**Online Supplemental Materials:**

1. **Diagnostic Test of Force and Motion**

Note: Items adapted from Alonzo and Steedle (2009) are marked with an asterisk (\*), which may also contain minor modifications.

1. A heavy box is initially moving to the right along a horizontal frictionless ice plane. If two forces in opposite directions are applied on the box (the force to the right is 10N, and the force to the left is 8N, ignore friction), what can you conclude about the motion of the box?

A. The box will keep moving to the right at the same velocity because the ice plane is frictionless.

B. The box will speed up to the right.

C. The box will speed up to the right till it reaches its maximum velocity, and then keeps moving at this maximum velocity.

D. The box will initially move to the right and gradually slow down because the box is too heavy.

Using the following information to answer questions 2 and 3.

Jeff's car ran out of gas, so he has to push it along a horizontal ice plane. There is no friction between the car and the ice.

\*2. As long as Jeff pushes with a constant force, how will his car move?

A. It will move faster and faster across the ice.

B. It will keep moving until Jeff stops pushing.

C. It will move at a constant speed across the ice.

D. It will speed up and then move at its maximum speed.

\*3. If Jeff stops pushing, his car will

A. gradually slow down because there is no force to keep it going.

B. gradually speed up because there is no friction between the car and the ice.

C. keep moving at the same speed because there is no force to slow it down.

D. stop moving as soon as Jeff stops pushing because there is no force to keep it going.

4. A box weighing 5 N is pulled by an upward force of 7 N. After a while, the box reaches a velocity of 5 m/s pointing upward. Ignoring air resistance. Determine how the up-pulling force should change in order to keep the box moving up at a constant velocity of 5 m/s pointing upward.

A. The force should increase.

B. The force should decrease.

C. The force should remain invariant.

D. The force should be zero.

Use the following information to answer questions 5 and 6.



Derek throw a stone straight up into the air. It leaves his hand, goes up through point A, gets as high as point B and then comes back down through A again.

\*5. Ignoring air resistance, what force(s) are acting on the stone when it is moving up through point A?

A. Only gravity is acting on the stone.

B. Only the force that Derek put on the stone is acting on it.

C. Both gravity and the force that Derek put on the stone are acting on it.

D. There are no forces acting on the stone.

\*6. Ignoring air resistance, why does the stone come to a stop at point B?

A. There are no forces acting on the stone at point B.

B. The force of gravity is now equal to the force from Derek’s throw.

C. There is no more force left from Derek’s throw.

D. Gravity has slowed the stone until it stops.

7. To keep a box from falling, Tom exerts an upward force to pull the box up. Ignore air resistance. If the force pulling the box is greater than the box’s force of gravity, what can you conclude about the motion of the box?

A. It will stop falling as soon as Tom exerts the upward force because the upward force is greater than the force of gravity.

B. It will move upward as soon as Tom exerts the upward force because the upward force is greater than the force of gravity.

C. It will continue to accelerate downward because the box has been falling for a while, which makes it hard to change the box’s motion.

D. It will deaccelerate downward for a while, then start to move upward.

\*8. A spacecraft moves at a constant speed in outer space. If there is no friction or gravity, what force(s) are acting on the spacecraft.

A. There are no forces acting on the spacecraft.

B. There is an unbalanced force acting on the spacecraft.

C. The spacecraft must have an engine which is exerting a constant force on it.

D. The force that launched the spacecraft into outer space is still acting on it.

9. A basket weighing 4 N is moving upward while being pulled by an upward force of 10 N. After a while, a stone weighing 6 N and traveling initially at the same velocity of the basket is put into the basket. Ignoring air resistance and possible collision effect. What can you conclude about the motion of the basket with the stone in it?

A. The basket will keep moving upward faster and faster.

B. The basket will keep moving upward at a constant velocity.

C. The basket will move upward at a velocity that gets slower and slower.

D. The basket will immediately move downward.

\*10. The boulder in the picture is not moving because

A. the boulder is too heavy for other forces to affect it.

B. no forces are acting on the boulder.

C. gravity is holding it down to the ground.

D. the ground pushes up with the same force that gravity pulls down.

\*11. José drops a ball from the top of a tall building. There is no air resistance, but gravity is acting on the ball. What will happen to the speed of the ball as it falls?

A. The ball’s speed will be constant because the force of gravity is constant.

B. The ball’s speed will increase until it reaches a constant speed because the force of gravity is constant.

C. The ball’s speed will increase as it falls because the force of gravity is constant.

D. The ball’s speed will increase as it falls because the force of gravity is increasing.

12. As shown in the diagram, a block sitting on a cart is moving with the cart to the right at a constant velocity. Ignore air resistance. Which of the following statements is true?

A. There is no friction between the cart and the block.

B. The faster the block and the cart move, the greater the friction between the cart and the block is.

C. The upward force pushed by the cart on the block is balanced by the downward force pushed by the block on the cart.

D. When the cart suddenly stops moving due to an emergent resistance, the block will flip to the right if the surfaces between the car and the block are frictionless.

13. A box is moving to the right along a horizontal plane. What can you conclude about any force acting on the box?

A. A force to the left is acting on the box.

B. A force to the right is acting on the box.

C. There is no force acting on the box.

D. All of the above is possible.

\*14. On a visit to a science lab, Madison observes a balloon, which appears to be floating in the air. The balloon isn’t moving. What can she conclude about the force(s) acting on the balloon?

A. Gravity cannot be acting on the balloon because it isn’t falling down.

B. Gravity must be acting on the balloon or it would be floating up.

C. There are no forces acting on the balloon because it isn’t moving.

D. Each force acting on the balloon has another one to cancel it out.

15. A rocket is speeding upward under the action of the force from the thrust of its engine. Ignore air resistance. Compare the force(s) acting on the rocket?

A. The force from the engine thrust is greater than the force of gravity applied on the rocket.

B. The force from the engine thrust is equal to the force of gravity applied on the rocket.

C. The force from the engine thrust is less than the force of gravity applied on the rocket.

D. The force from the engine thrust is gradually consumed by the force of gravity applied on the rocket.

1. **Intervention Course Plan**
2. **The first intervention lesson plan**

The first new lesson follows the procedure shown in Figure S1.

***Step 1.*** Define the concept of applied forces.

***Step 2.*** Introduce the concept of net force.

***Step 3.*** Introduce the operational concept of acceleration
with a demonstration.

***Step 4.*** Discuss the relation between the net force
and acceleration (the rate of change of velocity).

Figure S1. Procedure of the first intervention lesson.

**Step 1. Define the concept of applied forces rigorously.**

To do this, the teacher first discusses with students that an applied force is a result of an interaction between two objects. Then, two types of forces are introduced to students, i.e. contact forces and noncontact forces. Some common forces are used to illustrate as examples for the two types of forces. For example, the tensional, spring, normal reaction, friction are classified as contact forces, and the gravitational, electrical, and magnetic. To emphasize that the force is an interaction, students are asked to identify the existence of certain forces in different situations. For example, for a situation that a boy is kicking a football, students are asked to identify whether the force applied by the boy’s foot on the football still exist if the football flies off.

**Step 2. Introduce the concept of net force.**

The idea of the net force is introduced for considering the combined effect of all applied forces on an object. Since the Chinese 8th grade students have not learned vector additions, only 1 dimensional cases are used. Specifically, six cases are illustrated, which include an object with one external force, an object with two forces acting in the same direction, and an object with two forces acting in opposite directions horizontally (and vertically as another example). Students are asked to determine the magnitude and the direction of the net force in these situations.

**Step 3. Introduce the operational concept of acceleration with a demonstration.**

The formal definition of acceleration is not part of the curriculum standard, therefore, the concept of acceleration is introduced operationally as the rate of change of velocity over time. In this process, the teacher asks students to recall and relate daily experiences on riding a vehicle while accelerating or decelerating. These experiences are used to help students develop an initial understanding about the change of velocity.

Then, a demonstration involving a glider moving through two fixed photogates on an air track under a constant external force applied with a pulley system is conducted in front of the whole class. In the demonstration, a bucket filled with different mass is connected with a string to the glider through a fixed pulley. This system applies a constant horizontal tension force on the glider. Before conducting the demonstration, the teacher also introduces how the photogates can be used to determine the instantaneous velocity of the glider. That is, the velocity of the glider equals to the length of the blocker divided by the time the glider goes through a photogate, which is an on-and-off square wave signal). The velocities of the glider at the two fixed photogates can be used to compute the change of velocity ($∆V$). The time ($∆t)$ for the glider to travel between the two photogates is also recorded. Then the rate of the change of velocity can be determined by dividing the change of velocity with $∆t$ ($a=∆V/∆t$).

The demonstration is conducted for three trials. In the first trial, the bucket is empty. In the second trial, the bucket is half filled with salt. In the third trial, the bucket is fully filled with salt. Students are asked to observe and discuss the relation between the rate of velocity change and the net force applied on the glider.

**Step 4. Discuss the relation between the net force and acceleration (rate of velocity change).**

Following observations and guided discussions about the demonstration, the teacher helps students to synthesize the relations between the net force applied on an object and its acceleration (rate of velocity change): (i) the greater the net force, the greater the rate of velocity change, and (ii) the direction of the rate of velocity change is in the direction of the net force. Finally, students are guided to determine the direction of the rate of velocity change in the six cases presented in Step 2.

1. **The second intervention lesson plan**

The second lesson follows the procedure shown in Figure S2.

***Step 1.*** Analyze states of motion using a velocity vs. time diagram.

***Step 2.*** Analyze the relations between states of motion
and the acceleration.

***Step 3.*** Synthesize to develop a correct understanding of the relations between states of motion and the net force.

***Step 4.*** Apply the understanding of relations between states of motion and the net force.

Figure S2. Procedure of the second intervention lesson.

**Step 1. Analyze states of motion using a velocity vs. time diagram.**

An object’s motion in 1D is used as an example to help students understand different states of motion, i.e., accelerating (0 – *t*1), constant velocity (*t*1 – *t*2), decelerating (*t*2 – *t*3), and stationary (*t*3 – *t*4).

Figure S3. An example for velocity vs. time graph in 1D.

***Step 2.* Analyze the relations between states of motion and the acceleration.**

Again, using the velocity vs. time diagram illustrated in Figure S3, students are asked to identify the corresponding rate of velocity change in each of the four time periods. After this step, students are expected to understand how the different combinations of acceleration (zero or nonzero) and direction of initial velocity (in the same or opposite direction of the net force) correspond to the different states of motion: accelerating, decelerating, constant velocity, or stationary. A table is given to students (see Table S1 below).

Table S1. The relations between states of motion and the acceleration (net force)

|  |  |  |
| --- | --- | --- |
| Acceleration: The rate of change of velocity over time | Direction of the net force and the initial velocity | States of Motion |
| $$a=0$$ | N/A | constant velocity, or stationary |
| $$a\ne 0$$ | Same | accelerating |
| $$a\ne 0$$ | Opposite | decelerating |

***Step 3.* Synthesize to develop the correct understanding of the relations between states of motion and the net force.**

Following the analysis in the previous steps, the rate of velocity change (acceleration) and its relation with the net force is used as the central idea to understand the relations between applied forces and states of motion. To help students develop the correct understanding of force and motion, two expert-like conceptual pathways on force and motion are discussed and practiced in teaching (see Figure S4). For the first conceptual pathway, students start with given applied forces and are guided to obtain the net force, which leads to the acceleration that changes the velocity. The second conceptual pathway takes the reasoning in the opposite direction. Students are first given information to determine the states of motion. These are then used to determine the acceleration and the net force, which eventually lead to the applied forces.

 Analyze the applied forces

Determine the net force

Determine the acceleration

(rate velocity change)

Determine the state of motion

Determine the state of motion

Determine the acceleration

(rate velocity change)

Determine the net force

 Analyze the applied forces

Conceptual Pathway 1

Conceptual Pathway 2

Figure S4. Two types of expert-like conceptual pathway on force and motion.

***Step 4.* Apply the understanding of relations between various states of motion and the net force.**

In this step, 8 sets of practice problems are provided to demonstrate how the expert-like conceptual pathways aid in problem-solving and conceptual development. Students are asked to apply the conceptual pathways studied in step 3 to solve these problems. An example of the practice problems is given in Figure S5. The questions listed in Figure S5 are designed to scaffold students’ learning and application of the expert-like conceptual pathways towards developing a deep understanding on the relations between force and motion.

A rocket is speeding upward. Please analyze the situation and answer the questions listed below.

* While the rocket is speeding upward, its velocity is \_\_\_\_\_\_ (increasing, decreasing, or constant).
* The rate of velocity change is \_\_\_\_\_\_ (zero, or nonzero).

If the rate of velocity change is nonzero, please finish the following questions:

* The direction of velocity change is \_\_\_\_\_\_ (upward, or downward).
* The magnitude of net force is \_\_\_\_\_\_ (zero, or nonzero).

If the magnitude of net force is nonzero, please finish the following questions:

* The direction of net force is \_\_\_\_\_\_ (upward, or downward).
* In the vertical direction, what can you conclude about the force(s) acting on the rocket?

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

If two or more forces are identified, please finish the following questions:

* While the net force is \_\_\_\_\_\_ (upward, or downward), \_\_\_\_\_\_ (force(s) from your conclusion above) is(are) greater than \_\_\_\_\_\_ (force(s) from your conclusion above).

Figure S5. An example of a practice problem set designed to facilitate students’ learning and application of the expert-like conceptual pathways. The example is adapted from the exercise problems in the textbook.