Preamble [Note for Educators/Teachers]

We see these notes as teaching-learning materials for schools, as part of a series on the earth, sun, moon, planets, and stars, beginning with Class 6 (or the earliest appropriate class) and culminating in Class 9 or 10. We begin with what can be observed from the earth with the naked eye. Children observe the phenomena, and describe what appears to them. Based on careful systematic observation, imagination, and rigorous reasoning, they can go on to build a model of reality: the body of conclusions that we call ‘knowledge’.

Young children’s ‘knowledge’, based on their experience of the world, is that the earth is stationary, and that it is flat. So we begin with precisely such a model (the geocentric model with a flat earth). We will move on to the model of a spherical earth revolving around the sun (the heliocentric model, currently accepted by the scientific community) when the children are a bit older, and mature enough to understand the relevant evidence and arguments for that model.

The topic of the geocentric and heliocentric models is an excellent example for children to appreciate how ideas in science emerge, develop, and change over a long time, and how, when new technologies become available, and new observations are added to the pool, theories get revised. It is also a good example of a cluster of easily observable phenomena relevant in daily life. From this, they can learn to:

- observe phenomena,
- form generalizations about them, and
- articulate ideas about them explicitly.

For instance, once children have gone through the notes on these models, they should be able to:

- list the observational generalizations in the relevant phenomena;
- say how the two models explain the generalizations; and
- choose between the two for themselves.

This topic also involves a cluster of phenomena that lends itself well to developing inquiry and integration abilities.

Even though we need to rely on our own experience to arrive at conclusions and construct our knowledge about the world, we also need to doubt and question that experience. And when needed, we must modify those earlier conclusions. Our hope is that engaging with this material will help children internalize this idea.

Dealing with these phenomena form the practice grounds for developing:

- the habits of doubting and questioning;
- the ability to arrive at reliable conclusions; and
- the ability to reject conclusions when evidence and reasoning demand.

Motion as observed from the earth with naked eyes

Phenomena: observing the moon, sun, and stars, and the sky moving around the earth

1. daily cycle of the moon
2. monthly cycle of the moon among the stars (new/full moon)
3. daily cycle of the stars in relation to the earth (east to west)
4. a. daily cycle of the stars in relation to Polaris (in circles)
   b. position of stars with respect to one another (fixed)
5. daily cycle of the sun (day-night)
6. a. annual north-south cycle of the sunrise and sunset (seasons)
   b. annual cycle of where the sun is at its highest point
7. annual cycle of the sun through the constellations (zodiac)
8. retrograde motion

Grade 6 (or 5?)

Grade 10

[Additional set of related phenomena: Shadows: where appropriate.]

Exploring the Earth and the Sky

Constructing Scientific Theories

1 Can we trust our senses?

Have you ever seen a huge statue in the middle of a road? Have you noticed that as you go closer to it, it looks bigger and bigger? And as you go away from it, it looks smaller and smaller. Is the statue actually getting bigger and smaller? No! It just appears to be bigger or smaller, depending on how far you are from it, right?

Try this. Stand in a place where you can see a building far away. Now hold your arm out straight in front of you, with your thumb pointing up, such that the thumb is in front of the building. Look at your thumb with one eye, keeping the other eye closed. Now look at the building. Doesn't your thumb look bigger than the building? From this, would you conclude that your thumb is bigger? Of course not. You would conclude that your ***experience*** of seeing the building as being smaller is an optical illusion. In reality, the building is much bigger.

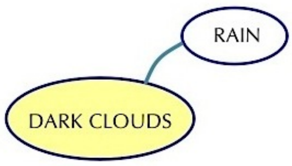
Another example. Take a straight stick, and place it in a glass of water, such that it is half in water and half outside the water. The straight stick would now appear to be bent. Would you conclude that the stick bends when you put it in water, and unbends when you take it out? No! You would conclude that the stick *appears* to be bent. It is an optical illusion. You can check this ***conclusion*** by feeling the stick in water with your fingers: though your eyes tell you that it is bent, your experience of touch will tell you that the stick is not bent.

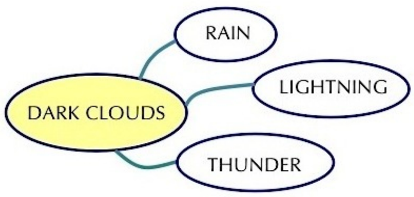
Our experience is a very important source of ***knowledge***. But these examples show that we can't always trust what our sensory experience tells us. To learn about the world we live in, we do have to rely on our experience. But we also have to distrust it, watching out for possible mistakes. We have to use our ***reasoning*** to correct those mistakes. So, experience and careful reasoning both help us to arrive at conclusions, which become part of our knowledge of the world.

EXPERIENCE → REASONING → CONCLUSIONS (KNOWLEDGE)

2 Making sense of the world

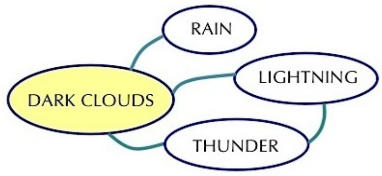
Little Mika was watching the rain pouring over the trees and the ground. She thought, "It never rains when the sky is clear. When dark clouds appear in the sky, it rains." She asked her aunt: "It doesn't rain when the sky is clear. And it doesn't rain when there are fleecy white clouds in the sky. Why does it rain only when there are thick, dark clouds?"





She heard the thunder and was scared, but she went back to the window and watched. She listened to more thunder, and saw flashes of lightning. She ran back to her aunt and said, "Thunder and lightning also come only when there are dark clouds. Why do thunder, lightning, and rain all come with dark clouds?" Her aunt just smiled.

Then she noticed something else. Every time she heard thunder, she also saw lightning. But when she saw lightning, sometimes there was no thunder. She asked her aunt: “Thunder never comes without lightning. Why? And it always comes *after* the lightning. Why can’t it ever come before lightning?”



When she was a little older, Mika heard this story in her science class.

> When the air up in the atmosphere cools, the water vapour in the air becomes liquid (water), and forms clouds. When it cools even more, droplets form in the clouds. This is what comes down as rain. Electricity flows through the clouds and causes lightning. Because of this, the air heats up suddenly, and results in the noise of thunder.

This explanation made sense to her.

The patterns that Mika noticed, the connections she discovered between dark clouds, rain, thunder, and lightning, are called ***correlations***.

Mika’s aunt now tells her a story that tries to make sense of the same correlations, but quite different from the one in her science class.

> “A thousand years ago, Mika, there was a little girl like you, Let us call her Zola. She too watched the thunder, lightning, and rain, and wondered like you. She discovered the same patterns as you. But her explanations were very different. For Zola, the dark clouds were the clothes of a rain-spirit. Lightning was the flash of his sword. Thunder was his laughter. He only laughed when he picked up his sword and it flashed. He also cried; in fact, he cried more often than he laughed. Raindrops were his tears. Zola and her friends believed this story, because that is what the grown-ups had told them.”

How could Zola believe this story to be true? Mika wondered.

3 Is the moon bigger than the stars?

Imagine Zola looking up at the night sky. Up there she sees little bright dots, which we call ‘stars’; and a larger shape, which we call the ‘moon’. Her eyes perceive the moon to be much bigger than the stars: this is her experience.

From what she has seen before, combined with her reasoning, she knows that if something is close by, it may look bigger than something very far away, but may actually be smaller.

What should she conclude in this case? She has at least two options:

- A1: The moon and the stars are equally far from the earth. So the moon is much bigger than the stars.
- A2: The stars are much farther away from the earth than the moon. This is why the moon looks bigger to us.

Which of these options should Zola choose? It would be sensible for her to say, “I can’t choose, I don’t know how to decide.”

Zola has seen that the moon hides the stars when it moves across them, just like clouds hide the moon when they move across it. So she tells herself that it is possible that the stars are farther away than the moon. Depending on how far away the stars are, some of them might be the same size as the moon, some may be smaller, and others might be much bigger.

How about you? May be your elders, teachers, or textbooks have told you that the stars are much bigger than the moon. What is your own conclusion?

If you don’t know how to decide, how to choose between A1 and A2, may be you should keep reading, and you might learn how to look for evidence to decide, and reach your own conclusions.

4 Stars: shining objects or holes in the sky?

Let us go back to Zola looking at the night sky. She sees the bright dots that we call stars. But what are these dots? Let us imagine that she considers two possibilities:

B1: The sky is a dark dome. The stars and the moon are shining objects stuck on it.

B2: The sky is a dark dome. The moon and the stars are holes on the dome. There is a bright fire burning behind the dome. The light from the fire coming through those holes makes them shine. (This is like an umbrella full of holes, with sunlight coming through them.)

Given your own experience and reasoning, which of these options would *you* choose?

To search for an answer, observe the night sky carefully. Look at the positions of the stars. In relation to them, look at the position of the moon. Does it remain fixed? Or does it change during the night? Your answer is going to be important for choosing between B1 and B2. Think about this carefully. It would be good to also discuss it with other people. Continue reading only after that.

5 Positions of the moon and the stars

In the imaginary conversations below, two children discuss the reasons in support of and against the positions in B1 and B2 in the previous section.

Scene 1

[Vani and Jim are in the same class at school. They are also neighbours, and friends. They often go up to the terrace of their building, and lie on their backs watching the night sky. One night, after watching silently for an hour, Jim starts a conversation.]

Jim: So, what do you think? What are the moon and stars? Are they shining objects stuck on a dome? Or are they holes in the dome?

Vani: Come on, Jim. They can't be shining objects on a dome, nor can they be holes in the dome. Because look, the moon seems to have moved farther than the stars. So it has to be moving faster. This wouldn't be possible if they were all on a dome.

Jim: You're right. So neither of those could be true.

Vani: (thoughtful for a while) You know, the moon and stars just might be holes in the dome. Suppose there is a dome with star-holes, and another dome with the moon-hole.

Jim: How does that help?

Vani: We've seen the moon pass over the stars, just like the clouds that pass over the moon and cover it for a while. This means that the moon is closer to the earth than the stars. So the dome of the moon must also be nearer to the earth.

Jim: No, no, no, there's a problem. If what you're saying is right, the moon-dome would cover the stars, and we shouldn't be able to see them.

Vani: Hmm. You're right.

Jim: Hey, what if the moon-dome is transparent?

Vani: No, that won't work, because then the moon can't be a hole. It would have to be a shining object stuck to its dome.

Jim: Okay, what if the moon and the stars are all shining objects on their own domes? With a transparent moon-dome, of course.

Vani: Good idea. Listen, I'm sleepy. And we have an early class.

Scene 2

[They continue their conversation the next night, after watching the night sky quietly for a long time.]

Vani: Have you noticed? The stars move, but they don't change their positions in relation to one another.

Jim: I was wondering about that. Looks like their positions in relation to the earth keep changing.

Vani: They seem to be moving in a circular orbit. How do we make sense of that?

Jim: What if both domes rotate. That way, the moon would change its position in relation to the stars. And the position of the stars in relations to one another would be fixed. (pauses) Are you listening?

Vani: (pointing) Look at that star. That's the Pole Star.

Jim: Oh yes, the star that doesn't move. The steady star. It's called *Dhruva*. My grandmother told me the story of *Dhruva*.

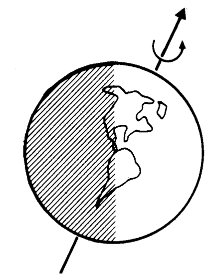
Vani: I read somewhere that it's also called Polaris. The stars move around it in a circular orbit.

Jim: So can we assume that Polaris is at the center of the stars?

Vani: I don't think so. If the stars are moving, and they are stuck on the star-dome, the star-dome must be rotating like you said. To rotate, it has to have an 'axis' on which it rotates. And the axis has to pass through the dome. Just like the earth's axis, which passes through the South Pole and the North Pole.

Jim: So Polaris must be one of the points the axis passes through. No wonder it's called Polaris! Or the Pole Star!

Vani: That also means that the axis passes through the earth. The earth then must be at the center of the dome!



Earth's axis of rotation

Jim: So, if the star-dome rotates on an axis, with Polaris sitting on one end of the axis, then we can see why the stars don't change positions in relation to one another. And their circular synchronized movement makes perfect sense!

Vani: You know what that means? If we go to the North Pole, Polaris would be much higher in the sky.

Jim: Why the North Pole?

Vani: Oh, in the same place where I read about Polaris, it said that you can't see it from the Southern hemisphere, only from the Northern hemisphere.

If we were to keep a still camera exposed to the night sky over a few hours, it would capture the movement of the stars that Vani and Jim are talking about. Here on the right is such a picture. Instead of dots for the stars, the photograph has bright circular lines showing their path.

Let us put together the conclusions that have emerged from Jim and Vani's discussion:

B3: The moon and the stars are shining objects.
The sky is made up of a star-dome and a moon-dome.
The moon is stuck on the moon-dome and the stars on the star dome.
The moon-dome is transparent.
The domes rotate with earth at the center.
The axis of the star-dome passes through Polaris.

We have imagined B1, B2, and B3, and chosen B3, rejecting B1 and B2. In doing this, we are using our imagination to create *models* of what reality might be like. We are also using our thinking and reasoning to figure out what the logical consequences of these models are, and to check if they match what we observe. This is a very important strategy in scientific inquiry.

The model in B3 is the best one so far. But that doesn't mean B3 is true. When we examine more observations, we may have to abandon B3 also. But for now, B3 seems to be satisfactory.

6 Earth: flat or spherical?

Suppose you go by just your experience. Wouldn't you think that the earth is flat? When we say 'flat', we don't mean that it is totally smooth and flat like the top of a table, or a sheet of paper. We know that the earth has lots of hollows and projections, valleys and mountains. When we say the earth is flat, we are contrasting it with the idea that the earth is 'spherical', more like a tennis ball.

Modern technology has allowed humans to travel around the earth in an airplane; and to see that we can keep traveling in the same direction and get back to the place where we started. For this to happen, the earth must be spherical. Spaceships allow humans to go far away from the earth, and from there we can actually see the spherical shape of the earth. But thousands of years ago, most human communities thought the earth to be flat. They were going by what their experience told them. Even till a few hundred years ago, we didn't have such technological resources, and our ancestors took the earth to be flat.

But not all ancients believed that. Aristotle was a famous Greek philosopher who thought carefully about a number of phenomena he had observed, and concluded that the earth is spherical. He was going against the accepted "common sense" flat-earth idea of his time. He had no technological help, no airplanes or spaceships. What could have led him to reject the idea that others accepted as commonsense knowledge?

In the imaginary conversations below, Jim and Vani (a couple of years older than in the earlier conversations) discuss with their teacher the reasons with which Aristotle supported his position.

Scene 3

[Razia is digging in her garden. Jim and Vani, her students, approach her. She looks up.]

Razia: Hello, hello! Want to learn something about my plants?

Jim: We'd love to, ma'm. But can we ask you some questions about something else?

Razia: (laughs) I should have known that was coming! (Vani and Jim start weeding.)

Jim: Well, is it possible that the earth is not flat but round?

Razia: Anything is possible, as long as it is logical. The real question is, do you have any *evidence* to prove that the earth is round?

Jim: Not yet. But I can ask the same question about the flat-earth idea, can't I? Is there any evidence to prove that the earth is flat?

Razia: Well, look at the earth. What we see is flatness, right? We don't see a round earth. So the evidence seems to favour a flat earth, don't you think?

Jim: But the earth is so huge, and we are so small, we won't see its roundness. If we were ants, and the earth were a sphere as big as a house, we would think it is flat, not round. Couldn't that be the case?

Razia: Good point, Jim. Let's see. How do we test the round-earth idea? Suppose the earth is indeed round. If we keep walking for a long time, so that we are not on top of the earth any more but on its side, won't we fall off the earth? Have you ever heard of anyone falling off like that?

Jim: Hmm! (Sits still for a while.) But wait, the flat earth theory has the same problem, doesn't it? If the earth is a flat disk, and we keep walking, we would fall off the edge of the disk.

Razia: May be the disk is so huge that we would never reach its edge in our lifetime.

Jim: But then the same would apply to a round earth!

Razia: You are right. So the two theories seem to be equal.

Vani: Ma'm, the idea of falling off a round earth — mmm, there's something wrong with it.

Razia: Hmm? What's wrong with it?

Vani: Which way would one fall 'off the earth'? DOWN, right? But take an ant on a basketball. "Down" for this ant, wherever it is on the ball, would be in the direction of its feet, which would be towards the center of the ball. So with its feet planted on the ball, the ant could never fall off.

Jim: Wow, that' s an insight, Vani. Yes, you're right!

Razia: Hm! You may be right. But where does that leave us? There doesn't seem to be any evidence either way, for flat earth or for round earth. (Keeps thinking.) I don't have an answer. Do you guys want to work on this as a project for my class?

Jim: Oh, yes, ma'm!...

Razia: Good. Let's do some work with our hands now. Enough use of the head.

Scene 4

[Jim and Vani are at the beach, watching the sunset.]

Vani: Hey, look at that sailboat!

Jim: (Peers at the horizon) Where? I don't see any.

Vani: (Points) Over there. You can't see the boat but you can see its sail. Look straight where I am pointing.

Jim: Oh yes. I see now. What about it?

Vani: I was going to say...

Jim: (suddenly interrupts and jumps up) Vani. I've got it!

Vani: (puzzled) Got what?

Jim: The proof! The proof! (dancing) Vani, I've got the proof! (Sings a proof song.)

Vani: (perplexed) Calm down, Jim. What on earth are you talking about? What proof?

Jim: I can prove that the earth is round!

Vani: But how?

Jim: The sailboat you showed me, it's not under water. Yet, we can see only the sail, not the boat, right? Why is the boat blocked from our view? What blocks it?

Vani: Hm! Interesting. (thinks, then suddenly) Oh! the water! Its level must be curved.

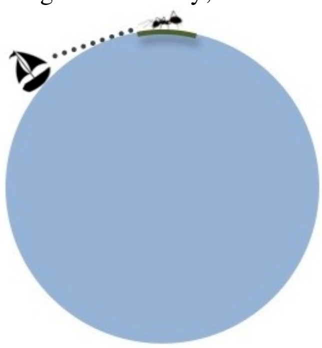
Jim: Exactly! That's the evidence. It shows that the earth must be round.

Vani: I don't get it, Jim.

Jim: Look, Vani. If we are looking at a lake, the water level appears flat, yes? But the ocean is huge. If the earth is round, the surface of the ocean will also curve with the earth. And if it is curved, we know why we can't see the boat, but we can see the sail that is standing tall above the boat.

Vani: I still don't quite get it.

Jim: Okay, imagine a little sailboat on a basketball. An ant is watching it move away, sliding along the surface of the ball. Gradually, the boat would disappear, and only its sail would be visible. And then the sail would also disappear. So, if we assume that the earth is round, we have an explanation for why we see only the sail at some point. If we were to assume that the earth is flat, there is no reason why we can't see the whole boat. Since the flat-earth theory doesn't explain what we see, and the round-earth theory does, we should accept the round-earth theory.



Vani: (thinks for a moment.) Jim! That is brilliant. It's your project paper for Razia Ma'm!

Jim: It's OUR paper, Vani, not mine. If you hadn't pointed that sail out to me, the proof wouldn't have hit me.

Vani: Yeah, but YOU saw the connection.

Jim: Never mind. We'll write the paper together.

Vani: I've to get home, it's getting dark.

Scene 5

[Vani and Jim are walking along. Vani stops suddenly and stares at the moon. Jim is puzzled.]

Vani: (Whispers excitedly) Jim.
Jim: Yeah?
Vani: Look at the moon.
Jim: What about the moon?
Vani: Just look at it.
Jim: What's the matter? Why this sudden interest in the moon?
Vani: Shut up, Jim, and just ...look ...at ...the ...moon!
Jim: (Looks at the moon.) I see the moon.
Vani: Can you now imagine a lunar eclipse?
Jim: Vani, can you tell me what's going on?
Vani: (Breathless) I think I just found another argument for the round-earth theory.
Jim: Huh?
Vani: When there is an eclipse, the shadow of the earth on the moon is curved, right? No matter when or where you see the eclipse?
Jim: So?
Vani: So what explains its being curved? Imagine the shadow of a flat circular disk on a really large ball. What kinds of shapes can the shadow take? It could be circular, or it could be an ellipse. It could even be a straight line. Right?
Jim: Right.
Vani: But if the earth is a sphere, the shadow will always be curved, no matter from which angle, right?
Jim: Right, so that means.... (stops. Sudden realization on his face.) Oh, oh, oh, I see. (Silent for a while.) Wow. (Silent) Vani, you are a genius! That is a knock-down drag-out argument for round earth!
Vani: (pleased) I knew you would like it.
Jim: Of course! It's brilliant! Now do you agree it's OUR paper? I can see the front page of the school newspaper: "*VANI AND JIM ROLL THE FLAT EARTH INTO A BALL*!"
Vani: You really think they would print it?!

Did you enjoy the conversations? Read them again, paying attention to evidence, arguments, and counterarguments. This kind of thinking is very important for scientific inquiry.

7 Earth: stationary or moving?

You have all observed the position of the sun changing through the day, right? In the morning, the sun is very close to the horizon, on the side that we call East. As the day moves on, we observe that the distance between sun and the horizon increases. Around midday, the sun is above our head. In the afternoon, the distance between sun's position and the horizon on the West side decreases, until in the evening it is at that horizon. And then it disappears behind the horizon.

So now we have this daily cycle of sunrise and sunset, and changes in the position of the sun in relation to the earth's horizon. How would you explain these patterns?

There are two ways of doing it. One is to assume that the earth is stationary, and the sun revolves around it. This is the idea of what is called the 'geocentric theory' of the earth and the sun. *Geo-* means 'earth', so geocentric is 'earth-centered'. This theory assumes that the earth is stationary, and that it is the center of the universe.

The other way of explaining these patterns is to assume that day and night are caused by the earth rotating, or spinning, and also revolving around the sun. This is the idea of what is called the 'heliocentric theory'. *Helio-* means 'sun', so heliocentric means 'sun-centered'.

Take an orange, and a lighted bulb. Move the bulb in a circular path around the orange. You will see that half the orange is brightly lit (daylight on earth), while the other half is dark (night on earth). As the bulb moves, it lights different regions along the way, till it returns to the original position. This is how the geocentric theory explains day and night.

Instead, we could keep the bulb stationary, and make the orange rotate, as in the heliocentric theory. And you would get the same effect of different regions of the orange getting lighted up. So, for the 24-hour cycle of day and night, both these theories work equally well.

Which of these theories should we accept?

As we mentioned earlier, our experience tells us that the earth is stationary. We don't feel the earth moving. If we go by our experience, we should conclude that the earth doesn't move. We would then be subscribing to the geocentric theory.

Now, the modern scientific community subscribes to the heliocentric theory. This by itself should not force you to reject the geocentric theory and accept the heliocentric theory. After all, you should go by your own experience unless you have reason to believe that what your experience tells you is false. In this case, can you conclude that our experience misleads us? Are there any persuasive reasons to conclude that even though we feel the earth to be stationary, it actually revolves around the sun, and rotates around itself?

Do you know why we explored the earth and the sky, and looked at two different theories of the solar system? It was to help you appreciate the role of evidence and arguments in constructing and evaluating scientific theories.