



## PCK Tools

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### Motion: Student Misconceptions and Strategies for Teaching

According to Eryilmaz (2002), “mechanics is the most frequently studied subject in physics; in mechanics, force and motion are the most widely discussed topics.” The Newtonian view of motion is a crucial concept in physics but can be one of the most difficult areas of science for a student to come to understand since it goes against much of the knowledge a child has acquired over time. Indeed, Wolpert (1992) writes that “the physics of motion provides one of the clearest examples of the counterintuitive and unexpected nature of science.” Student misconceptions around this topic are common and have been widely studied; as a result, the research provides a number of ways to look at this topic as well as strategies to help students come to the scientific viewpoint.

#### What Are Motion and Force?

In physics, *motion* means a continuous change in the position of a body relative to a reference point. In the Newtonian model, the properties of space and time determine the nature of motion; the properties of motion, in turn, are determined by the nature of force. *Force* is that which changes or tends to change the state of rest or motion of a body.

The three laws of motion developed by Newton are the following:

1. An object at rest tends to stay in rest and an object in motion tends to stay in motion in a straight line at constant speed unless acted upon by an outside force.
2. If one object has more inertia than another, more force is required to give that object the same acceleration as the first.
3. To every action (force applied), there is an equal but opposite reaction (equal force applied in the opposite direction).

The first law also is known as the Law of Inertia. There are no perfect demonstrations of the law, as friction usually causes a force to act on a moving body. However, the law emphasizes the elementary cause of changes in an object’s state of motion—force. *Friction* is the force that opposes the relative motion or tendency of such motion of two surfaces in contact.

According to the second law, a force causes only a *change* in the speed and direction of an object; it does not maintain the speed and direction, as Aristotle held. According

to Aristotle, there is only a speed and direction if there is a force, but according to Newton, an object with a certain speed and direction maintains that speed and direction *unless* a force acts on it to cause a change in speed and direction. Aristotle's view tends to align with common sense and misconceptions on the part of students who fail to recognize that friction acts as a force to slow down an object and that the force that is "apparently" needed to sustain the object's motion merely offsets the friction force.

It is essential to understand that forces only cause a change in the state of an object from being either at rest or in motion with constant speed and direction. Motion must *not* be conceived of as an effect; instead, there must be an understanding of rest and motion as being essentially the same.

### **What Problems and Common Misconceptions Do Students Have Around Motion?**

Students of all ages seem to have trouble grasping the Newtonian view of motion. Everyday experiences suggest and reinforce "gut dynamics," the notion that "if an object is pushed with a constant force this produces constant motion, and if that pushing force ceases there is a force in the moving object that keeps it from going but which gradually gets used up and then the object stops." Additional explanations that people develop for themselves to explain the ways in which objects move have been termed "lay dynamics." Such ideas are very similar to the notions devised by Aristotle (Driver, et al., 1994).

## **State Standards**

On the topic of motion, **New Jersey Core Curriculum Content Standards** set the following expectations of what middle school students should learn about and be able to do:

6<sup>th</sup> grade

- Recognize that an object at rest will remain at rest and an object moving in a straight line at a steady speed will continue to move in a straight line at a steady speed unless a net (unbalanced) force acts on it.
- Recognize that motion can be retarded by forces such as friction and air resistance.
- Recognize that everything on or near the earth is pulled toward the earth's center by gravitational force.

8<sup>th</sup> grade

- Use quantitative data to show that when more than one force acts on an object at the same time, the forces can reinforce or cancel each other producing a net (unbalanced) force that will change speed and/or direction of the object.
- Recognize that every object exerts a gravitational force on every other object, and that the force depends on how much mass the objects have and how far apart they are.

**The Texas Essential Knowledge and Skills (TEKS)** standards set these expectations:

6<sup>th</sup> grade

- Identify and describe the changes in position, direction of motion, and speed of an object when acted upon by force.
- Demonstrate that changes in motion can be measured and graphically represented.

7<sup>th</sup> grade

- Demonstrate basic relationships between force and motion using simple machines including pulleys and levers.
- Demonstrate that an object will remain at rest or move at a constant speed and in a straight line if it is not being subjected to an unbalanced force.

8<sup>th</sup> grade

- Demonstrate how unbalanced forces cause changes in the speed or direction of an object's motion.
- Recognize that waves are generated and can travel through different media.

Indeed, students typically embrace the Aristotelian model, which argues that force causes motion, and that the larger the force, the greater “the motion.” Additionally, the force applied is believed to be in the direction of the motion. This conception has proved remarkably common across cultures and remarkably resistant to teaching. The Aristotelian model also has multiple elements, according to Mildenhall and Williams (2001):

- The force has to be big enough before motion can take place.
- When the force is big enough, it causes motion rather than change in motion.

They found that the “threshold of force required to cause motion is found to be explained as partly ‘inertia,’ partly resistive. The resistive part is related to the quality of frictional contact of the surfaces and the ‘inertial’ part is usually related to the magnitudes of the masses involved. This picture was complicated by the ‘balance’ intuition, in which the actions of the forces were misinterpreted.”

Discussion of these alternative notions, or “dynamics,” will be broken into the following topics: Force, rest, friction, and velocity and acceleration. While these topics are interrelated, the misconceptions might be easier to look for and work with if categorized.

**Force.** Force is essentially an interaction between objects. Often students think that an object in motion requires a force to stay in motion. Their everyday experiences provide evidence for this viewpoint. However, this perception contradicts Newton’s first law that a force is not needed to maintain motion, only to change it (Espinoza, 2005).

The work of a large number of researchers, as compiled by Driver, et al., (1994) has identified the following generally held ideas regarding motion:

- If there is motion, there is a force acting.
- There cannot be a force without motion.
- If there is no motion, then there is no force acting.
- When an object is moving, there is a force in the direction of its motion.
- A moving object stops when its force is used up.
- Motion is proportional to the force acting.
- A constant speed results from a constant force.

Students often cannot envision a force acting (such as a table beneath a book) without causing motion. Further, two notions—that force determines speed and that a stronger force makes an object go faster—were found in a number of studies, including Champagne, et al. (1980). Similarly, researchers have found that students strongly believe that an object traveling at a constant speed requires a constant force.

Teachers should be aware of the following common student misconceptions:

- *Objects have a “force inside” that keeps them moving.* The students’ idea of force as an acquired property has close links with the pre-Galilean notion of *impetus*: It is conceived to be an inanimate “motive power” or “intrinsic force” that keeps things moving (Hestenes, Wells, & Swackhamer, 1992; Sequira & Leite, 1991). In this view, for an object to move it must be supplied with impetus or “momentum.” This is inconsistent with Newton’s first law. Hestenes, Wells, & Swackhamer (1992) argue that the impetus concept of motion is the most difficult and usually the last of the alternative conceptions to be overcome in the transition to Newtonian thinking.
- *Motion is seen as a result of a force.* Students have trouble moving from the idea of a force as an innate property to seeing forces as interactions between objects. Students believe that if a body is moving, there is a new force acting upon it in the direction of the movement. If the body is not moving, there is no force acting on it (Watts & Zylbersztajn, 1981).
- *An inanimate and inert object cannot exert a force.* Students do not grasp the third law of motion, which argues that each action creates an equal and opposite reaction. They may think that a table does not exert a force on a book lying on it—it is just “in the way” (Minstrell, 1982).
- *An interaction between objects is seen as a struggle between unequal forces.* It follows from the metaphor that victory belongs to the stronger. In a conflict, the more forceful exerts the greater force. Therefore, students often believe that greater mass implies greater force, or the most active mass? produces the greatest force (Maloney, 1984; Minstrell, 1982; Sadanand & Kess, 1990; Sequeira & Leite, 1991). Brown (1989) used a multiple-choice question in which students were asked to compare the forces that a 16-pound bowling ball and a 4-pound stationary pin exert on each other when the ball strikes the pin. Only 5% of students answered the question correctly (stating that the forces will be equal) after a full year of traditional physics instruction. Most students seemed to think in terms of a “dominance principle,” where the bowling ball is “more forceful” because it is moving, is heavier, and is more able to cause damage than the pin. Watts and Zylbersztajn (1981) provide the example of a person winning at a game of tug-of-war; it is very difficult for students to understand how the forces on the rope are equal if one side is clearly winning. In other words, Bao, et al., (2002) argue that while students recognize that both objects exert a force, they fail to appreciate the fact that the forces arising from an interaction are always symmetrical.
- *An applied force is necessary for the continuity of motion at a constant velocity.* It is found that such imagined forces are especially common in explanations of motion that continues in the case of obvious opposing forces. In addition, some

students believe that such a force dies out or increases to account for changes in an object's speed (Sadanand & Kess, 1990; Sequeira & Leite, 1991).

**Rest.** This special case of motion in which the velocity of an object is constant at zero is not held by students. They regard the state of rest as different from the state of motion. Rest is widely regarded as a “natural” state in which *no forces are acting* on an object (Driver, et al., 1994). In the context of making a graph to show the movement of an object over time, 12- to 14-year-olds tend not to represent time passing for any period when an object is stationary (Bliss, et al., 1988).

**Friction.** Students have difficulty visualizing a frictionless world. Some students believe that the speed of an object decreases even though the net force acting upon it is zero, because it can be difficult to include the notion of friction (Halloun & Hestenes, 1985). Fifty percent of 13-year-olds define *friction* as rubbing, according to Stead and Osbourne (1981). Other common ideas were that friction

- 1) is a force;
- 2) is the same thing as reaction;
- 3) depends upon movement;
- 4) is associated with energy, especially heat;
- 5) occurs only between solids;
- 6) occurs with liquids but not with gases;
- 7) causes electricity;
- 8) “does this and that” as if it were an object; and
- 9) is “trying to do” this and that.

**Velocity and Acceleration.** Students often confuse these two terms. While *velocity* is simply the speed of an object, *acceleration* is the rate of change in that velocity. The period of change when an object speeds up or slows down is less frequently a focus of children. The idea of acceleration is not considered by most students until they take a formal science class, and the idea of going faster is used in ambiguous ways (Driver, et al., 1994).

- *Students often confuse the velocity and acceleration of an object.* When two objects have the same speed, students think that they have the same acceleration at that time (Rosenquist & McDermott, 1987; Trowbridge & McDermott, 1980).
- *If speed is increasing, then acceleration is also increasing.* Only 68% of a sample of 52 17-year-olds who had studied physics recognized that an overtaking object is going faster all of the time. It is also common for 12- to 14-year-old students to think that if speed is increasing, then acceleration is also increasing (Jones, 1983).
- *There is a linear relationship between force and velocity (instead of acceleration).* Students appear to associate force with velocity rather than with acceleration. This makes it even more difficult for students to accept the idea of force causing a change in motion; instead, they think of continuing to apply a force if they want

an object to move at a constant speed. Therefore, these students expect a constant velocity from a constant force (Sequeira & Leite, 1991).

- *Heavier objects fall faster.* Students believe that a heavier weight causes a greater acceleration in free fall or that gravity varies significantly over a few meters. Moreover, some students believe that gravity does not act until impetus wears down (Minstrell, 1982).

At a more general level, students' understandings of the force concept are very often context-dependent, meaning that a student may show correct understanding in some exercises involving the force concept but fail to apply this in other contexts. Steinberg and Sabella (1997) argue that "different contexts and presentations can trigger different responses from a given student, even if the underlying physics is identical."

In trying to learn the Newtonian model, students tend to *modify* their gut and lay understandings rather than abandon them altogether. Mildenhall and Williams found that students often choose one model or the other, depending on the parameters involved. This choice is not arbitrary: They choose the intuitive model for small forces and the academic model for larger forces, the changeover depending on the relative magnitudes of the weight of the mass being moved and the motive force when faced with similar problems. In other words, they do not reserve their taught, academic model for academic questions and their intuitive model for "real-world" questions, but rather respond intuitively for some values and use their taught model for others.

### **Key Points on Student Misconceptions: Motion**

- Student misconceptions often are aligned with the Aristotelian model, which argues that force causes motion and that the larger the force, the greater the "motion."
- Everyday experiences help create "gut dynamics," the notion that "if an object is pushed with a constant force, this produces constant motion, and if that pushing force ceases, there is a force in the moving object that keeps it from going but which gradually gets used up and then the object stops."
- Students do not see an inanimate and inert object as exerting a force and fail to understand that the forces arising from an interaction are always symmetrical.
- Students regard the state of rest as different from the state of motion—rather than recognizing the state of rest as being motion in which the velocity is at zero.
- Students have trouble understanding friction as the force and also the notion of the "frictionless" world required to prove Newton's first law.
- Students often confuse the velocity (speed) and acceleration (rate of change in velocity) of an object and believe that heavier objects fall faster.

## What Are Some Strategies to Address Student Misconceptions About Motion?

These findings indicate that there is a big gap between alternative conceptions and scientific views in the case of the motion. The change from seeing force as an innate property to seeing forces as interactions between objects requires more than just extending existing ideas—it requires changing points of view (Savinainen & Viiri, 2003).

The conditions for conceptual change as outlined by Posner, Strike, Hewson, and Gertzog (1982) are as follows:

- There must be dissatisfaction with existing conceptions. Scientists and students are unlikely to make major changes in their concepts until they believe that less radical changes will not work.
- A new conception must be intelligible.
- A new conception must appear initially plausible. Any new concept to win adoption must at least appear to have the capacity to solve the problems generated by its predecessors. Otherwise, it will not appear as a plausible choice. Plausibility is also a result of consistency of the concepts with other knowledge.
- A new concept should suggest the possibility of a fruitful research program. It should have the potential to be extended and open up new areas of inquiry.

### Identify and Confront the Misconceptions

Whether they are called alternative frameworks or life lessons, the knowledge that students have acquired from their own experiences must be identified and addressed first. According to Driver, et al., (1994), science teachers at the secondary level “need to be aware of pupil’s existing ideas, of the learning goals and also of the nature of any differences between the two” when they are planning for and implementing science lessons. The first thing to do is to consider the nature of any differences between children’s prevalent thinking and the scientific viewpoint. Once the teacher has identified the nature of any differences between the pupils’ thinking and the scientific viewpoint, then it will become easier to plan the lesson and activities. In some cases, such as learning the Newtonian view of motion, students may have trouble with the new scientific notions being expressed. Time will be needed for the students to come to terms with a concept that is foreign to them.

Work by Nachtigall (as cited in Van Hise, 1988) and Brouwer (1984) developed instructional programs with the following key points:

- Ensure that students are aware of their preconceptions (Nachtigall);

- Allow students to make their own conceptions or hypotheses explicit and test them (Nachtigall & Brouwer);
- Confront students with situations where their preconceptions cannot be used as explanations (Nachtigall);
- Let students become aware of this conflict (Nachtigall);
- Help students accommodate the new ideas presented to them (Nachtigall);
- Make students conscious of the fact that their new knowledge is more powerful than their previous ideas by applying the model in familiar and new situations (Nachtigall & Brouwer);
- Give students a feeling of progress and growth in mental power and help students develop confidence in themselves and their abilities (Nachtigall);
- Test scientific understanding both conceptually and quantitatively (Brouwer).

### **Bridge the Gap**

Instruction should not only provide information on the basic concepts but also connect those understandings to issues in everyday life. Students must be given an opportunity to express what they understand about motion before formal instruction begins. With this as the focus, Duit and Haeussler (1994) argue that we must “reject the idea of replacing students’ conceptions with scientific ones. If we were to try, students would learn a conception that is at least partly contradictory to the life-world conceptions.”

Indeed, Gilbert, et al., (1982) proposed a number of outcomes that might result from teaching if students are not able to bridge the gap between life experience and the scientific view.

- *Undisturbed outcome*: Students retain their intuitive ideas.
- *Dual perspective*: The academic and intuitive ideas coexist, and students use their intuitive ideas except in the classroom.
- *Incorrectly reinforced outcome*: Some scientific ideas are absorbed, but students use them incorrectly to justify intuitive ideas.
- *Mixed reaction*: Academic ideas are learned, but not totally integrated, and students use either academic or intuitive ideas for similar problems.
- *Unified outcome*: Students learn the material and integrate those ideas into their cognitive structures, presenting a scientific view of the world.

### **Introduce the Idea of Motion as Interaction**

Some researchers recommend that the concept of force might be more effectively taught by emphasizing forces as interactions between objects (Brown, 1989; Hellingman, 1989; Reif, 1995). For instance, Reif (1995) recommends analyzing a physical system by describing both motion and interactions. He argues that identifying interactions first helps to avoid the inclusion of nonexistent forces. Just “telling” students that forces arise due to interactions is not going to be very effective.

## **Use Analogies**

Once students have decided that their previously held ideas are unsatisfactory, they might use anchoring ideas or intermediate “bridging” analogies between the prior ideas and those of physics. For example, if pupils cannot accept the idea of a force of reaction exerted by a table on a book resting upon it, they can be offered the analogy of the book on a spring. Two intermeshed hairbrushes might provide an analogy to help students understand friction. Two skaters pushing against one another might provide an analogy for Newton’s third law of equal and opposite reactions (Driver, et al., 1994). The analogies must be concrete and not abstract, and must also be evaluated by the students in order to determine if they are helpful to a particular class (Clement, et al., 1989).

## **Make Sure Students Can Describe Motion Scientifically**

Driver, et al., (1994) argue for the importance of working with children on scientific terminology relating to motion. Children need to develop the language tools to describe motion appropriately, including vocabulary, graphical representations, and numerical formulas (i.e.,  $v = d/t$ ) prior to developing an understanding of dynamic principles.

## **Focus on Teaching Momentum Early When Discussing Motion**

A number of researchers support focusing on momentum early in the introduction of motion, and doing so in qualitative terms. This allows students to accept along with their own ideas that “a moving object has something that keeps it going.” This lets students to view the idea of force as “that which causes a change in momentum” and not “something in an object which keeps it moving.” An early focus on relating distance, time, and speed have also been recommended (Driver, et al., 1994).

## **Use the History of Motion Theory**

Gilbert and Zylbersztajn suggest that it may be helpful for students to understand that many of their ideas were once held by Aristotle and others, but that new ideas about motion have been developed. Specifically, the Impetus Theory of the Middle Ages offers a link to student perceptions and can provide an approach to starting the discussion.

## **Use Experiments Based in History**

Espinoza argues that the use of experiments in instruction simulating or reproducing activities chosen from historically known analyses “is not only likely to enhance the students’ appreciation of the difficulties encountered by past thinkers, but can also provide a historical context where the students can see the interdisciplinary aspects of the physics curriculum.” To recognize and attempt to reverse misconceptions held by students requires the design of activities that elicit their input from the beginning. Students should be made to predict the outcome of an experiment before it takes place. Then, the activity should be designed to lead to an unlikely outcome for students. This will require students to confront their own misconceptions and understand that while they

may be similar to the views held in the past, they are no longer scientifically accurate. For example, a discussion of accelerated motion might include an experiment with falling water from a certain height. If the size of the opening is controlled so that the students see that the initial linear flow is continuous, their observation that at some point during the motion the stream of water breaks up into droplets can be used to demonstrate that the water is accelerating as it falls.

## **Motion: Lessons Learned**

According to Driver, et al., (1994),

the most helpful message of all to emerge from the research is that difficulties do not betoken either poor teaching or poor learners: difficulties are inevitable in view of the everyday effectiveness of “gut dynamics” and “lay dynamics” for coping with the world.

Science teachers are working against common sense to teach students about concepts that in many ways defy experience. The similarities also are reflected in the teaching methods suggested to reach students: Start with understanding student misconceptions, engage in classroom discussions to disprove these misconceptions, and make the students defend their positions with explanations. Create a bridge between the misconceptions and the scientific understanding of these concepts. These things take time and patience. Students will resist this teaching and these topics are not easy. However, motion is a fundamental concept in understanding the way the world works around us.

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