EXPLORING ALTERNATIVE CONCEPTIONS OF FORCE

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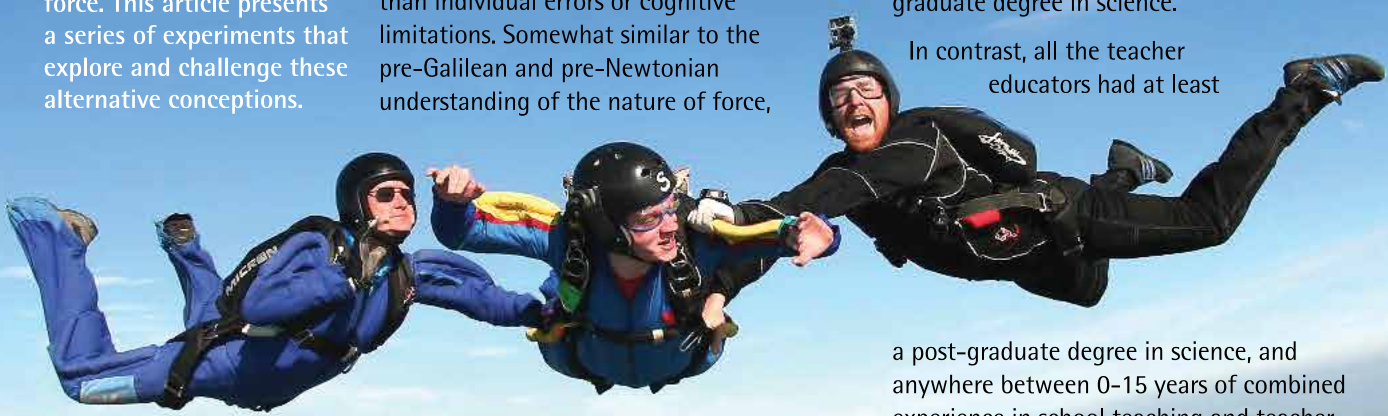
Force is a fundamental concept in Newtonian mechanics that teachers and teacher educators are expected to understand well. However, even when teachers and teacher educators are familiar with Newton's laws of motion and gravitation, they continue to hold several misconceptions about force. This article presents a series of experiments that explore and challenge these alternative conceptions.

Understanding force and concepts of Newtonian mechanics is fundamental to elementary physics. However, this is also an area where many alternative conceptions (or misconceptions) abound among not only students, but also teachers and teacher educators [1, 2, 3, 4,] and [5]. Often, even practicing scientists tend to lack conceptual clarity in this area[6].

Most misconceptions about force arise mostly out of real life experiences rather than individual errors or cognitive limitations. Somewhat similar to the pre-Galilean and pre-Newtonian understanding of the nature of force,



they are so deeply ingrained that it unlikely that merely pointing out mistakes or sharing the correct response will change them. Instead, it is important to explore the individual's conceptual framework, and then challenge the framework by situations designed to create cognitive conflicts[4].

In this article, the author presents his experiences from engaging with teachers and teacher educators in a workshop session designed to address some of their most common misconceptions about the way forces act.

About the workshop

Participants

The session on forces was attended by nineteen teachers and eight teacher educators, all working in a single district of a state in North India.

All the teachers had been teaching science and/or Environmental Studies in primary, middle and high school for at least ten years. Some of them had an under/post-graduate degree in science.

In contrast, all the teacher educators had at least a post-graduate degree in science, and anywhere between 0-15 years of combined experience in school teaching and teacher education.

Overview of session structure

The session was structured in order to create cognitive conflict among the participants. A schematic diagram of the process cycle is shown in Fig. 1.

The general format of the session consisted of introducing a problem context to the participants, and then asking them a question. Participants were encouraged to choose their answers from a list of

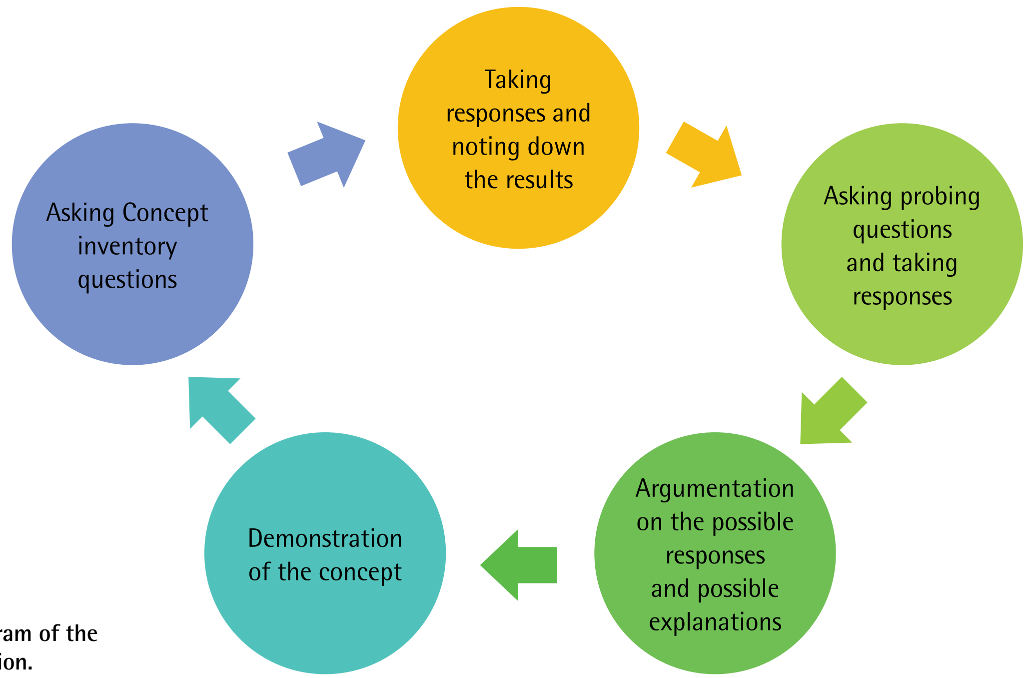


Fig. 1. **A schematic diagram of the process cycle of the session.**

multiple options shared orally and in writing on the board. For each question, participants would indicate their option by writing it down on a chit of paper. The author would collect the chits and note down the frequencies of different responses. This method was used to protect the identity of the respondents.

Except the first question, all other questions were adapted from the Force Concept Inventory or FCI[7]. The questions as well as responses were rephrased in order to simplify and make them more context-relevant for the participants. Also, slight modifications were made in the language and order of the multiple options, mainly to allow these questions to be presented orally in Hindi (the language that participants were most familiar with).

After noting down the frequency of responses, the author would ask the participants probing questions in order to initiate discussions and arguments. In some cases, the author would introduce new concepts while discussing different types of responses. It was only after a question was thoroughly discussed and the participants demonstrated a reasonable degree of understanding of it that the author would move onto the next question.

How well do we understand force?

No motion no force!

Question 1: There are two identical chairs, A and B, facing the same direction. A man sits on chair A and places his hand on the back of chair B. Suddenly, the man pushes chair B. Observe the result of the push. In this situation, which of the following statements would be correct?

a) Neither the man nor chair B exerts a force on the other.

b) The man exerts a force on chair B, but the chair does not exert any force on the man.

c) Both the man and chair B exert force on the other, but the chair exerts a greater force on the man.

d) Both the man and chair B exert force on the other, but the man exerts a greater force on the chair.

e) The man and chair B exert the same amount of force on each other.

Responses: 22 (81%) participants opted for option b, while five (19%) of the participants opted for option e.

What option would you choose?

Fig. 2. Man sitting on chair A, pushing chair B.

Answer 1: The correct answer to question 1 is that stated in option (e). Why did most participants choose option b then?

Participants observed practically no motion in chair A and, in contrast, a considerable amount of motion in chair B. They associated application of force with the motion of an object, in this case, the moving of a chair. Citing Newton's first law of motion, the participants argued that as chair A remained at rest, there was no force acting on it.

Why is this incorrect? It is crucial to note that in choosing this option, the participants neglected two important considerations: the violation of Newton's third law of motion, and the force of friction. In accordance with Newton's third law of motion, when the man sitting on chair A exerts a force on chair B, chair B also exerts an exactly equal force on the man on chair A. But as the two chairs experience this force and move, a second force – the force of friction comes into play, acting in the direction opposite to the rotation of each chair's wheels. The difference in the weights of the two chairs means that although they both experience the same force of push, they don't experience the same force of friction. Since chair A carries the additional weight of the man sitting on it, it experiences a greater force of friction than that acting on chair B. This causes the two chairs to move different distances.

Interestingly, when asked about Newton's third law, all the participants were able to state it – "Every action has an equal and opposite reaction", but knowing this had not influenced their responses

Greater the motion greater the force!

Question 2: Imagine the same scenario as in Question 1. Only, now, a man sits on chair B too. The mass of the man sitting on chair B is about 1.5 times that of the man sitting on chair A. The man sitting on chair A gives a sudden push to the chair B. Take a look at what happens, and choose the correct explanation for it from the statements given below:

a) Neither the man on chair A nor chair B exerts a force on the other.

b) The man on chair A exerts a force on chair B, but the chair does not exert a force on the man.

c) Both chair B and the man on chair A exert force on the other, but the chair exerts a greater force on the man.

d) Both chair B and the man seated on chair A, exert force on the other, but the man exerts a greater force on the chair.

e) Chair B and the man seated on chair A exert the same amount of force on the other.

f) Chair B exerts a force on the man on Chair A, but the man in chair A does not exert a force on chair B.

Responses: Fifteen (56%) of the participants opted for (c), five (18%) for (e), three (12%) for option (f), two (7%) for option (b), and one (4%) for option (a).

What option would you choose?

Fig. 3. Man in chair A pushing chair B with the other man sitting in it.

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Answer 2: The correct answer to question 2 is that stated in choice (e). Why were the responses of the participants so varied then?

It is evident that those choosing option (c) overlooked Newton's second law of motion. Simply comparing the distance travelled or acceleration produced is not sufficient to conclude that the amount of force acting on the two bodies is unequal. We must also know the mass of each body. Similarly participants who chose option (f) ignored the motion of chair B, as it was much less than that of chair A. In both these cases, respondents tried to estimate the amount of force acting on the two bodies by taking into consideration the distance travelled by the chairs, but ignoring their respective masses. The two participants who chose option (b) made the erroneous assumption that only animated objects or objects having intention to push can apply force. One of the participants even mentioned that neither the man nor the chair was exerting any force on the other - option (a).

At this stage, participants were asked to compare their responses to Questions 1 and 2. Although, in many cases, the responses received from the two demonstrations were contradictory, both of them stemmed from the same misconceptions of force. A majority of participants had explained the first demonstration by suggesting that only the man in chair A was applying force on chair B. And in the second demonstration, most participants had suggested that both the man in chair A and the chair B were applying force on each other, although the two forces were unequal in magnitude. In the first case chair B was empty, and in the second, the chair was occupied by a motionless man, heavier than the one seated on chair A.

It was pointed out that in responding to both these questions, most of the participants had associated only the amount of motion of objects with the force acting on that object. Hearteningly, this initiated a discussion among participants, where they began acknowledging and reflecting on these contradictions, although they were still not able to apply Newton's third law to either situation.

No attempt was made, even at this juncture, to mention or explain the correct responses to the two questions. Instead, to help participants understand the unequal motion of the chairs, the author introduced them to Newton's law of gravitation. Attention to the connection between Newton's three laws of motion and Newton's law of gravitation was drawn by specifically stating that the force exerted by Earth on any object is exactly equal to the force exerted by the object on Earth.

Both heavier and lighter objects land at the same time.

Question 3: In each of three scenarios given below, two objects are dropped from the same height. Which of them will fall faster to the ground?

Scenario 1: An empty bottle versus a bottle completely filled with water.

Scenario 2: A purse versus a sheet of paper.

Scenario 3: A notebook versus a sheet of paper from it.

Which objects would you pick?

Answer 3: Presented with the **first scenario,** the participants predicted that the two bottles would fall to the ground at the same time. To confirm this, this experiment was performed with two water bottles. As suggested by the participants, the two bottles were dropped from increasingly greater heights. As predicted, in every case, the two bottles touched the ground at almost the same time.

In response to the **second scenario,** the participants predicted that the purse would fall faster than the sheet of paper. A demonstration confirmed this prediction. When asked the reason for this observation, the participants indicated that the paper falls slower due to greater air resistance, caused by its larger surface area.

To present the **third scenario,** a notebook and a piece of paper from he same notebook were taken to ensure that both objects had the same surface area. When the objects were dropped from a height, keeping the faces of the objects horizontal, the paper fell slower than the note book. It was pointed out how this was because the paper, being lighter, could not overcome air resistance as easily as the heavier notebook. In contrast, when the two objects were dropped keeping their faces vertical, both of them fell almost at the same time.

From these demonstrations, all the participants agreed that all objects, irrespective of their mass, fall to the ground at almost at the same time, if they are released from the same height.

Gravitational force is the same on all objects!

Question 4: Imagine two iron balls of the same size rolling on a horizontal table with identical uniform velocity. One of the balls is hollow, while the other is solid. The solid ball is 10 times heavier than the hollow ball. Both the balls slip from the edges of the table at the same time. The hollow ball touches the ground at a horizontal distance of DH from the base of the table while the solid one traverses a horizontal distance of DS from the base. Which of the following statements best describes the relation between DH and DS?

a) DH > DS

b) DH < DS

c) DH = DS

Responses: Seventeen (65%) of the participants opted for (a), one (4%) for (b), and eight (31%) for option (c).

What option would you choose?

Answer 4: The correct answer to this question is that stated in option (c). Why were the majority of responses of the participants so different then?

In an effort to get the participants to apply their understanding of gravitational force to this situation, the author asked them to name the forces that were acting on the balls when they left the table surface. While some of the participants named gravitational force, one participant argued that gravitational force was also acting on the balls when the balls were moving on the surface of the table. Justifying choosing option (a), participants compared this situation with their real life experiences of throwing lighter and heavier objects, arguing that even when thrown with the same force, lighter objects traveled further than heavier ones.

It is interesting to note that in spite of being aware of Newton's law of gravitation, participants continued to hold the view that the magnitude of gravitational force is independent on the mass of the object it acts upon. The demonstrations, of different objects falling to the ground simultaneously, conducted prior to posing this question did not challenge this misconception. All objects fall towards earth with equal rapidity due to equal acceleration produced in the objects and not due to the equal gravitational force acting on the objects. The participants wrongly equated equal acceleration with equal force.

Responses to this question brought to light three more aspects of forces that are difficult to appreciate:

1. A force acting perpendicular to the direction of motion does not do any work.
2. Newton's laws of motion help predict the resolution of different forces acting simultaneously on an object.
3. No impetus force is required to sustain the motion of an object.

Motion due to impetus force!

Question 5: A student throws a cricket ball, as shown in Figure 4. What force(s) act on the ball during its flight at the points A, B and C. Please do not consider the effect of air resistance on the ball.

How would you answer this question?

Answer 5: The responses given by the participants were varied and interesting. All the participants opined that two forces acted on the ball at point A. One was the force of gravity, and the other was the force with which the ball was thrown. Some also rightly said that the force of air friction also acted upon the ball.

However, the participants had differing views regarding the nature of forces acting on the ball at points B and C. Ten (38%) participants had the view that the force of the throw would become zero at point B, and by the time the ball reached point C only the force of gravity continued to act upon it. In contrast, 16 (62%) participants held the view that the force of throw would remain in the ball till it touched the ground. However, the magnitude of the force of the throw would continue to reduce at every point in its trajectory. Thus, at point B, it would be equal to force of gravity and at point C, it would be much weaker than the force of gravity.

At this point, the trajectory of a ball when hit with a bat was demonstrated, and the participants were asked to predict how long the force of hitting would continue to act on the ball. All participants responded that the force would remain in the ball till it reached the ground. Pointing out that the person hitting the ball was not traveling along with the ball; the participants were asked how the force with which the ball was hit would travel along with the ball? Also, if the force of hitting was travelling with the ball, why did the ball stop after traveling a certain distance, rather than continue to move further? And how was the force of hitting transferred to the ball, even when contact between the ball and the bat no longer existed?

To further clarify this point, the participants were asked to reflect upon the same situation under circumstances where there was no force of gravity acting upon the ball. According to Newton's first law of motion, what would happen to a ball thrown in a gravity-free environment? What would be the trajectory of the ball? By applying Newton's first law to this situation, participants could predict that the ball would continue moving in a straight line. They also explained that this would be due to the inertia of motion and not due to the force of hitting. However, in the presence of the force of gravity, the ball follows a curved path. This led them to conclude that once the ball was hit, only one force continued to act on it and this force was that of gravity.

Interestingly, some participants expressed their dissatisfaction with this explanation. For example, one participant said "How is it possible that the ball makes a trajectory under the influence of the force of gravity without having any force continuing to act in the direction of motion?"

The discussion was then steered back to question 3, reminding the participants that irrespective of their mass, all objects fall to the earth with the same acceleration. Hearing this, some of the participants concluded that both balls in Question 3 would take the same time to reach the ground. By the end of this session, many of the participants started appreciating the fact that Newton's third law meant that forces exist in pairs and that freely falling objects are acted upon only by the force of gravity. However, the answer to the third question continued to remain unresolved.

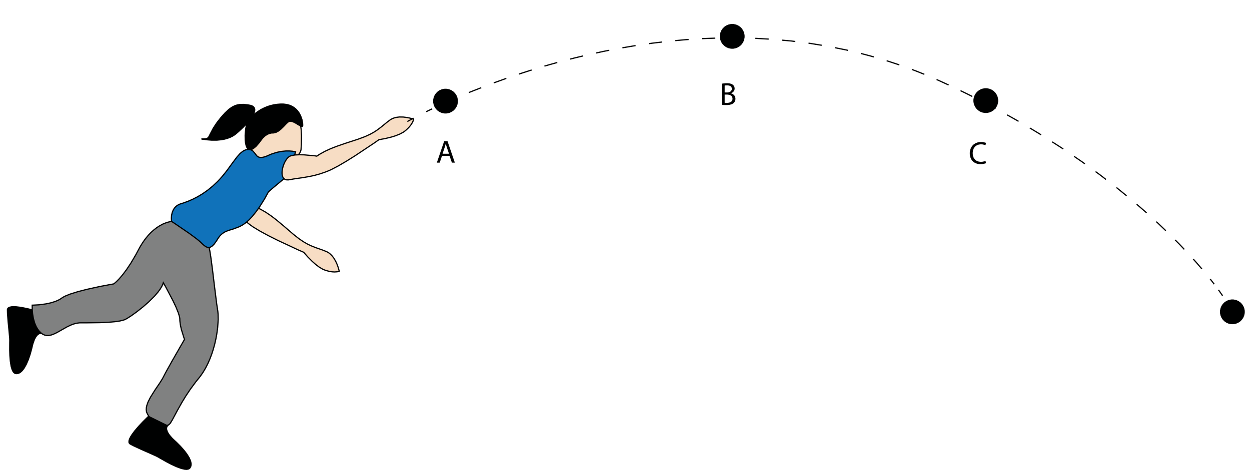

Fig. 4. Different forces act upon a ball thrown by a student. Credits: Saurav Shome. License: CC-BY-NC

Conclusion

Many science students and teachers find it difficult to differentiate between force, energy and momentum.

Even when reminded that energy and momentum are conserved quantities and properties of the object that are carried with it as opposed to force that is neither carried with the object nor conserved, these statements alone are not sufficient to bring about conceptual change. For example, although participants of the workshop session were able to state Newton's laws of motion and the theory of gravitation, they showed inadequate understanding of both. They tended to associate force with motion, rather than inertia with motion, an idea similar to motive/ impetus force.

Similarly, experiments to demonstrate the workings on force may also not be sufficient in helping students develop a conceptual understanding of force in Galilean and Newtonian mechanics. For example, despite elaborate demonstrations that all objects in free fall move towards ground with equal rapidity, participants adhered to their initial understanding that the mass of objects influences the horizontal distance traversed by the same object after it has reached the ground. Their alternative conceptions seemed to stem from their inability to differentiate between physical quantities at least at three levels: a) mechanical force and gravitational force, b) energy and force, c) velocity and acceleration.

From our survey with teachers, it seems likely that questions around counter intuitive examples may be a great way for teachers to help rid students of learning misconceptions. We have illustrated a few such examples. However, these could be changed in a variety of ways. For example, while discussing the responses in Question 1 and 2, other sets of demonstrations could be included. These could take the form of exchanging the students; or putting the heavier student in chair A and lighter student in chair B with the heavier student pushing the chair B; or, equalizing the mass on each chair; and comparing the relative distances traveled by the chairs in each case. The sequences and intermediate questions could be structured in alignment with the conceptual pitfalls that appear in discussions. The situation in Question 4 could be demonstrated, by allowing hollow and solid balls to fall from increasing heights.

Now it's your turn - try out some of these experiments with your students today. You may find yourself surprised at their responses!

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