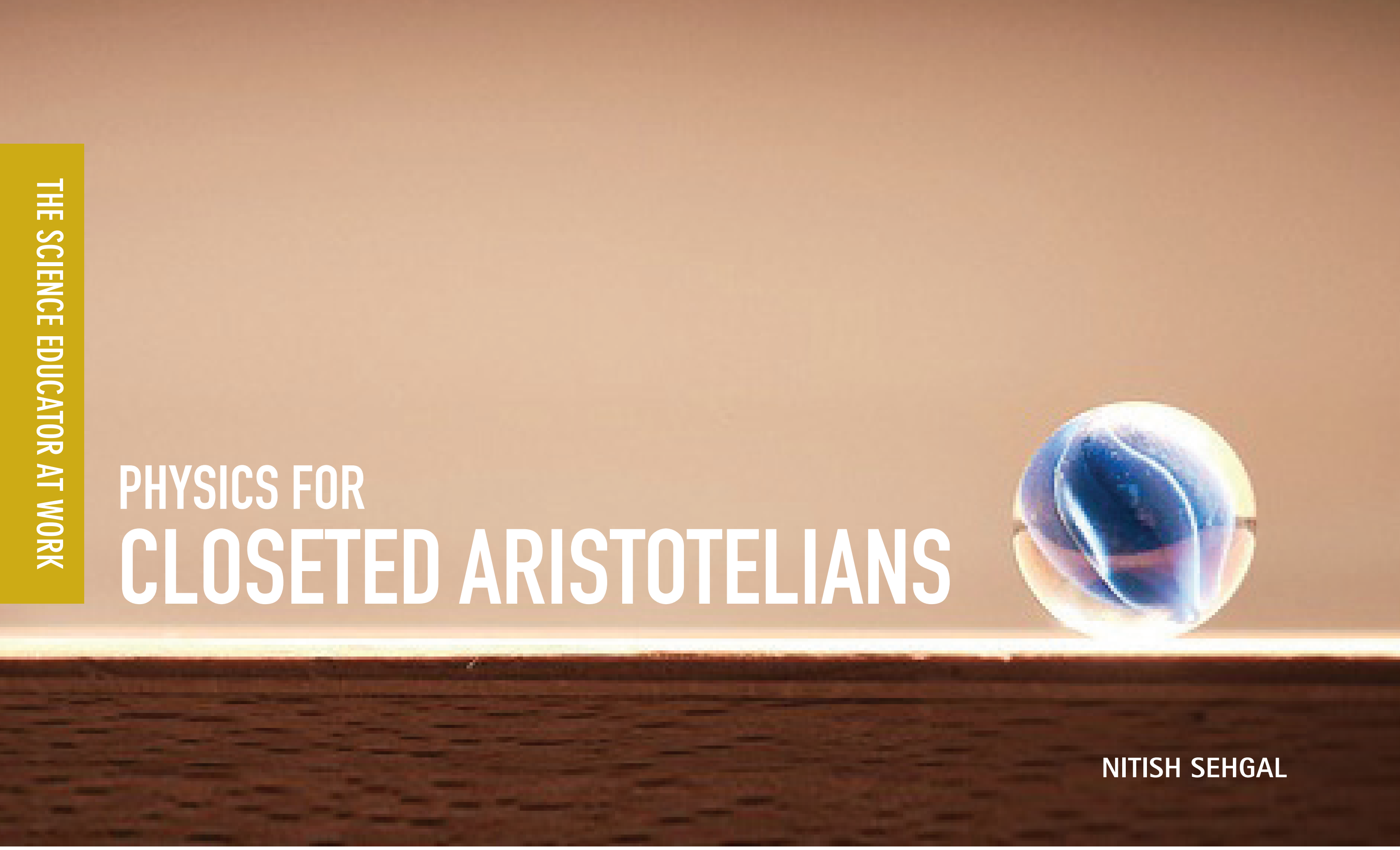


PHYSICS FOR CLOSETED ARISTOTELIANS

NITISH SEHGAL

Children aren't empty vessels. They come to class with amusing, surprising and deep-rooted ideas, inconsistent with contemporary science. It is imperative for a teacher to recognise this and initiate a process of change as such ideas could hamper learning.

We grapple with physics every day, often without recognising the insights that established theories in this discipline provide to our understanding of day-to-day phenomena. Given the human tendency to rationalise, we tend to construct intuitive causal theories to understand and make predictions about the world around us. These intuitive theories are usually inconsistent with established scientific theories, leading to myriad misconceptions about physical phenomena.

One such misconception, around the concept of force, emerged from a discussion on projectile motion with 70 (20 boys & 50 girls) grade IX students of a government high school at Bairagarh Chichli, Bhopal, Madhya Pradesh.

Drawing out intuitive models of motion

The students were asked to predict the path a ball or marble would take if it were to be rolled off the edge of a table with a certain horizontal velocity (see **Concept Builder: Motion under the influence of gravity**). Only two students chose Option II, while the rest chose Option I.

In an effort to bring their underlying theories on motion to light, the students were invited to share the rationale for their predictions. Those who chose Option I reasoned that the force applied by the agent to push the ball from the table would be transferred to the ball. As a result, the ball would continue to move in the same direction (~ a straight line) till this force became weak enough to have no effect on the ball's motion. At this point, gravity would start acting on the ball, pulling it down. This seemingly logical explanation is not new — it has a lot in common with the impetus theory of motion (see **Box 1**). In contrast, the two boys who chose Option II explained that their response was based on the positions they were most likely to take to field a catch in their daily game of cricket.

One way of getting learners to question the validity of their mental models is to provoke some **cognitive dissonance** by offering counter-examples. Thus,

students from both groups were encouraged to test their predictions before the next class. To identify any change in their existing cognitive schemas, even if only at the peripheral level, students were given the choice of revising their responses.

Testing intuitive models of motion

When discussion around the experiment was resumed in the next class, both groups continued to stand by their earlier choices. However, the first group (of closeted Aristotelians) suggested that the path of the ball in Option I be modified to reduce the length of its linear portion (see **Box 2**).

It is likely that on trying this experiment out, the students who'd chosen Option I had noticed that the ball or marble they'd launched did not show such a prominent horizontal path. This was reflected in their attempt to tweak their intuitive model (to accommodate the anomalous observation) instead of rejecting it entirely. Consequently, their ideas about motion remained fairly consistent with those of the impetus theory and reflected certain elements of Albert of Saxony's model for projectile motion.

In order to provoke students to question the validity of their preferred mental model of motion, the class

Box 1. Theories of motion — a brief history:

One of the earliest explanations of motion came from Aristotle who proposed that 'rest is the natural state of all objects and every (instance) of motion has a cause'.[1] He believed this to be true even in cases where the cause was not apparent. For e.g., he explained the motion of an arrow after it had left a bow by concluding that the medium (air) through which the arrow travelled had motive power that pushed it forward.

These Aristotelian ideas were rejected by the 6th century Alexandrian philosopher Johannes Philoponus. Philoponus proposed that the active agent imparts an immaterial motive power to an object thrown into the air. This motive power sustains the motion of the object until it gets dissipated due to resistance by the medium. Jean Buridan, a 14th century French philosopher, used the term 'impetus' to refer to this motive power.

Soon after, Albert of Saxony used the impetus theory to suggest that the motion of a horizontally launched projectile could be explained in three stages. In the first stage, the impetus imparted by the launcher suppresses the effect of gravity and pushes the projectile forward. In the second stage, the impetus is weakened by air resistance. Thus, the motion of the projectile in this stage is the result of a compromise between impetus and gravity. In the final stage, the impetus is exhausted and the projectile falls vertically under the effect of gravity (see **Fig. 1**).[2]

It was only in the 17th century that Newton managed to successfully codify the behaviour of objects in motion in the form of three laws. According to the first of these laws, all objects tend to be in a state of rest or uniform motion in a straight line unless compelled by an external force to change this state. This law helped resolve some key questions related to the motion of objects after their separation from an active agent. For e.g., why do objects keep moving when separated from the agent? This law states that they just do; it's in their nature. Newton called this 'nature' inertia, but could not explain why objects behave the way they do. Thus, Newton's 'inertia' seems akin to the Aristotelian concept of 'natural motion' that is directed towards the natural place of the body and requires no explanation for its continuation.

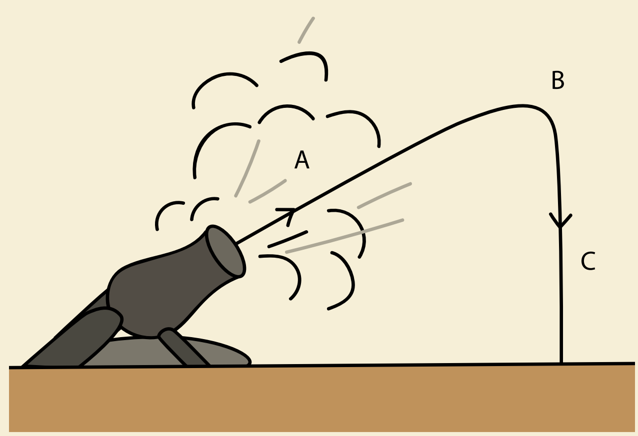


Fig. 1. Medieval ideas of projectile motion.

Box 2. Who are closeted Aristotelians?

Once a child realises the need to exert a force to push or pull an object (see **Fig. 2**), she may arrive at the hypothesis that force is required for motion.

Belief in this hypothesis may become stronger with every case where the child observes the motion of an object under the influence of a force exerted by a 'visible' external agent. As this hypothesis gets tested time and again and is found to be robust each time, it may get elevated to the status of a theory.[3] Interestingly, this folk theory is consistent with the Aristotelian idea that force is imperative for motion.

By the time the child comes across Newtonian ideas of motion in the school physics syllabus, her belief in this folk theory may interfere with her ability to understand or apply Newtonian ideas to her observations of real-world physical phenomenon. In fact, Newton's first law of motion and the concept of inertia may often seem counter-intuitive since we never come across a system in our lives which is free from all forces. This is likely to become evident in her predictions about the trajectory of an object moving under the influence of non-contact forces or in the absence of an external agent.

At this point, the child may lead a dual life. She may describe the motion of objects with Newton's first law in classroom discussions and examination papers, while subscribing to the seemingly intuitive Aristotelian folk theory to understand it in real-world phenomenon. It is this dual life that is captured by the term — 'closeted' (meaning: in private) Aristotelians.

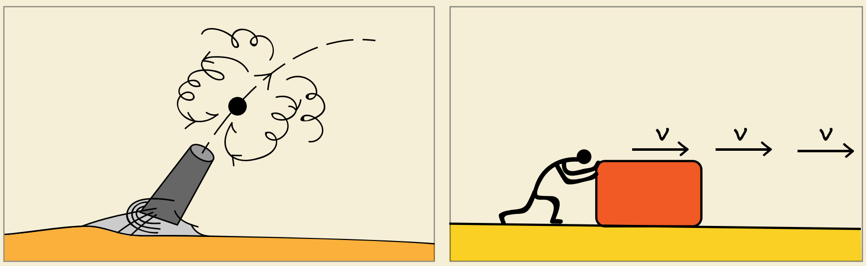


Fig. 2. Intuitive folk theories on motion may be consistent with the Aristotelian idea of motion: (a) A rush of moving air pushes to keep the cannon ball going; **(b)** A push is needed to maintain motion.

was encouraged to set-up a practical demonstration of the experiment. This led to a discussion on method — how would the path (I or II) of a marble to point B be determined? One of the students recommended creating a video since the marble's speed may cause its path to remain imperceptible to the naked eye. Although he could not verbalize what he wished to do with the video, the other students agreed to try this method out.

Prior to the next class, the instructor shot many videos of marbles with different horizontal velocities being rolled off the edge of a table. These videos were shot at a relatively high frame rate (i.e., in slow motion) so as to allow viewers to trace the path of the marble. When these videos were projected on the blackboard, the students argued that if a marble were really to move at the sluggish pace seen in the videos, it would simply topple off the edge of the table. Re-iterating that the videos had been shot in slow motion seemed to make no difference to student views on the motion of the marble. To remedy this, the students were encouraged to record their own videos of the marble's path, and use these to make sense of how a slow-motion video depicts things occurring in real-time.

Once the student-shot videos were ready, the instructor used their projections on the blackboard to trace the path of the projectile. A marble seemed to take ~400 milliseconds to hit the ground. Given the marble's negligible vertical velocity, no appreciable vertical displacement was observed within the first few milliseconds of its leaving the table. The students continued to interpret this as evidence that the marble moved in a straight line, albeit for a much smaller amount of time than in their original prediction. This seems to suggest that even when faced with scenarios that present information or evidence inconsistent with their intuitive theories, children may tend to focus on those elements of the scenario that seem vaguely consistent with these theories. This tendency can be explained through two facts — we are cognitive misers, and processing familiar information requires a smaller cognitive effort than that required for processing new information.

Once it was established that the marble took a curved path, some students voiced their concerns regarding the demonstration. They asserted that it was because the marble was round in shape that it took a curved path. A cuboidal object would take the path depicted in Option I; a sharpener with both square and circular edges would take the path depicted in Option II; and an irregular object would take an irregular path. The instructor asked the children to test their assertion by using slow motion videos to record the launch of each of these objects. This new batch of videos was projected on the blackboard, and students were invited to trace the trajectories of each of these different objects. This exercise proved beyond doubt that the shape of the objects did not alter its trajectory. However, the belief that objects continue to move in a straight line after breaking contact with the table seemed to remain more or less unaltered for students who started out with such a preconception.

Teaching reflections

At a programme level, it may be worth considering why Newtonian ideas on motion are introduced only in high school. Why are students given so much time to form their own ideas and theories about motion before there is any curricular intervention to address them? Then, over a course of the 2-3 years of secondary and higher secondary schooling, the student is expected to shun her beliefs and accept what the textbook presents as 'correct knowledge'. Research shows that older children may be less flexible (sometimes, even less interested) than younger children in altering their mental models, suggesting that it may be better to catch them young (see **Box 3**). This does not discount the difficulties of making such concepts intelligible, plausible, and useful for young children.

At the curricular level, it may be useful to re-consider the sequencing of topics in mechanics in science textbooks (see **Box 4**). Students are first taught about motion in kinematics without learning its causes (or the manner in which forces influence motion). They study acceleration as a mathematical quantity without having insights into its causes or physical implications. It is only when the topic on forces is introduced do they get a taste of the causes of acceleration. Till that time, they are left alone with own imagination about the causes of motion. Is this what leads them to seek various common sense and intuitive ideas about different phenomenon?

Pedagogically, folk theories may be best addressed by devising exercises that help students become 'acutely aware of their misconceptions'.[1] Getting students to verbalize or pictorially depict the models they have of a particular phenomenon may help teachers understand the specific nature of their folk theories. This can be used to plan an intervention that introduces the concept in an intelligible, coherent (internally consistent), plausible (not irreconcilable with the child's other world views) and fruitful (more useful than the older viewpoint) manner.[4]

Box 3. A discussion with an older student:

The instructor happened to pose the same question to a grade X student during an informal interaction. The following is an excerpt from the interaction (although not verbatim):

I: *"Do you think the marble launched from the table would continue to move in a straight line once it leaves contact with the table?"*

S: *"Yes, it would. Because it was pushed in the horizontal direction. It was imparted a force which would keep pushing it in the horizontal direction. Say, if the agent applied 100 N of force, 40 N of force was transferred to the ball. This force would dissipate as a consequence of friction from the table, and when the ball leaves the table it would have a force smaller than 40 N. Then, air friction would further dissipate this force, and the object would start falling due to gravity..."*

At the time of this interaction, the student had received instruction about projectile motion in kinematics both at a private school of 'repute' and a 'good' coaching institute. However, his conception of projectile motion remained the same as that held by a majority of students from the government school with no access to tutoring outside school or resources other than school textbooks. One could be treading on thin ice in drawing generalizations, but providing 'quality instruction and resource material' may not be sufficient in challenging a child's preconceptions and folk theories.

Box 4. How do textbooks introduce motion?

A couple of physics textbooks were examined for the manner in which projectile motion was introduced. 'Concepts of physics' by H.C. Verma introduces projectile motion in this way:

"*...When a particle is thrown obliquely near the earth's surface. It moves along a curved path. Such a particle is called a projectile and its motion is called projectile motion...*".[4]

This is followed by an elaboration of the mathematical treatment of this concept, without any attempt whatsoever to help the student reflect on her understanding of motion. Similarly, Sears and Zemansky's 'University physics' provides an elaborate introduction of the concept of motion, offering many illustrations and solved examples, but does not provoke students to reflect on their own ideas about the phenomenon. It is likely that the authors of these texts look at students as mere recipients of knowledge instead of reflective practitioners capable of constructing knowledge and questioning it.

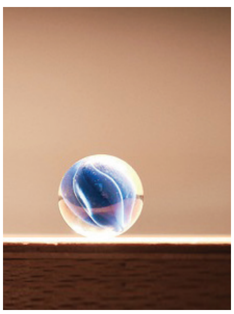
To conclude

Here's another exercise for the physics educator:

A person holds one end of a string in her hand. A mass is tied to the other end. The person starts rotating the mass along a horizontal plane. What path would the mass take once the person lets go of the string?

How would you respond to this question? Pose this question to your students, and seek their responses. If quite a few responses turn out to be folk myths, can you think of an experiment or a pedagogical strategy that counters it?

Key takeaways



- Given the human tendency to rationalise, we tend to construct, often incorrect, intuitive causal theories to understand and make predictions about the world around us.
- With foundational concepts, students may use accepted scientific theories, like Newton's first law of motion, in classroom discussions and examination papers, while holding on to intuitive folk theories to understand real-world phenomenon.
- Providing 'quality instruction and resource material' may not be sufficient in challenging a child's preconceptions and folk theories.
- Exercises requiring students to verbalise or pictorially depict their understanding of particular phenomena may help teachers draw out folk theories that children have constructed.
- An understanding of student folk theories can be used to design pedagogical strategies (like the use of counter-examples to provoke cognitive dissonance) that introduce foundational concepts in an intelligible, coherent, plausible and useful manner.

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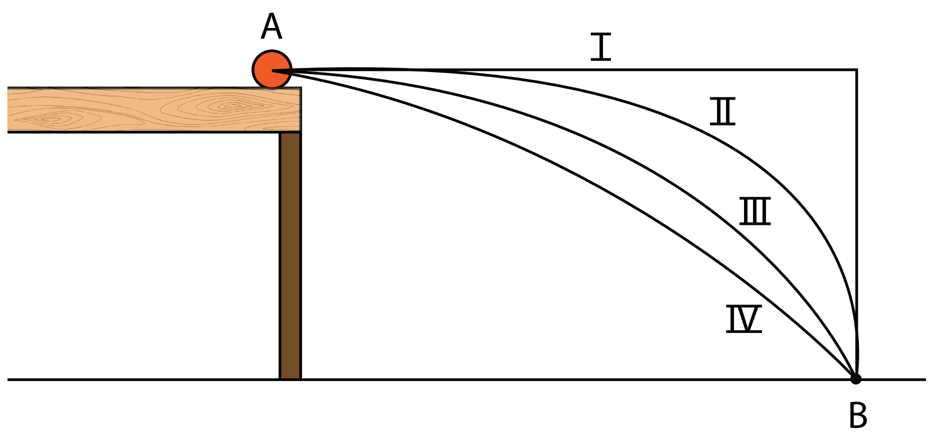
The Science Educator at Work

CONCEPT BUILDER: MOTION UNDER THE INFLUENCE OF GRAVITY

Imagine:

A moving ball rolls off the edge of table (position A) and falls to the ground (position B).



Predict:

Which of these paths is the ball most likely to take?

- I
- II
- III
- IV

Explain:

Your reason for choosing the Path you predicted.

Discuss:

How would you test if your response is accurate?

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