observe their surroundings with attention, we can help them build care, empathy, and compassion.

TEACHER'S GUIDE

Contributed by:

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LET THERE BE NIGHT

AMOL ANANDRAO KATE

In 1879, Thomas Edison commercialized the electric light bulb. Since then, nights are becoming about 10% brighter every year. What role does artificial lighting have in the loss of the night? What are the impacts of this loss?

We were watching the night sky, when my friend exclaimed, *"Look at that big illuminated cloud! Doesn't it look amazing?!"*

Looking at what she was pointing at, I said, *"That is the center of the Milky Way."*

Stunned, she turned to me and said, *"This is the first time I have seen such a wonderful sight."*

My friend grew up in Mumbai. Like many other people living in metropolitan cities flooded with artificial lights, she had never seen a sky full of stars. I grew up in Kalyan, a small town 40 kilometres from Mumbai. This was at a time when apartments were rare. Most settlements consisted of small houses that were quite far from each other. The night sky was not littered with artificial light. Many constellations were visible from my house. Even the fainter ones like Cancer, Cetus, and Camelopardalis. This is when I first observed and learnt to identify them. In the next few decades, this view changed. As Mumbai grew in size, the glow of its lights hid more of the horizon towards the west. Then, as our town grew, our own use of artificial lights increased. Many stars and constellations were no longer visible from my house. I would have to travel about 60-70 kilometers away from the town to get a good view of the night sky. Today, we can hardly see any stars from Kalyan.

I now live in Sirohi, a small town in south Rajasthan. When I moved here in 2011, I could see clear night skies from the roof of my house (see **Fig. 1**). But this joy was short-lived. In 2016, the Rajasthan government decided to adopt the Street Lighting National Program (SLNP) in all its urban local bodies. Five lakh conventional street lights were replaced with Light-Emitting Diode (LED) lamps. Compared to incandescent and fluorescent lamps, LED lamps are better at directing light to a targeted area and are more energy

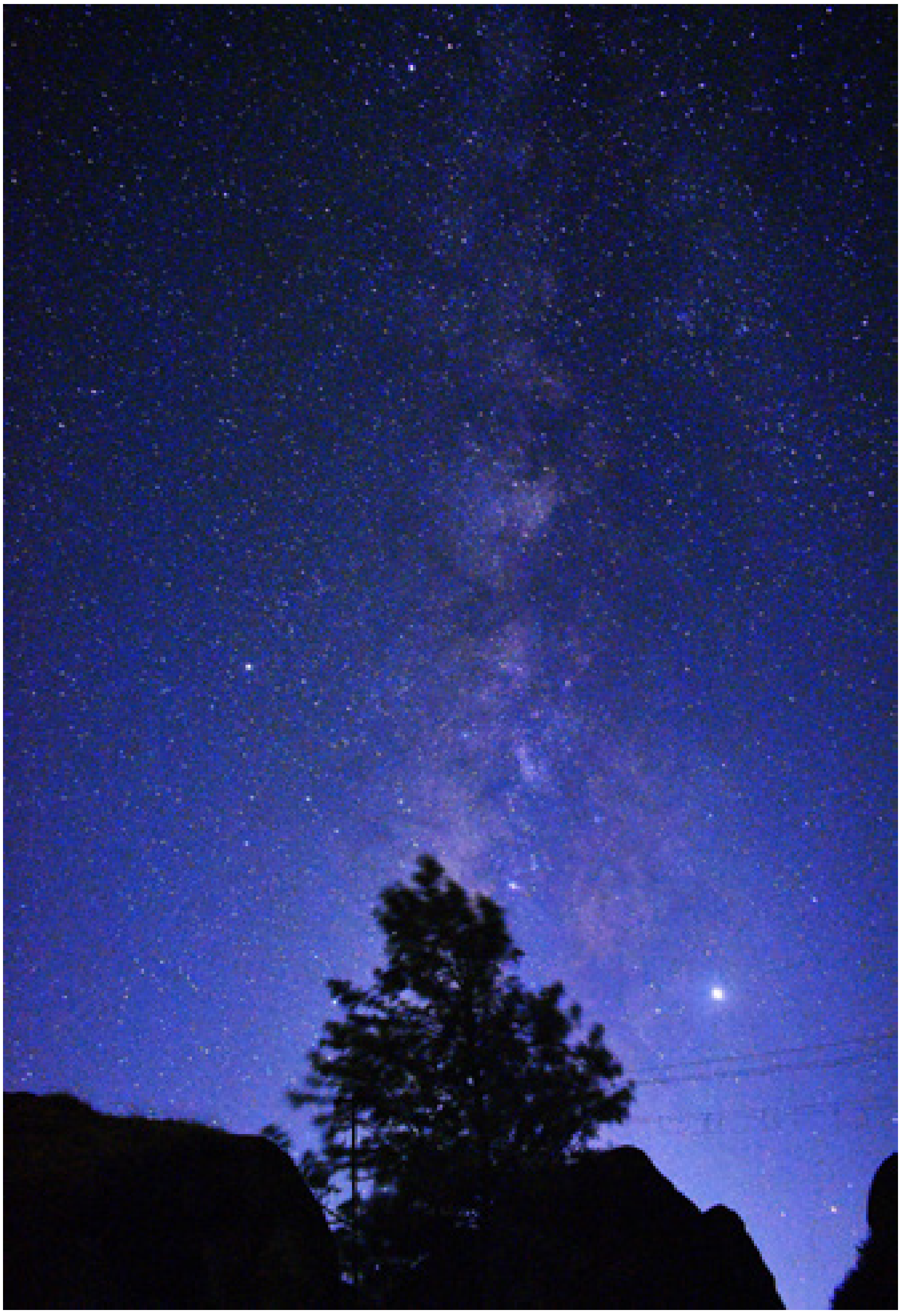

Fig. 1. A stunning view of the Milky Way. This photo was taken from Mount Abu, Sirohi, Rajasthan.

efficient.[1] Since they provide the desired levels of illumination at much less cost, the Rajasthan government has been able to afford the installation of many new lighting units. People have welcomed this change because brighter streets seem safer. But not all of these lighting units are necessary and this well-intentioned effort has badly impacted our view of the night sky.[2] The starry patch of the Milky Way has been erased by the bright glow of LED lights.

This is a growing challenge across the world. Estimates suggest that the number and radiance of artificial lights is increasing by about 2-6% every year.[3] Rapid economic growth and urbanization play key roles in this increase.[4] We rarely hear of the negative impacts of this increase because they have been harder to identify and study than those of other pollutants.

Impacts of light pollution

Any **unwanted**, **excessive**, **intrusive**, or **inappropriate** use of artificial lighting is called light pollution.[5, 6] According to the International Astronomical Union (IAU), an area is light polluted when the level of lighting from artificial sources is more than 10% of that from the natural background. A study in 2016 calculated that about 83% of humanity lived in light polluted areas and more than a third of the world's population at the time could no longer see the Milky Way.[7] But the night sky is not important for its beauty alone.

Across the ages, humans have turned to the night sky to find answers to some of our deepest questions and to develop an understanding of our place in the universe. It has influenced all dimensions of our survival on the planet—religion, philosophy, art, literature, and science. The history of scientific discoveries is tightly linked to our access to this universal laboratory. Children are introduced to it in Chapter 12 ('Beyond Earth') of the Grade VI science textbook (NCERT, 2024-2025). The section titled 'Night Sky Watching' invites children and teachers to try and spot some of the planetary bodies (planets, stars, and constellations) they learn about in this grade. But it also cautions them: *"Light pollution is reducing our ability to enjoy and study objects in the night sky... If it is a clear cloudless night, a large number of stars may be visible in the sky. If you stay in a big city, you may find that the sky is rarely clear and only a few stars are seen in the night sky. In villages or areas where there is less light pollution, a larger number of stars can be seen".*[8] Artificial lighting is cutting off their (and our) access to this shared heritage (see **Fig. 2**).

We are also learning of the many ways in which light pollution affects human health. For example, the day/night cycle

Fig. 2. An example of the impact of light pollution on the number of objects visible in the night sky. This image is a modification of a photograph of the night sky taken at ESO's Paranal Observatory in Chile, a place with excellent dark-sky conditions.

influences our natural wake/sleep cycle (called circadian rhythm). Exposure to natural darkness triggers the pineal gland in our brain to produce a sleep-inducing hormone called melatonin. This hormone also boosts our immune system, lowers our cholesterol, and helps regulate the functions of other hormone producing glands in our body (like the thyroid, pancreas, adrenal glands, ovaries, and testes). Exposure to artificial light suppresses the production of melatonin, reducing the duration and quality of our sleep. All artificial light has this impact, but cold light sources (like white-light emitting LEDs) interfere more with our sleep than warm ones (like incandescent lamps). This is because the photoreceptors that suppress the production of melatonin are most sensitive to blue wavelengths and cold light sources produce more blue light than warm ones. Poor sleep can impair our ability to function well in the day. It can also increase the risk of high blood pressure, obesity, diabetes, cardiovascular diseases, anxiety, and depression. Some studies suggest that light pollution may be linked to a higher risk of breast cancer.[9]

The day/night cycle is important not only for humans but also many other plants and animals. For example, artificial lights attract many flying insects, which hover below them for so long that they die of exhaustion. This loss can affect all those species of plants and animals that depend on insects for food or pollination. Studies from across the world suggest that artificial lights cause the death of millions of sea turtles every year. These reptiles hatch from eggs laid on the beach and make their way to the sea by crawling away from the darkness of the dunes and towards the brighter horizon over the water. But bright lights from beach resorts, lit roads, and hoardings mislead them and draw them towards the city instead. Many die of dehydration and exhaustion. Others are eaten by predators or crushed by vehicles. The males of many species of tree frogs use nocturnal calls to signal their location to potential mates. By reducing the length and darkness of the night, artificial lights may interfere with their breeding cycle. Hunting at night allows owls and bats to avoid diurnal predators (like raptors) and competition from other insect- or rodent-eating birds. Light pollution reduces their hunting opportunities and increases the risk of attacks by other birds or animals. Artificial lights can cause migratory bird species to migrate too soon or too late, missing the conditions they need to nest and forage. The absence of a clear night sky can cause migratory birds to wander off course. Sometimes for so long that they drop dead due to exhaustion from these much longer flights.[10]

Parting thoughts

It is important to discuss the causes and impacts of light pollution with our students. To point out how it is no longer limited to big cities and has started affecting small towns and big villages too. It is also important to draw their attention to the fact that, unlike other forms of pollution, it does not accumulate in the environment and is reversible. Involve them in an exercise to examine what we need light for and how much of it we need. Their responses to this exercise can be used to explore and discuss how each of us can choose to: (a) Use warmer and more energy-efficient light sources, (b) Choose light sources with the minimum intensity needed to meet their purpose, (c) Ensure that lights are shielded and directed downwards to reduce scattering, (d) Reduce the amount of outdoor lighting to a minimum, and (d) Switch off lights (indoors and outdoors) when they are not needed. Let there be night again. Not only for us but for all life on Earth.

Key takeaways

- Any unwanted, excessive, intrusive, or inappropriate use of artificial lighting is called light pollution.
- Light pollution impacts our access to the night sky and interferes with our ability to observe celestial objects.
- Exposure to artificial light at night disrupts our circadian cycle and increases the risk of many physical and mental illnesses.
- Light pollution also impacts the survival of many other plants and animals that depend on the natural day/night cycle for hunting, navigation, sleep, protection from predators, breeding, or migration.
- Unlike other forms of pollution, light pollution is reversible. We can reduce our contribution to it by using artificial lights only when and where necessary and choosing less harmful and more energy efficient lighting units.

Notes: Credits for the image used in the background of the article title: Earth at Night, NASA. URL: https://earthobservatory.nasa.gov/images/90008/night-light-maps-open-up-new-applications. License: CC-BY.

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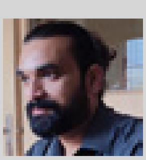
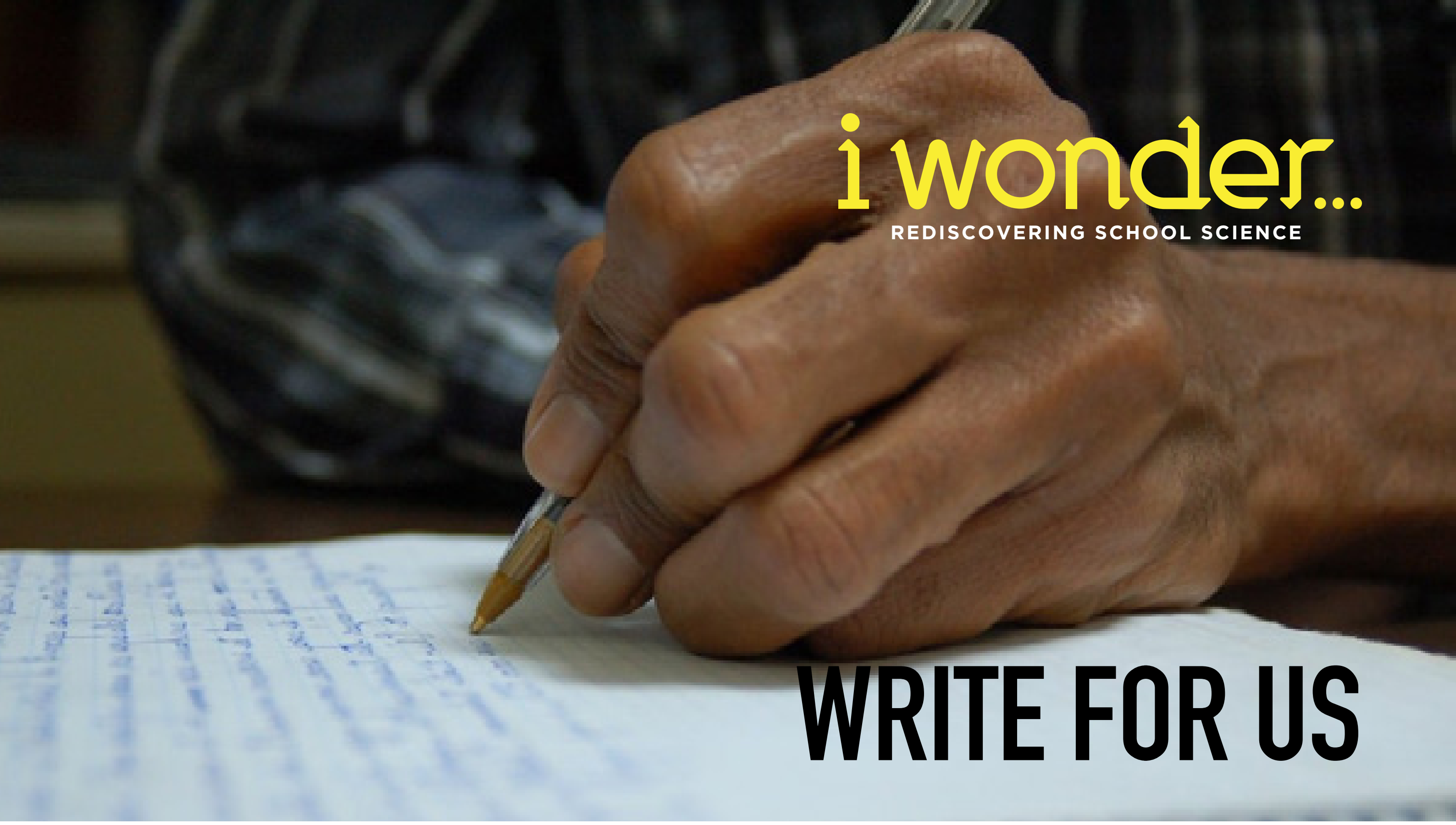


Amol Anandrao Kate works with the Azim Premji Foundation as a teacher educator and science resource person at Sirohi, Rajasthan. He can be contacted at: amol.kate@azimpremjifoundation.org.



WRITE FOR US

i wonder... is a science magazine for middle stage (Grades VI-VIII) science and preparatory stage (Grades III-V) environmental studies (EVS) teachers. Our aim is to publish articles and resources that government school teachers can use in their classrooms.

What kind of subject knowledge, pedagogical approaches, and perspectives to school education would support these teachers in meeting grade-appropriate curricular goals and build related competencies in their students? If you are a practicing science teacher, teacher educator, or researcher engaged in exploring this question, share your experience with us.

Requirements:

1. Choose a topic from the latest version (NCERT, 2024-2025) of the middle stage science textbook or preparatory stage EVS textbook. These are freely available here: https://ncert.nic.in/textbook.php. Highlight explicit connections to the content of these chapters. Allow the grade-appropriate learning outcomes for these subjects to guide the scope, complexity, and level of abstractness of your draft.
2. The National Curricular Framework for School Education (NCF-SE) 2023 recommends specific curricular goals for middle stage science and preparatory stage EVS education. This document is freely available here: https://education.gov.in/sites/upload_files/mhrd/files/ncf_2023.pdf. Teachers are expected to meet these goals in ways that help their students develop and practice certain competencies in their real worlds. Present your article and/or resource from a perspective that supports teachers in this task.
3. Context plays an important role in what teachers can do in their class. Share classroom resources with materials that government school teachers and students can find easily, locally, and inexpensively. Where necessary, share how teachers from government schools can use your article or resource in their class.

Your submissions:

- Must be original. Include references and acknowledgements to indicate contributions from others.
- Must be as concise as you can make them. They can be as short as 800 words. Try not to exceed 1500 words.
- Need to be written in simple non-academic language. Show us why the ideas in your draft matter to you.

Share your pitch with us:

Write a brief outline that tells us what you want to write about and the key questions you hope to address. Also, tell us how your article:

- Supports the content of the grade-appropriate NCERT textbook.
- Aligns with the stage-appropriate curricular goals in the NCF-SE 2023.
- Can be used by teachers in their classroom instruction.

Include a brief bio (< 50 words) that tells us something about your background in science and/or science education, and areas of interest in school science.

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Glimpses from the field. (a) Rajkumari Ji's class. **(b)** Teachers in the workshop. Credits: Aditya Prakash. License: CC-BY-NC-ND.

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—Vijeta Raghuram, Radha Gopalan, and Chitra Ravi.

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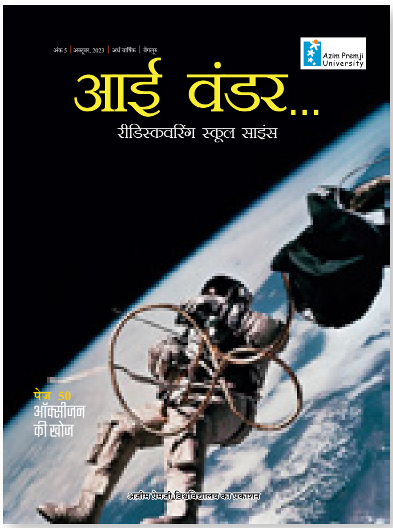

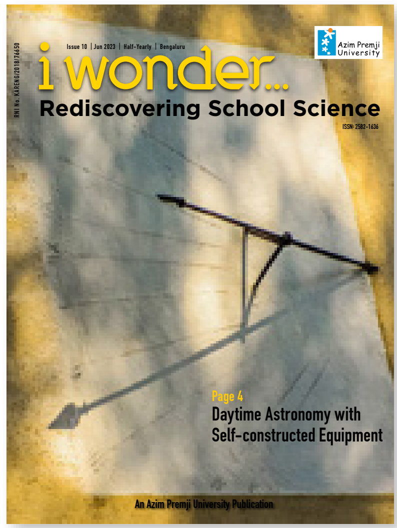

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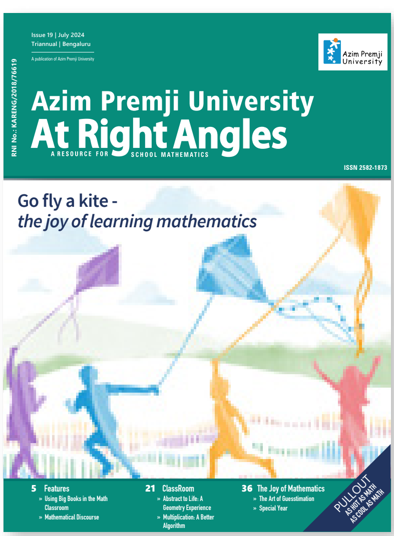

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Azim Premji University
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