Saurav Shome

When objects fail to move despite force being exerted!

Abstract

The textbook is the only teaching learning material used by both, teachers and students in most elementary Indian classrooms. Therefore, it is important to ensure that these textbooks represent conceptually correct content and ideas. In this paper, I discuss an incorrect sentence found in a science textbook: "When force is applied to a stationary object it moves" and how this sentence is interpreted by teachers, teacher educators, and educational researchers. While interpreting the sentence, participants articulated several alternative conceptions about force. The paper elaborates each of their alternative conceptions and presents expert views corresponding to each of them with familiar examples.

Introduction

Like several other countries, textbooks act as the sole authoritative teaching-learning material in India, and their authority remains largely unquestioned in Indian classrooms (Kumar, 1988; NCERT, 2005). However, they do not always represent conceptually correct content and sometimes become a source of alternative conceptions (Gunstone and Watts, 1985; Kaur, 2013). It is not possible to frequently change the textbooks. However, an empowered and willing teacher can take the role of a moderator to present the textbook content with caution and adequate care (Krishna, 2012).

NCF 2005 (NCERT, 2005) and the National Focus Group Position paper on Teaching of Science (NCERT, 2006) delineated six validity criteria for an ideal science curriculum. This paper is based on a study which is guided by one of these six criteria viz. content validity. The position paper states "*Content validity requires that the curriculum must convey significant and correct scientific content. Simplification of content, which is necessary to adapt the curriculum to the cognitive level of the learner, must not be so trivialized as to convey something basically flawed and/or meaningless.*" (NCERT, 2006; pp. 3)

As part of a larger study to develop a set of Project Based Learning (PBL) modules for Indian middle and high school students (Shome and Natarajan, 2010), the researcher had to analyse the textbooks (both NCERT and State Board textbook) with respect to the criteria delineated by NCF 2005. In this exercise, while reading a science textbook of Class VI, it was seen that the chapter on "motion and types of motion", begins with the statement: "When force is applied to a stationary object it moves." Researchers found this statement incorrect, thus proving that this particular presentation of the force concept in textbook violates the criteria of content validity.

Now it is important to know how teachers and teacher educators interpret this incorrect content. It is assumed that if they have conceptual clarity about force, they would be able to communicate a correct concept. Otherwise, the incorrect sentence given in the textbook would go unwarranted and reinforce students' alternative conceptions further.

Relevant literatures on concepts of force

There is abundant literature on studies of students' and teachers' concepts of force (a list can be accessed from the blog link given at the end of this paper). It is reported that students and teachers alike hold several conceptions about force, not aligned with expert conceptions (Driver et al., 1994). These non-expert conceptions are termed as misconceptions, alternative conceptions, common sense concepts, children's conceptions etc. In this study, the researcher has viewed these conceptions as alternative conceptions.

From personal experiences, individuals try to construct meanings and form theories which can explain these experiences. These experiences include sensory experiences with the natural world, conversations with other individuals (parents, people, teachers, peers etc.), watching and reading print and non-print media content like newspapers, books, textbooks, television programmes and movies, etc. These theories can explain several experiences and therefore, cannot be discarded on the basis of their explanatory power. Some of the explanations individuals hold have remarkable resemblance with the evolution of particular concepts in the history of science itself (Halloun and Hestenes, 1985). Individuals use everyday terms to explain phenomena which are inconsistent with the correct scientific terminology. For example, in explaining projectile motion, an individual can consistently equate force with momentum and mechanical energy, and use the term "force" with different meanings for different problems at hand.

These personal constructs are consistent in themselves and therefore alternative to the expert concepts, and not necessarily a set of wrong concepts (or misconceptions) or common sense. They are found in both children and adults, and can hence not be considered as just children's concepts. They are so robust that even after formal training in a discipline (like in physics), learners retain them. Fortunately, they are limited in number and have a universal pattern. Therefore, it is possible to address these alternative conceptions with an adequate teaching-learning plan within an appropriate context (Driver et al., 1994).

There are reported research literatures, in the Indian context, on students' and teachers' conceptions of force and direction of motion, velocity and acceleration (Saxena, 1996; Kumar, 1997; Rampal, 1998). It is acknowledged in these reports that the alternative conceptions held by students are so robust that these cannot be eliminated by mere pointing out the mistakes and mentioning the correct response. It would be effective to explore students understanding, and then provide them a situation to experience a cognitive conflict. That would eventually lead towards expert understanding (Saxena, 1996).

Importance of developing concepts of force

Developing the concept of force is a precursor for constructing a sound understanding in elementary physics. This section discusses some important aspects and also mentions some of the prevalent alternative concepts about force while discussing its importance.

Elementary physics taught at Indian schools prepares students for understanding Galilean and Newtonian mechanics in higher class. The conceptual framework of force in Newtonian mechanics sometimes appear contradictory and conflicting to the "common sense belief" or everyday experiences (Halloun and Hestenes, 1985) or alternative ideas (Reynoso et al., 1985). If students' conflicts are not addressed while teaching, students could get disinterested in physics. For example, from everyday experiences it is observed that when ball or marble is rolled and no more force is applied on them, they eventually come to at rest. From this common sense observation, it is absurd to consider Newton's first law of motion as a valid law.

Now, in some cases students would be able to solve problems based on textbook concepts, and at the same time hold the alternative ideas. For example, a student could successfully solve a problem of projectile motion using appropriate formula, and still hold the view that there are two forces constantly act on the moving object during its flight. One force is due to the earth's gravity and the other force is imparted by the agent in the body. And this hybrid understanding prevents the development of other concepts in physics like momentum and energy. This hybrid understanding can lead students to infer something which is not consistent with laws of physics (like conservation laws). These also pose difficulties for students to tackle problems in non-trivial and novel contexts.

Finally, the state of motion or rest of the objects in the physical world can be conceptualized through the understanding of four fundamental forces. Understanding force demystifies the "natural place" idea in the Aristotelian world view and provides a single explanatory framework for motion of both, the celestial and terrestrial objects.

The paper reports a study on teachers', teacher educators', and science education researchers' interpretation of a middle school science textbook's statement about force. Here, attempt has been made to construct conceptual pattern in the responses given by individual participants and classify the patterns. The paper also cites some examples in order to challenge the alternative conceptions held by the participants. This exercise would help us to structure adequate teaching-learning strategies to address the corresponding conceptual pattern.

Methodology

Objective: The objective of the study is to find out how teachers, teacher educators, and educational researchers interpret the particular sentence, "when force is applied to a stationary object it moves" and what views they hold about force and its role in motion. The views expressed by the participants would help the researcher to find out the participants' ways of conceptualising force. Familiarity with the participants' existing concepts would help the researcher to develop adequate teaching learning module appropriate for both teachers and students.

Research Design: The study begins with reading the textbook with the intention of analyzing validity of the content represented in the textbook. Once an incorrect content is detected, the researcher explores how teachers, teacher educators, and science education researchers interpret the sentence (refer to earlier section); what ideas they hold about force; as well as cases where motion occurs due to the application of net non-zero force. Discussion between the researcher and participants is conducted in an individual semi-structured interview format. The discussion starts with introducing the textbook and communicating the intention behind conducting the interview.

The researcher first asks participants to read out the sentence and explain what they understand from the sentence and to elaborate the sentence in the context of daily observations. They are also asked to infer whether this sentence represent correct concepts. The responses given by participants are taken as a cue for asking probing questions and extending discussions to explore broader conceptual frameworks. Attempts are made to enhance both, the researcher's and participants' understanding about force and motion during and after the discussion. Interestingly, each interview provides a rich insight for conducting the next interview.

Participants: Twenty one participants voluntarily took part in the study (10 teachers, 4 teacher educators, and 7 science education researchers). They all hold a masters degree in the discipline of science or mathematics and are in the 25 to 35 year old age group. The researcher was personally acquainted with all participants. The researcher was interested in finding out the participants' interpretations and their conceptual structure on force, irrespective of their professional status and finer academic qualifications. Therefore, no attempt was made to correlate the participants' response pattern and their teaching profession and academic profile.

Data collection and analysis: The researcher took extensive notes during individual interviews. After each interview, notes were checked and elaborated if required. Each of the detailed notes were checked for constructing a conceptual pattern and compared with successive interview notes.

Findings and discussion: All the participants reworded the sentence in the form: "application of force results in motion of objects." When asked whether this sentence is true for all cases, it was heartening that all the respondents said that the sentence is either incomplete or wrong. They also mentioned that to move an object there must be non-zero resultant force. They expressed that the textbook statement is true only if we read the word "force" as "net or resultant force".

From daily experiences we observe that in some cases an object moves when we apply a force and sometimes it does not move even after applying a force. For example, when we lift something, we do apply force vertically upward against the force of gravity. The ease of lifting depends on the weight of the objects. We can easily lift objects of lesser weight like paper, book, pen, pebble, small luggage etc. For a healthy adult, it would be difficult to lift heavy luggage say, weighing 40 kg. For a 10 year old child, it would not be possible to lift luggage even after applying force. Let us consider another situation. What happens when we apply force by pushing a concrete wall? Children as well as healthy adults cannot move the wall by applying a force through hand-push.

What does it mean? Does applying force necessarily lead to motion in the object? Can we think about some more examples?

For example, when we pull a heavy object, say a cupboard full of books, we exert a force on it. But this is not the only force acting on the cupboard. The cupboard and the earth attract each other with an equal magnitude of force all the time. Force exerted by the Earth on the cupboard is equal to the weight of the cupboard. The weight is exerted on the surface of earth or floor. And the surface exerts a reaction force on the cupboard's legs. Now, when we exert a force to pull the cupboard, frictional force develops between the pair of surfaces at contact. The frictional force is numerically equal to the product of reaction force and co-efficient of friction. There would be some other forces in other situations. If we want to move the cupboard, horizontal to the surface, we must have to pull with a force which is at least of equal magnitude to the force of friction. Although, we are applying only one force, there are other forces acting on the body. And these forces are invisible to us.

Let us take another example. Consider, a stone thrown, vertically upward. At its highest position of flight, the stone will cease its motion, momentarily. During its flight, ideally the stone experiences only gravitational force, acting vertically downward. During its upward motion it moves opposite to the direction of gravitational force. At its highest point, the stone comes at rest, even when total force acting on it is non-zero. However, the object can no longer be at rest, because a force acting on it will pull the stone downward.

The participants were also asked to elaborate their response in the context of moving a heavy object by applying a force on a concrete floor or road. It is interesting that, although, everyone correctly identified the inadequacy of the textbook statement, the explanation they have mentioned to elucidate the given context are varied.

Applied force has to overcome inertia and weight of the body

Some participants thought that the applied force have to overcome the "inertia" and "weight" of the body. On a positive note, some of them could correctly state inertia as something different from weight and not a force but the remaining were not able to distinguish between these two. Interestingly, all the participants in this category became confused while explaining how applied force had to overcome "inertia" and "weight". They failed to bring friction in this context. They also failed to take into account component of forces in explaining the state of motion or rest in the body.

Considering inertia, weight and force as qualitatively the same quantity is a very old and persistent idea in the history of science. This idea has its historical root in Aristotelian physics. Although some of the participants found inertia and weight as qualitatively different, they still held the view that force has to overcome inertia. It is noteworthy that Newton himself conceptualized inertia as a mixture of the old and the modern idea of force (Gunstone and Watts, 1985).

Theoretically, any amount of force sets into motion an object of any amount of mass. The acceleration produced in the body can be calculated from Newton's second law of motion. Therefore, if a small magnitude of force acts on a massive body, the acceleration due to the force will be appreciably small and we can safely say that the object does not move. One nice example is when a big ripe jackfruit detaches from its branch and falls towards the earth, the earth and the jackfruit both exert an equal force upon each other. However, due to the relatively very small mass, the acceleration produced in the jack fruit becomes much higher than that produced in the earth. As a result, the jack fruit reaches the earth's surface much faster than the earth makes any appreciable change in its position within the same time interval. Here, we can see that the jackfruit is in motion while the earth is at rest.

The idea of overcoming inertia by a force is to some extent, misleading. Inertia is the property of the body due to its mass and is not even a physical quantity, but force is a vector quantity and not the property of the body itself. Therefore, the quantities are not commensurable at all. The respondents failed to take in account of this aspect.

Applied force has to overcome weight of the body and friction

Some participants said that the applied force has to overcome both weight and friction. However, they exhibited no proficiency or attempt to explain the motion of the object in connection with direction of weight and frictional force.

According to most of the respondents, the force had to overcome weight. This idea is also a result of an incomplete understanding of the origin of friction and how frictional force works. Consider the case when we want to lift a rectangular object of weight 10 N. To lift the object we must apply a force greater than 10 N, say 11 N. Now, acceleration produced in the object will be due to 1 N force and not due to 11 N. However, if we want to slide the same object on a concrete floor, we need to overcome the frictional force acting between the surfaces of the object and floor. And this force is equal to the product of weight and coefficient of friction (say ì) between the surfaces. In most cases the magnitude of ì is less than 1 and therefore, the product is less than weight of the object. Now we can modify frictional force by changing the properties of the surface and thus changing the magnitude of ì.

Applied force has to overcome force of friction only

The last category of respondents stated that "applied force has to overcome force of friction only". In the above case, applied force actually does not overcome weight, it overcomes friction (ignoring other possible obstructions). While we slide an object on a surface, weight of the body remains unchanged. Moreover, in the object's motion along horizontal direction, the weight acts in perpendicular direction and has no contribution along horizontal direction. The force we apply along horizontal direction is to overcome frictional force acting horizontally but in the opposite direction.

Implications in teaching

Here we have found that the textbook statement is inadequate to construct the correct conceptual base on force. At the same time, we have encountered that even teachers, teacher educators, and educational researchers find it difficult to explain the action of force on the state of motion or rest in an object. But the question that arises is what should we do in the classroom? Should we give some standard definition of force to students? Or as Rampal (1995) suggested, provide them multiple situations similar to those discussed in this article? Should we allow students to experience force and its action through various activities designed by teachers and students, where their existing views will be challenged (Gunstone and Watts, 1985)?

Kumar (1997), in his paper "Pitfalls in elementary physics" elaborated the reasons of these alternative conceptions about force. He attributes these alternative conceptions as product of improper understanding of Newton's second law of motion. According to Kumar, we tend to ignore the idea of locality in Newtonian force. Ignoring this important characteristic gives rise to several alternative conceptions about force.

We educators need to improve our understanding. We could read some existing research literature on concepts of force and discuss among ourselves. We could come up with real-life situations where our existing ideas can be probed and learners (both teachers and students) can face cognitive conflicts. If we educators are clear about the concepts and its associated pedagogy, we would be better equipped to handle students' alternative conceptions during our classroom teaching. Interested readers are requested to initiate discussion on online platforms. The web-links of some online platforms are given below.

Resources for teachers and teacher educators: Some research literature on concepts of force published in national and international journals can be accessed by visitng:
http://continuinglearning2teach. wordpress. com/e-r/articles/r-l-s-o-f-c/
Discussions on concepts of force can be accessed by visiting the following page:
http://continuinglearning2teach. wordpress. com/e-r/d-p/on-force-concepts/

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References

1. Driver, R., Squires, A., Rushworth, P., and Wood-Robinson, V. (1994). Making sense of secondary science: Research into children's ideas. London and New York: Routledge Falmer.
2. Gunstone, R. and Watts, M. (1985). Force and motion. In Driver, R., Guesne, E., and Tiberghien, A. (Eds.), Children's ideas in science (pp. 85-104). UK: Open University Press.
3. Halloun, I. A. and Hestenes, D. (1985). Common sense concepts about motion. American Journal of Physics; 53 (11), 1056-1065.
4. Krishna, K. (2012). Dealing with misconceptions in science. Teacher Plus, 10 (8), 6-8.
5. Kaur, G. (2013). Textbook representations as reinforces of (mis)understandings : The case of ray diagrams in optics. Voices of Teachers and Teacher Educators, 2 (1), 13-17.
6. Kumar, A. (1997). Pitfalls in elementary physics. Resonance, 2 (7), 75-81.
7. Kumar, K. (1988). Origins of India's "Textbook Culture". Comparative Education Review, 32(4), 452-464.
8. NCERT (2005). National Curriculum Framework 2005. New Delhi: National Council of Educational Research and Training.
9. NCERT (2006). Position paper: National Focus Group on Teaching of Science. New Delhi: National Council of Educational Research and Training.
10. Rampal, A. (1995). Were the force is absent. Sandarbh, pp. 19-33. Accessed online on December 8, 2012 from www.eklavya.in/pdfs/Sandarbh_03/19-33_Where_the_Force_is_Absent.pdf .
11. Rampal, A. (1998). Can We Disbelieve Newton. Sandarbh, 24-25, pp. 28-36. Accessed online on March 22, 2013 from www.eklavya.in/pdfs/Sandarbh_24-25/28-36_Should_We_Dont_Trust_Newton.pdf .
12. Reynoso, E. et al. (1985). The alternative frameworks presented by Mexican students and teachers concerning the free fall of bodies. International Journal of Science Education; 15 (2), 127-138.
13. Saxena, A. B. (1996). It is Necessary to Know the Preliminary Understanding. Sandarbh, 11, pp. 34-38. Accessed online on March 22, 2013 from http://www.eklavya.in/pdfs/Sandarbh_11/34-38_Necessary_to_Know_Preliminary_Understanding.pdf .
14. Shome, S. and Natarajan C. (2010). HBCSE Guidebook on Project Based Learning. Technical Report; December 2010. Mumbai: HBCSE.