From diagnosis to treatment: Diagnosing understandings about force and motion and providing analogies for stimulating meaningful learning and conceptual change

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Abstract

Student misconceptions in science and particularly about force and motion have been studied over the years. These studies provide a wealth of knowledge for researchers and educators. The purpose of this study was to develop a diagnostic test that can easily reveal student misconceptions about force and motion. The Force and Motion Diagnostic Test was developed over the years and addresses Newton's first and second laws of motion. Teacher candidates were administered the test and consecutively their misconceptions were identified. The test consists of 20 true / false questions about a situation described both verbally and by providing a graph in the question. The situation involves an object on which a net force is applied. However, during the first half of the whole time the force diminishes linearly and becomes zero and then it increases again linearly in the opposite direction. The true/false questions, besides the correct scenario, also model typical student misconception like "there is no motion unless there is a force," "speed is proportional to applied force," and "objects always move in the direction the force is applied." On top of revealing student misconceptions the provided situation in the question also assesses how participants understand the concept of acceleration. The concept of acceleration is the key to understanding Newtonian mechanics. Without comprehending this concept appropriately no meaningful learning is likely to occur. Therefore, two daily life analogies for acceleration outside physics are provided for in class discussions that can foster desired understandings about acceleration: population growth rate, and inflation of prices.

Introduction

Students' ideas about force and motion has been investigated in numerous studies at different levels and settings. Indeed, it has been the most intensely studied area in science education research (Duit, 1993). In time, standard comprehensive tests have been developed (e.g. Hestenes, Wells & Swackhamer, 1992; Hestenes & Wells, 1992; and Thornton & Sokoloff, 1998) again to reveal students' ideas about what effects forces bring about.

Driver, Squires, Rushworth, and Wood-Robinson, (1994, p. 149) highlighted students' alternative ideas about force and motion as follows:

- if there is motion, then a force must be acting;
- if there is no motion, then there is no force acting;
- without motion one can not talk about force;
- when a body moves, there must be a force in the direction of motion;
- a moving body will stop when its force is exhausted;
- there exists a force in moving bodies that maintain motion;
- motion is proportional to acting force;
- a constant velocity (in 1-D) is brought about by a constant force.

It is seen that these and other alternative conceptions are very persistent to change and present a learning difficulty for learners at all levels (see for example Tasar, 2001). Therefore diagnosing students' alternative conceptions and presenting a helpful treatment for them is extremely important for developing instruction and fostering meaningful learning.

Purpose

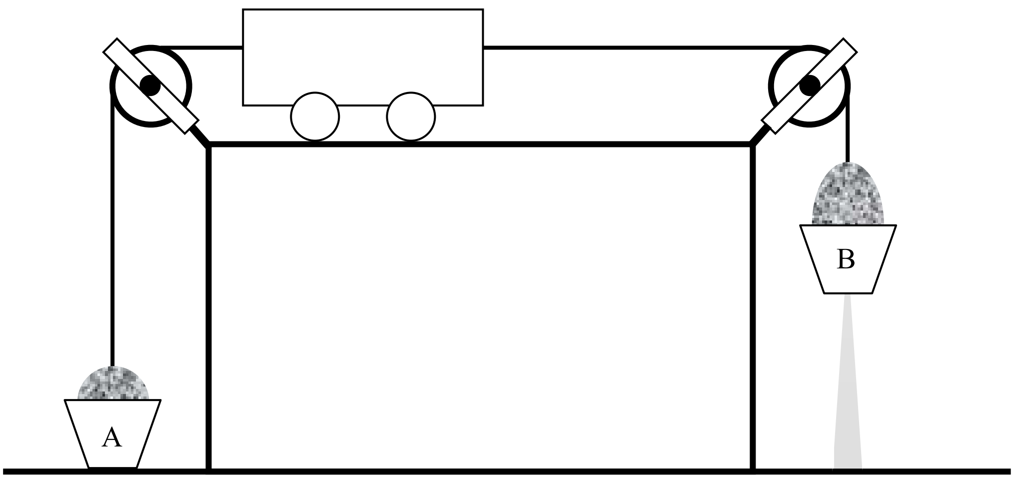
This research study is based on the common naïve idea that "force and velocity are directly and linearly related." It is extremely important to determine whether students are subscribed to this idea or hold scientific conceptions expressed by Newton's laws.

Method

For this purpose a 20 item true/false questionnaire called "The Force & Motion Diagnostic Test" (FMDT) has been developed. Here a case of diminishing net force is presented with a graph where the net force increases in the second half (see also questions 14-21 in Tools for Scientific Thinking: Force & Motion Conceptual Evaluation in Thornton & Sokoloff, 1998). It is observed that students are not familiar with such kind of changing net force in time and consequently undergo difficulty in understanding and responding to such cases. It is also seen that such varying force questions has a great potential to reveal student understandings of Newton's Laws. The force described in the questionnaire can be obtained on an object as seen in figure 1.

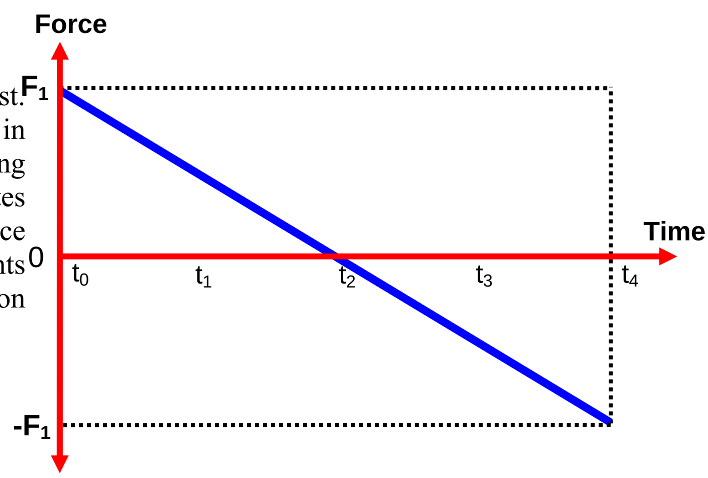
Here a toy car, on a sufficiently large table with frictionless surface, is connected to two buckets filled with sand. Initially bucket B is filled with twice the amount of sand in bucket A. The hole at the bottom of bucket B lets sand to leak uniformly. This system initially has a uniformly decreasing net force towards right. The net force on the toy car becomes zero, when the amount of sand in bucket B equals the amount of sand in bucket A. Afterwards, the increasing net force is towards left since the amount of sand in bucket B continues to decrease until there is non left.

Figure 1. A system where the net force first decreases uniformly and then increases uniformly in the opposite direction.



THE FORCE & MOTION DIAGNOSTIC TEST (FMDT)

A force is applied on an object initially at rest. The figure shows the change in **net** force in time on the object (t_0 denotes the beginning of application of force, t_1, t_2, t_3 and t_4 denotes equal time intervals). The direction of force is reversed at t_2. Which of the judgments below are TRUE or FALSE about the motion of the object during $t_0 - t_4$ time interval?



1. At t_2 where force becomes zero velocity will be **zero**, too.
2. At t_0 and t_4 velocity will have its **maximum** value.
3. At t_2 velocity will have its **maximum** value.
4. At t_2 the object's direction of movement will be **reversed**.

5. The object’s direction of movement will **not** change between t_0 - t_4 .
6. At t_2 the object will **stop** momentarily.
7. At t_4 the object will be at the point **where** it started its motion.
8. At t_4 the object will be at the **farthest** point with respect to where it began its motion.
9. At t_1 and t_3 the object will be at the **same** point but moving in **opposite** directions.
10. At t_0 the velocity will reach its maximum, then will gradually decrease and afterwards will linearly increase in the **same** direction.
11. At t_0 the velocity will reach its maximum, then will gradually decrease and afterwards will linearly increase in the **opposite** direction.
12. The velocity of the object will be **zero** at t_0, t_2, and t_4; whereas at t_1 and t_3 it will have the **maximum** values.
13. The object will start its motion with zero velocity, and it will steadily speed up; and then in the second half it will steadily slow down until it stops.
14. The object's velocity will **increase** at a decreasing rate, and then will **decrease** at an increasing rate.
15. The object's velocity will **increase** at an increasing rate, and then will **decrease** at a decreasing rate.
16. The object's velocity will **increase** at a decreasing rate, and then will **decrease** at an decreasing rate.
17. The object's velocity will **decrease** at an increasing rate, and then motion will be **reversed** and velocity will **increase** at an increasing rate.
18. The object has a **constant** acceleration throughout its motion.
19. The object has a **decreasing** acceleration in the first half and an **increasing** acceleration in the second half of its motion.
20. The object has an **increasing** acceleration in the first half and a **decreasing** acceleration in the second half of its motion.

The test was administered in mid 2006 spring semester to a total of 80 middle grades science teacher candidates in two groups. There were 39 participants in one group and 41 in the other. Participants were in their junior years. Science education majors take introductory physics courses in the first year. So, this test was administered 2 years after taking the physics courses.

The 20 questions can be divided into 5 groups (or themes): magnitude of velocity, direction of velocity, position of the object, the form of velocity vs. time graph, and acceleration. Since it is observed in in-class discussions previously that students’ propose a large number of forms for the velocity-time graph for such a motion eight most common ones were included as statements in the questionnaire.

Findings

As seen in table 1 only 10% of the participants correctly predicted the results in all four themes. Other response patterns are also given in table 1.

Table 1. Response patterns (× non-appropriate, and ✓ appropriate response combinations for each theme).

Theme	Magnitude of velocity	Direction of velocity	Position of the object	The form of velocity vs time graph	Acceleration	Number of Responses			Percentages
Related questions	1, 2, 3	4, 5, 6	7, 8, 9	10,11,12,13, 14,15,16, 17	18, 19, 20	Group A	Group B	Total	
Correct response patterns	FFT	FTF	FTF	FFFFTFFF	FTF	*N*=39	*N*=41	*N*=80	
Response combinations	×	×	×	×	×	8	8	16	20.00
	×	×	×	×	✓	20	19	39	48.75
	✓	×	×	×	×	0	1	1	1.25
	✓	×	×	×	✓	0	2	2	2.50
	×	✓	✓	×	✓	0	2	2	2.50
	×	✓	✓	✓ (13-14)	×	0	2	2	2.50
	✓	✓	×	×	✓	1	0	1	1.25
	✓	✓	✓	×	×	1	0	1	1.25
	✓	×	✓	✓	✓	0	1	1	1.25
	✓	×	✓	✓ (13-14)	✓	1	0	1	1.25
	✓	✓	✓	×	✓	0	1	1	1.25
	✓	✓	✓	✓	×	1	1	2	2.50
	✓	✓	✓	✓ (13-14)	×	2	1	3	3.75
	✓	✓	✓	✓	✓	3	0	3	3.75
	✓	✓	✓	✓ (13-14)	✓	2	3	5	6.25

Some participants regarded items 13 and 14 similar or complementary to each other. This was also seen in a previous administration of the test (Tasar, 2002). Hence, if a participant signed item 13 together with item 14 as true then the fourth theme for such cases is considered appropriate.

When first three themes are considered only 18.75 % (*N*=15) of the participants did not show any misconceptions. It should also be noted that most participants (68.75 %, *N*=55) correctly predicted the pattern of acceleration resulting from such a changing force in time.

When responses were evaluated in terms of if they show misconceptions it is seen that more than two thirds of the participants hold misconception regarding force's effect on motion. About a quarter (22.50%) of the participants showed perfect misconception pattern in their responses to the first three themes.

Results and Implications

It is seen that most science teacher candidates cannot respond appropriately to the questions and consequently it is inferred that most of them still hold misconceptions about force and motion. It is noteworthy that although about half of them (48.75%) can figure out the relationship between force and acceleration, they cannot comment correctly on force's effect on velocity (speed in 1-D) and resulting displacement. This can be associated with rote memorization of concepts. The results show that only 10% can correctly answer all questions. Most definitely this is not a desired level of achievement for teacher candidates. By and large, there exists a huge gap between their understandings of the concepts and the scientifically accepted ones.

Since the relationship of force and velocity are neither direct nor linear instructors, by presenting appropriate analogies preferably already known by their learners, can help overcoming conceptual difficulties. Force is related to the change in velocity by Newton's second law. If there is a change in velocity then there must be a net force applied or vice versa. If there is no net force applied then the law of inertia applies (no change in velocity).

Table 2. Number of respondents showing complete or partial misconceptions regarding first three of the themes.

Theme	Magnitude of velocity	Direction of velocity	Position of the object	Number of Responses			
Related questions	1, 2, 3	4, 5, 6	7, 8, 9	Group A	Group B	Total	Percentages
Response pattern showing the misconception	TTF	TFT	TFT	*N*=39	*N*=41	*N*=80	
	✓	✓	✓	10	8	18	22.50
	✓	✓	✗	2	1	3	3.75
	✗	✓	✓	9	8	17	21.25
	✓	✗	✓	0	3	3	3.75
	✗	✓	✗	2	1	3	3.75
	✗	✗	✓	2	8	10	12.50
TOTAL				25 31.25%	29 36.25%	54 67.50%	

Similarly, if inflation in prices is reduced that does not mean that the prices will also be reduced. It simply means that prices will increase in a decreasing rate (contrary to the layman's interpretation that prices will fall). If inflation rate is steady, then it means that prices are going up at a constant rate. If inflation rate is going up in time, it means that prices are increasing at an increasing rate.

In the same way, an analogy can be made between rate of change of population and acceleration. If the population increase rate is reduced then the population increases at a lower rate, but never decreases. If the population increase rate is constant then the population increases steadily.

It is suggested here that by discussing these analogies a more meaningful understanding of the relationship between force (acceleration) and motion can be achieved. This is seen as the key since the findings here suggest that although students understand the relationship between force and acceleration they cannot predict the features of resulting motion.

References

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (1994). *Making Sense of Secondary Science: Research into Children's Ideas*. New York, NY: Routledge.

Duit, R. (1993). *Research on students' conceptions – developments and trends*. In The *Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics*, Ithaca, NY: Misconceptions Trust.

Hestenes, D. Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher*, **30** (3), 141-158.

Hestenes, D. & Wells, M. (1992). A Mechanics baseline test. *The Physics Teacher*, **30** (3), 159-166.

Thornton, R. K., & Sokoloff, D. R. (1998). Assessing student learning of Newton's laws: The force and motion conceptual evaluation and the evaluation of active learning laboratory and lecture curricula. **American Journal of Physics**, *66* (4), 338-352.

Tasar, M. F. (2001). *A case study of one novice college student's alternative framework and learning of force and motion*. Unpublished doctoral dissertation, The Pennsylvania State University, University Park, PA.