History of Science & Science Education

(Some Observations)

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Introductory Remarks

- Most scientists and science teachers do have interest in history of science. It is not uncommon for a teacher to narrate interesting historical episodes (usually associated with 'great' scientists) in the class, and occasionally, some teachers may even dig deep into the historical development of the concepts they are teaching. Yet this is almost always taken as a refreshing digression from the main business of teaching; 'covering' the topics of science laid out in the syllabus.

- The 1960s saw a wave of curricular reforms across many countries and a feeling was beginning to grow among some people that we should go beyond this token use of history of science and examine more thoroughly how HoS could be an important resource for science education.

- Since around the same time philosophy of science (PoS) was getting intertwined with history of science (due mainly by Thomas Kuhn’s work), it is not surprising that PoS (once regarded abstract and esoteric) was also thought to have a role in science education.

- This was the beginning of the new field "History and Philosophy of Science, and Science Education", which is currently an active area of science education research.

- The field has several dimensions, and is relevant to education in different scientific disciplines: physics, chemistry, biology, mathematics etc. across different (middle school, high school, college/university) levels.

- An impressive body of work in this field has accumulated over the last five decades. An excellent journal “ Science and Education” (edited by M. Matthews) and recent Handbooks on the subject give a good idea of the scope of this field and have many insightful articles by leaders in the field. (References at the end.)

- Recent curriculum reforms in several countries have stressed the importance of history of science, particularly in connection with teaching ‘the nature of science’ as part of science curriculum.

- In India, The National Curriculum Framework-2005 does recognize the importance of this subject; but so far it has not influenced in any noticeable way the science textbooks in the country or science teaching.

- One aim of this talk is to advocate this field for science education research, particularly in India. HPS has much to offer to science education, but we are not for unqualified HPS-based science curriculum. Its precise role and its efficacy for science learning are matters for research and the answers may vary between different disciplines, and from one topic to another in a discipline.

- Still, a good thing about the field of HPS and Science Education is that it brings scientists, science teachers and science educators, historians and philosophers of science on a common platform. It has a potential to bridge the divide between humanities and sciences.

‘Historical Approach’ to Science Education

- The history of science-inspired approach to science education – the historical approach, for short – has many distinctive positive points in its favour, that we now describe briefly.

‘Historical Approach’ to Science Education *(continued)*

- ***Interest and motivation***

Historical narratives generate interest and motivation for science. Stories of great scientists and their work can be a source of inspiration to everyone, especially young students. Such scientists become role models for students.

- ***Demystification of science***

- Historical approach demystifies science. It helps us view science as an activity carried out by humans like us. We become aware that science is a result of work not by just a few ‘chosen’ extraordinary individuals, it is a cumulative effort of many ordinary men and women throughout history.
- Also, great scientists too can go wrong and astray occasionally. This demystification of the scientific enterprise can help us in shedding inhibitions and generating self-confidence.

- ***Propagating science related values***

- History of science can be an effective vehicle for propagating science related values such as curiosity, objectivity, honesty and truthfulness, courage to question, open mindedness, search for perfection, team spirit, antiauthoritarianism, etc.
- (We must add that many philosophers and sociologists hold the view that actual scientific practice does not really follow these professed values, but we do not enter into that debate here.)

- ***Mature perspectives on the scientific enterprise***

- Historical approach helps us develop mature perspectives on science. History puts science in its proper context. The historical approach goes against a static, ‘finished product’ image that many people have about science. It projects science as ever dynamic, expanding its scope and depth with time.

- Further, it helps us view science as a social endeavour that transcends boundaries of class, religion, country, etc. We come to realize that scientists are a social community, much like any other social community, with its own interests, norms and conventions.

- ***Perspectives On The Nature of Science***

- The methodology of science emerges implicitly in an historical approach. We also learn that as science progresses, our ideas on the so-called scientific method also change. The ‘scientific method’ has been a subject of much philosophical debate.

- History-inspired science education is a natural context for bringing out the philosophical underpinnings of science.

- ***Understanding the content of science better***

- Lastly, and perhaps most importantly, historical approach to science education can improve and deepen students' understanding of science in several ways :

- ***Parallels between history of science and student conceptions***

- One significant observation in this regard is that in several areas/ topics of science, there are interesting parallels between students' spontaneous cognitive frameworks and the conceptual frame- works encountered in the history of science (before the emergence of modern scientific concepts).
- Thus history can be used to help students confront their spontaneous ideas, see their limitations and arrive at the modern conceptions in science.

- ***Critical understanding of science***

- History brings forth alternative concepts/ models/ arguments at different stages of scientific development. Understanding how and why one particular concept/ model was preferred (that eventually led to the modern conceptions) can help students develop a critical understanding of science.

Examples from History of Science

- We consider the following three examples from history of science:

1. The concept of force: Aristotelian and Impetus theories
2. Theories of vision, and
3. Combustion and the Phlogiston theory.

- We feel such vignettes on historical debates on key ideas in science can alert students about their alternative conceptions, and improve their perspectives on the nature of science and its development.

The concept of force: Aristotelian and Impetus theoretic notions

A widely prevalent students' notion is that a force is always required to keep a body in motion; the greater the velocity and mass, the greater the force needed to keep it in motion. This notion is, of course, rooted in our experience of bodies coming to rest when (apparently) there is no external force acting on them.

- Of course, we have all learnt that when bodies initially in motion eventually stop, they do so under the action of <u>external</u> forces – the frictional/viscous forces, etc. that cannot be completely eliminated in practice.

- Yet this fundamental insight (due to Galileo, Newton) that rest and uniform motion are equivalent is not an easy concept to internalize.

- This is hardly surprising; even Aristotle, regarded as one of the greatest thinkers of antiquity, did not have this insight.

- Aristotelian physics was part of a grand holistic worldview that we cannot go in detail here. Briefly,

- Aristotle regarded all (terrestrial) matter to consist of four elements: earth, water, air and fire. (The heavens are different, made of ‘ether’--pure and unchangeable.)

- Each element has a tendency (‘desire’) to reach its ‘natural place’ of rest : earth at bottom, then water, then air and fire at the top.

- All motion was viewed in terms of two categories: ‘the natural movement’ and the ‘violent movement’.

- The ‘natural movement’ is the spontaneous motion of an object towards its ‘natural place’. (Actual motion is determined by which of the elements is more abundant.) The ‘natural movement’ of the heavenly objects was circular (without a beginning or end).

- A corollary of this view was that the speed of natural motion was proportional to the amount of the dominant element. That is how Aristotle concluded that bigger stones will fall to the earth faster than smaller stones.

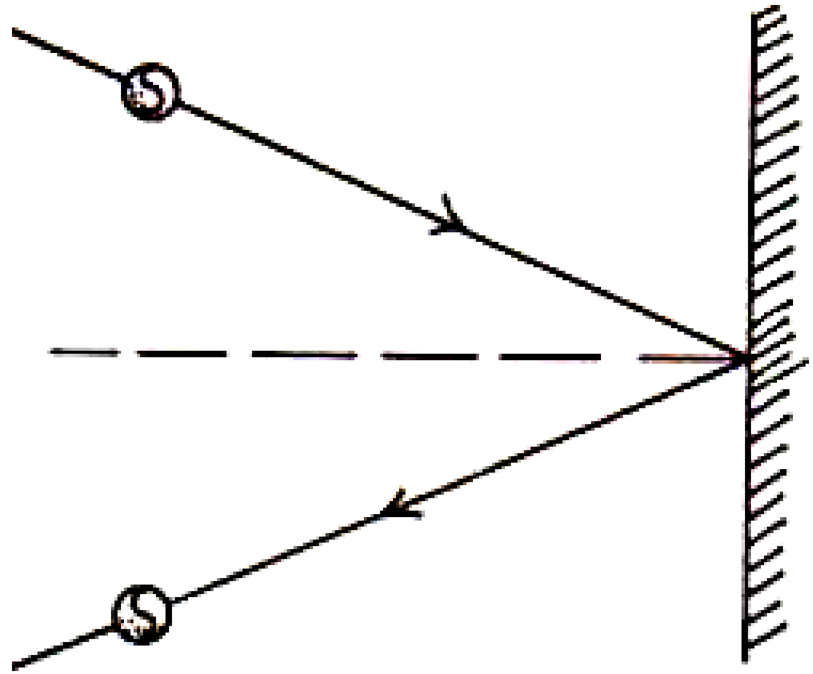
- The other category, ‘violent movement’ is the motion caused by an applied force. The greater the applied force, thought Aristotle, the higher the object’s speed; the higher the mass, the lower is the speed for a given force. In modern terms, Aristotle’s principle of motion is

Force *proportional to* mass x velocity

This agrees with the spontaneous ideas among students about the need for external force to keep a body in motion.

- The *Force* α *velocity* syndrome is very robust; it can appear disguised and in combination with another prevalent misconception.

- To see this try the following question on a student who correctly recites all the three Newton's Laws of Motion.



A ball hits a wall obliquely as shown. What is the direction of the force with which the ball hits the wall?

- A common answer: The force is in the incoming oblique direction.

Just what the Aristotle's principle of movement says! Clearly, the student has not internalized the Second Law which tells you that <u>force</u> is always in the direction of <u>change of momentum</u>.

- *(Correct answer: force on the wall by the ball is along inward normal direction for elastic collision.)*

- If you probe the student further, something else may reveal itself, something that is not an Aristotelian response:

- The force is in the incoming oblique direction since somebody must have thrown the ball with a force in that direction. In the student's mind the force is being 'carried' from the initial time the ball was thrown at the wall. This widely prevalent notion shows up even in the simplest of questions:
- Describe what happens when a ball is thrown vertically upward, <u>after</u> it is out of touch with the hand.

- A typical response:

During the upward journey, there are two forces acting on the body, one due to gravity and the other, the force needed to throw it up.

The second dominates in the upward journey.

At the uppermost point, the initial force has spent itself out; the ball then falls freely under gravity.

- This ‘absurd’ response (from the point of view of modern physics) seems actually very natural.

- It arose in history in the Middle Ages, when people began to feel uncomfortable with the Aristotelian answer to the question “why does an arrow go so far?”

- For Aristotle, this was an example of ‘violent movement’, so something must be pushing the arrow. That ‘something’ was the air behind the arrow.

- Jean Buridan (14th century) was among those who argued against the Aristotelian view and advocated the so called 'Impetus Theory'.

- According to him, the arrow continues to move not because of air pushing behind but because at the initial time it is projected it stores something called impetus. The more the impetus the farther it will go.
- Impetus theory was a transitional stage between Aristotelian and Newtonian mechanics.

- Aristotle said that an external force was needed to keep a body moving (violent movement); in impetus theory a body moves by an internal force impressed in it when it is set in motion.

- “When a mover sets a body in motion, he implants into it a certain impetus, that is, a certain force enabling the body to move in the direction in which the mover starts it, be it upward, downward, sideward, or in a circle. It is because of this impetus that a stone moves on after the thrower has ceased moving it”. (Buridan)

- Even Galileo was not free from impetus theory ideas in his early writings.
- “The body moves upward provided the impressed motive force is greater than the resisting weight. But since that force……is continually weakened, it will finally become so diminished that it will no longer overcome the weight of the body and will not impel the body beyond that point…As the impressed force characteristically continues to decrease, the weight of the body begins to be predominant, and consequently the body begins to fall.” (Galilei G., *De Motu* (ca.1590)).

- The similarity with a typical student response is striking.

Early Theories of Vision and Children's ideas

Early Greeks had conflicting models of vision.

- *Extramission theory* was advocated by the Pythagoreans:

The eye emits out something in the act of perception.

- Plato had a more sophisticated version of this view:

The 'visual fire' emitted by the eye merges with daylight and forms a single homogenous body extending from the eye to the object – this body transmits the image from the object to the eye.

- ***Intromission theory***

Epicurus:	Objects emit ‘particles’ that (atomist) have the same appearance as objects – and thus cause perception.
Aristotle (not an atomist)	Medium plays an active role.

Advocates of extramission criticized intromission and vice versa:

- Intromission theory would mean objects would diminish with time. (Not quite, said Epicurus, other particles continuously take their place!)

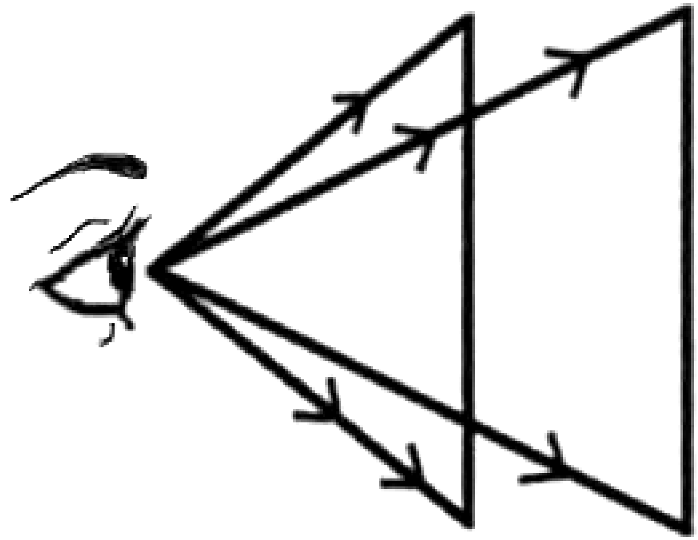
- Extramission theory cannot be correct, said Aristotle

  Visual fire from eye reaching out to the sun and stars is inconceivable each time we open our eyes to look at the sky.

- But for a while Extramission Theory seemed to have an upper hand mainly due to Euclid's book on optics.
- **Euclid's argument**:

  To see a needle, you must see it directly, else you cannot see it. You must actively send rays from the eye; in the alternative (intromission) picture, the needle is sending rays all the time, then you should be able to see it as long as your eyes are open, whether or not you are looking at it directly.

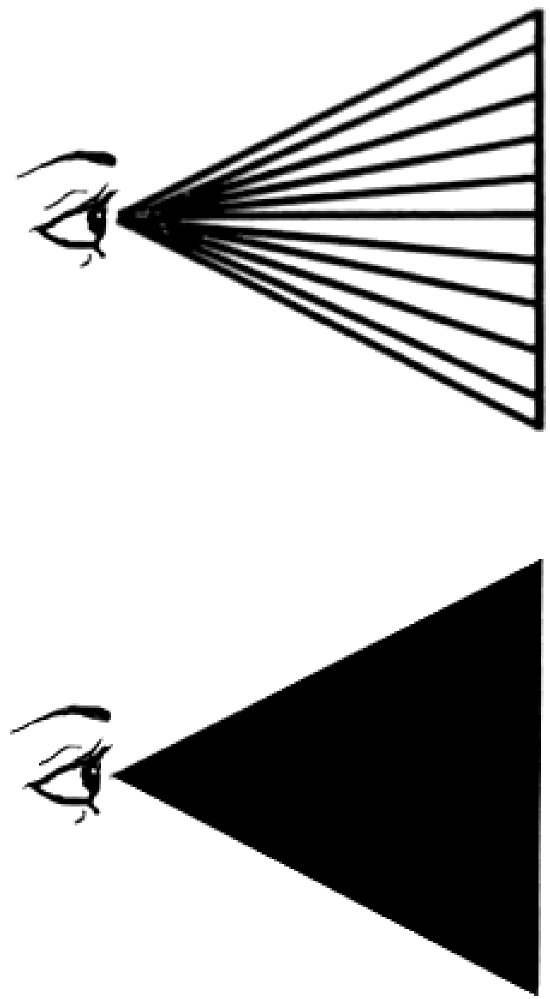
- This argument in its different versions held sway for centuries.



Euclid’s model of vision

Eye sends out visual straight rays to the object being perceived. These rays form a cone with its apex at the eye. The apparent size of the object is the angle of the cone.

- Is the eye sending a finite number of rays or is the visual cone completely filled with light from the eye?



- There are problems with both.

If there is finite number of rays, objects located between two rays could not be seen – very small nearby objects and larger objects at greater distance. But in this view objects at a distance would be alternately visible and invisible as the head is turned slowly !

In the continuous view (held by Ptolemy), the eye will emit infinite number of rays from a single point

- While Europe entered its Dark Age, Optics became a forte of Arabian science.

al-Kindi (9th century AD) supported extramission and argued against intromission.

- A flat circular disk looks a line segment not a circle when viewed edge on.

- Hearing by intromission: ear not movable but has a shape to receive sound. By contrast the eye is movable directing itself to the object to be seen.

- If intromission were true, objects at the edge of visual field would be seen as clearly as those at the centre.

- When you look at the page of a book, you don't read the entire page simultaneously – you move your eye along to select a small portion.

- For Al-Kindi, Extramission involved visual rays being emitted from all points on the open surface of the eye. (Contrast this with Euclid and Ptolemy.) Objects at the centre of visual field would receive more rays than those at the edge

- Extramission theory was widely accepted up to the 13th century, though the meaning of visual rays/fire was not clear and many reservations remained unanswered.

- Among the strong advocates of intromission was Avicenna (986–1037 AD). His criticism of al-Kindi's extramission theory:

* Two or more people with weak vision standing close would improve vision of each !

* In the continuous case (Ptolemy), it is absurd to think the eye can produce something to fill half the entire universe.

* In the discrete case (Euclid), you will see only a few tiny parts of the distant bodies, missing most of their surfaces. But in realty our vision is continuous, not spotty.

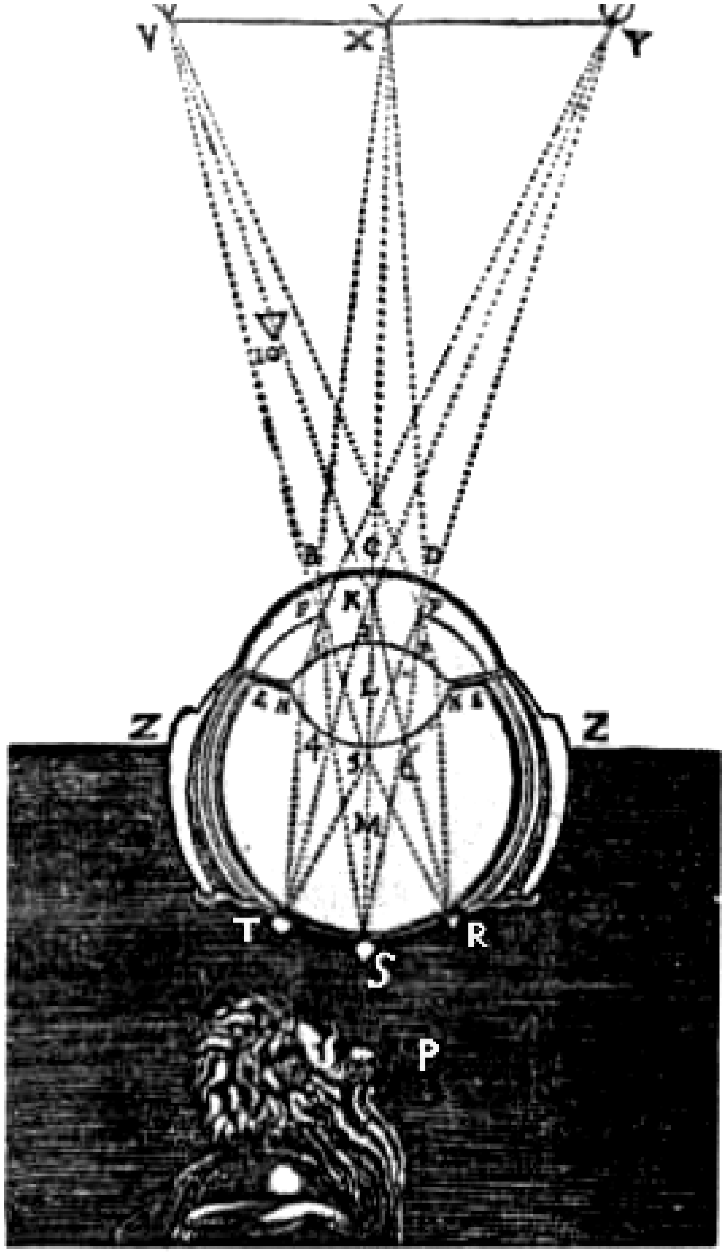
Alhazen – A step forward in intromission theory.

Rather than thinking that the entire object sends out tiny 3D copies of itself, Alhazen said that each point or small region of the object radiates in all directions. This was a key step forward.

But Alhazen could not satisfactorily deal with the problem that each point of the eye would receive a jumble of rays from all points of the object.

Kepler – Towards Modern View

- The pinhole camera used by astronomers of his day gave the concept of image: one to one correspondence of each point in the object with a point in the image.
- Using the knowledge of eye anatomy at the time, Kepler correctly argued that the diverging rays from a point on the object striking different parts on the eye get refracted by the eye lens at a single point on the retina at the back of the eye.
- This resolved Alhazen’s difficulty.



On the retina is the inverted image of the object. It is actually not necessary to correct this inversion. The brain co-ordinates physical movements of our body with the inverted image itself.

Figure from **Physics the Human Adventure (Holton and Brush) p.47**

Children's ideas on light and vision

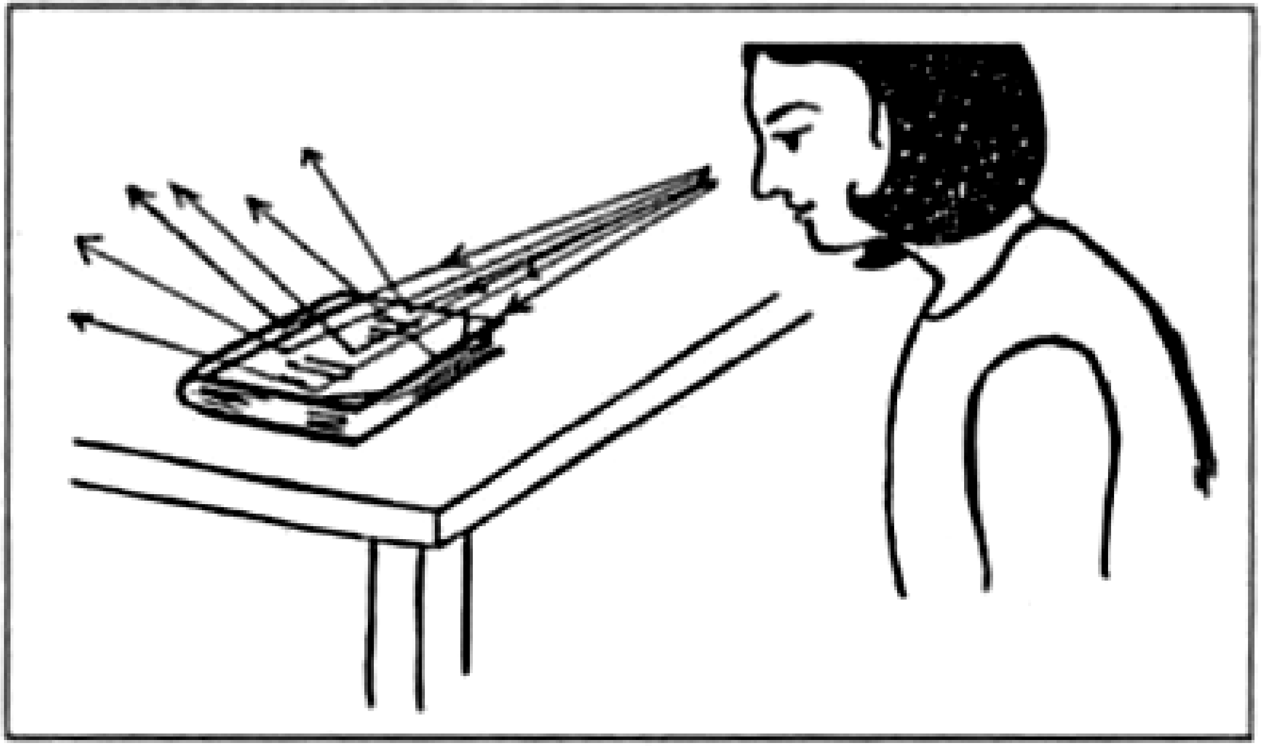
- An early systematic study of this topic was carried out by Jayashree Ramadas and Rosalind Driver.
- Many children equate light either to its source or to its effect (i.e. brightness) but do not give it a clear autonomous status as an entity existing in space between the source and the effect.
- Some do not appreciate that light from a source propagates in every direction and to any distance; for them light 'stays' on a burning candle or it comes out to us but not farther.

- How do we see objects ?

- Interestingly, vision is ‘explained’ differently depending on whether the object is self-luminous or not.

- We see the former since light comes out from it. For non-luminous objects, vision is explained by giving the eye an active role. Light comes out of the eye to see the objects!

- If you ask a child to draw a free drawing of how she thinks she sees say a book on a table, chances are that the figure will show rays coming out of the eye, striking the book and going off in other directions.



- The child’s model is not very different from the extramission theory discussed earlier.

- Many languages embed this intuitive model of vision. Phrases like ‘the twinkle in his eyes’, ‘her eyes shining with pride’ engender or reinforce the wrong model.

- Metaphorical statements that appear in many Indian languages (e.g. “The flame in his eyes extinguished at last”) clearly give the eye the role of a source, not of a detector that it is.

Combustion and Phlogiston Theory

The phlogiston theory originated around 1700 from the ideas of Joachim Becher (1635-1682) and was consolidated by George Ernst Stahl (1660-1734). Several prominent European chemists of the 18th century supported the theory. Joseph Priestley (1733-1804), the discoverer of Oxygen, was among its most ardent supporters.

The theory was overthrown mainly by the quantitative experimental work of Antoine Lavoisier(1743-1794) ushering in what is often termed 'The Chemical Revolution'.

- The phlogiston theory was motivated by the fact that a large number of chemical substances were combustible; some like carbon and sulphur burned with a flame and released a large amount of heat, while others like metals transformed during calcination and left residues of combustion (*calxes*).

- The theory postulated that there was a component (which Stahl named *phlogiston*) present in all bodies that carried the property of combustibility (*the inflammable principle*).

- Bodies that burn easily, like wood, charcoal, sulphur and phosphorus contain large amounts of phlogiston. Metals also contain phlogiston; calxes do not . Both burning and calcination were seen in a unified way as release of phlogiston; the residue, consequently, was devoid of it (or had little of it).

- In this theory, the calx is the simple substance, what burns or transforms is a ‘compound’. Thus metals differ because of the difference in their calxes.

Properties of Phlogiston

- Phlogiston can never be destroyed. For producing a flame, both phlogiston and free air are necessary.

- During combustion, it is released in the form of fire and dissipated in air. There it occurs in a free state, in winds, clouds (sometimes showing up in lightning!). It is passed from air to plants to animals. There is a phlogiston cycle in nature.

Properties of Phlogiston *(continued)*

- Combustion needs a large amount of air since air has a low capacity for absorbing phlogiston.

- Phlogiston does not combine with water or highly watery bodies.

‘Evidence’ for phlogiston theory

- Stahl showed that if the metallic calx is heated with a substance rich in phlogiston, the initial metal is recovered (proof of transfer of phlogiston).
- For example, lead (more phlogiston)on heating became litharge (less phlogiston) which on further heating became minium (still less phlogiston).
- Reverse way, litharge heated with wood charcoal (rich in phlogiston) regenerates the metal.

Difficulties with phlogiston theory

- According to this theory, combustion should result in a decrease in weight. The observations were just the opposite : the resultant body was found to weigh more than the original—the phlogiston seemed to have negative weight!

Fixing the difficulties with phlogiston theory

- Numerous ideas were floated to fix this problem. The negative weight of phlogiston was explained by saying that phlogiston being lighter than air decreased the apparent weight of a body carrying it (much like a piece of cork tied to a dense body decreases its apparent weight in water.)
- Others argued that phlogiston was not a ponderable substance at all; it was imponderable like light, heat, electrical matter, etc. on which gravity did not act.

- Other difficulties: Why does combustion cease in an enclosed vessel? Why can it not happen in vacuum? Why is the volume of air reduced by combustion?

The theory accommodated these observations as follows:

Fixing the difficulties of phlogiston theory

- A given volume of air can absorb only a certain amount of phlogiston, so phlogiston released must be carried away by air. Hence nothing will burn in vacuum and combustion ceases in confined air.

- Air saturated with phlogiston takes up less volume (like cotton wool saturated with water takes up less room)

Enter Lavoisier (1743-1794)

- Lavoisier focused on the weight problem and showed that it was possible to explain quantitatively the weight gain in combustion by saying the substance combined with a fraction (20%) of ordinary air. Air was a mixture of two fractions, one that was active in combustion/respiration (which he named oxygen), the other not involved in these processes (it extinguished fire and caused asphyxia).

- In terms of the phlogiston picture, nitrogen was phlogisticated air which therefore did not support combustion. Oxygen was dephlogisticated air that readily supported it.

- He performed experiments on the burning of sulphur and phosphorous in air confined over water and found that he could attribute weight gain to the combination with oxygen. The same was true, he suggested, for calcination. He thus arrived at the basic principle of conservation of mass in chemical reactions.

- Lavoisier’s theory was just the opposite of the phlogiston theory; in the latter, combustion and calcination were decompositon into residue plus phlogiston; in the new view they were synthesis (with oxygen).

- This was the beginning of the chemical revolution. Note, however, the caloric view of heat was still on—indeed Lavoisier was its proponent. The caloric theory had to wait for its dismissal by the rise of thermodynamics in the 19th century.

Students' concepts of combustion

- Students' concepts of combustion indicate phlogiston-like ideas but nowhere as elaborate as that theory.

- Some responses from different studies quoted in (Barke et.al.(2009) *Misconceptions in Chemistry.*) are:

- In the burning process, " *something is going up in the air, that something disappears and only a few ashes remain..*"

- When asked to sketch their idea for what happens to the magnesium particles during the magnesium burning process:

- *Magnesium consists of two kinds of particles, one is vaporized by the burning process, and the other remains as magnesium oxide.*

- The destruction concept of burning say of iron wool and phosphorous is quite robust. Even older students after many years of chemistry continue to be guided by it.

Teaching the Nature of Science through history

History of science is not only useful to motivate and improve student learning of the content of science; it can play a vital role in student understanding of the nature of science.

‘The nature of science’ is part of the wider scholastic discipline ‘Philosophy of Science’. Learning the ‘nature of science’ is now regarded as one of the important aims of science curriculum all over the world.

Actually, ideas about ‘The nature of science’ are implicit in science textbooks and teaching. These books often portray a naïve idealistic view of how science is actually done; in particular they do not take into account the developments in ‘philosophy of science’ of the 20th century.

Key ideas on 'The Nature of Science'

What is it that we should convey about the nature of science in our textbooks and teaching? We quote from a debate in the U.K about this matter : *(Ref*. Taylor & Hunt,(2014))

1. Meaningful observation is not possible without a pre-existing expectation.

2. Nature does not yield evidence simple enough to allow one unambiguous interpretation.

3. Scientific theories are not inductions, but hypotheses which go imaginatively and necessarily beyond observations.

4. Scientific theories cannot be proved.

5. Scientific knowledge is not static and convergent, but changing and open-ended.

6. Shared training is an essential component of scientific agreement.

7. Scientific reasoning is not itself compelling without appeal to social, moral, spiritual and cultural resources.

8. Scientists do not draw incontestable deductions, but make complex expert judgements.

9. Disagreement is always possible.

- How should we communicate these mature ideas on the ‘nature of science’ ?

- One strategy is to teach carefully prepared history vignettes on suitable topics. Different vignettes can illustrate the diversity of ways ideas in science develop, are negotiated and then accepted.

- Such an approach seems more practical than teaching the nature of science through abstract philosophical discussions.

Criticism of Historical Approach

The criticism of the historical approach largely derives from the following points:

- Scientific knowledge, especially of physical sciences, is a-historical. This means we can explain a scientific concept or theory by recourse to logic, mathematics and the present experimental evidence. There is no need to dig up history, teach conflicting and wrong ideas and confuse the students. (Purists in science)

- Even if the historical approach may have some merit, there is simply no time in the current curriculum to deal with history with any seriousness. There are too many important topics to be covered and any history-based approach is bound to be at the cost of these current topics. It is more important to teach modern, rapidly growing body of knowledge than dwell on old and outdated ideas. All one can do is to insert in the text books short biographies of some leading scientists and describe their work briefly. This can be of some help in motivating and inspiring students. (Pragmatists)

- History of science-based curriculum distorts history. History in the service of science education is a prejudiced history. It picks up just those ideas and concepts in history that are the precursors of modern concepts. In so doing it strips history of its richness, diversity and context. It teaches students a wrong, biased history of science. (Purists in history of science).

Concluding Remarks

- Despite the caveats and criticism of HPS based approach, there seems to be a broad consensus among science educators that learning and teaching of science can improve if we go beyond mere tokenism and regard history of science as an important resource for science education for the purpose of
- cultivating interest in science,
- anticipating and addressing students' spontaneous conceptual pitfalls in particular topics of science,
- developing a critical understanding of scientific concepts, and
- developing mature perspectives on the 'nature of science'.

- Of course, these benefits are

- “dependent on the presence of reference to sound historical resources and, insightfully, upon the warrant of coherent triad of underlying rationales; an epistemological rationale, an ontological rationale, and a content rationale.”
(J. Wandersee and P.B. Griffard (2002))

- In simple words, HPS approach can be useful provided we sensibly choose topics that are amenable to this approach.

THANK YOU

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