Grade 8: **Instructional Segment 1 Teacher Background and Instructional Suggestions**

What happens when two moving objects bang into each other? In part it depends on how much mass each of the two objects has, how fast they are traveling, and the directions in which they are traveling (MS-PS2-1). A particularly interesting example involving planet Earth happened 66 million years ago. You might wonder how we could possibly know with reasonable certainty about something that happened that long ago.

Five Periods of Major Extinctions

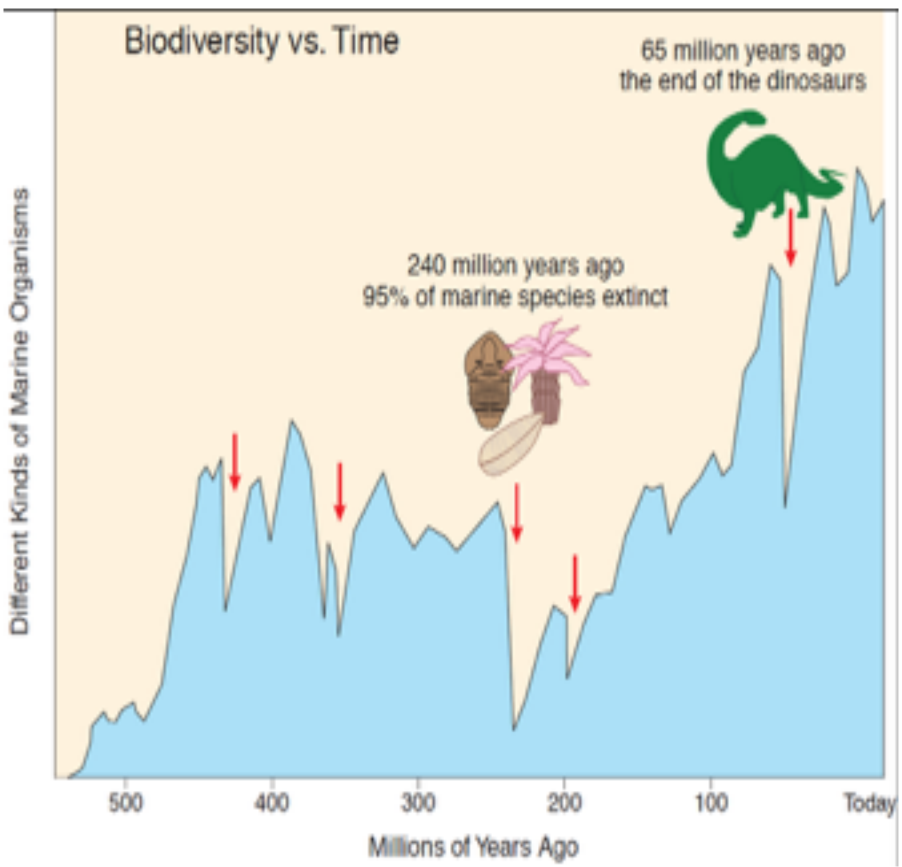

Figure 2: The fossil record of marine organisms indicates five major periods when Earth's biodiversity dramatically decreased. (Illustration from *Dr. Art's Guide to Science*, courtesy of WestEd)

As shown in Figure 2, Earth's fossil record provided the first major ***evidence*** that something changed life on Earth (MS-LS4-1) 66 million years ago. The fossil record of

marine species indicates that there have been five periods (indicated by arrows) when Earth's biodiversity dramatically decreased. The most famous in this ***pattern*** of great extinctions included the extinction of all the approximately one thousand different dinosaur species that existed at that time.
In the case of this major extinction event, scientists have amassed huge amounts of **evidence** that reinforce each other and indicate that an asteroid about 10 kilometers in diameter speeding at about 100,000 kilometers per hour crashed into the Yucatan region of Mexico. This collision released thousands of times more energy than exploding all the nuclear weapons currently on this planet. Global fires, dust and ash circling the globe and blocking sunlight, acidity changing the chemistry of the ocean, and drastic climate changes all combined to kill most of the multicellular organisms living on the planet at that time. Many species recovered but a high percentage of species became extinct.

Students can work in teams to **research** the different periods when these great extinctions happened and the **evidence** supporting those theories. Alternatively, the class could focus on the period of the dinosaur extinction and have different teams explore different kinds of evidence that integrate across the disciplines to convincingly support this ***cause and effect*** theory. The Howard Hughes Medical Institute BioInteractive website has many resources related to Earth's history and mass extinctions including a free App called EarthViewer that illustrates key features of Earth's 4.6 billion year ***time scale*** including fossil information.[1]

In addition to introducing one of the year's major topics (the history of life on Earth), the asteroid impact also leads into many key concepts related to forces, motion and gravity. How does science **describe, model and explain** the motions of objects such as an asteroid or our planet? How can we investigate phenomena related to motions and collisions?

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[1] Howard Hughes Medical Institute (HHMI) BioInteractive Earth History resources can be accessed at: http://www.hhmi.org/biointeractive/earthviewer

Fortunately for teachers and students of physical science, motions and collisions provide many engaging ways for learners to **design experiments, manipulate variables, and collect useful data** over the course of a single or multiple succeeding class periods. Few topics in other science disciplines provide this abundance of laboratory experiences that ignite enthusiasm and quickly provide meaningful data. On the other hand, few topics in science provide as many challenges with respect to a) using familiar words in ways that have different meanings than their common usages, and b) encountering concepts that seem to be the opposite of a person's everyday experiences.

Every day we push or pull many things. An object begins to move after we exert a force on it, and then it stops moving shortly after we stop pushing or pulling it. We conclude that forces cause temporary motions in objects. In complete contrast, Newton's First Law of Motion teaches that a force can ***cause*** an object to move, and that the object should keep moving at exactly the same speed until another force slows it down, speeds it up, or causes it to change direction. As illustrated in the vignette below, students need to **investigate, model and analyze** many phenomena in order to use common words about motion in scientifically accurate ways, and to correctly use motion concepts to ***explain the cause and effect relationships*** that result in observed phenomena.

Vignette: Learning About Motion[2]

This Vignette presents an example of how teaching and learning may look like in the classroom when the *CA NGSS* are implemented. The purpose is to illustrate how a teacher engages students in three-dimensional learning by providing them with experiences and opportunities to develop and use the Science and Engineering Practices and the Crosscutting Concepts to understand the Disciplinary Core Ideas associated with the topic in the Instructional Segment.

Introduction: From Position to Velocity

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[2] In addition to cited illustrations, the physical science narrative in this Vignette and Instructional Segment uses material from Making Sense of Science *Forces and Motion* course, courtesy of WestEd

Figure 3 is an example that shows three types of models applied to the scenario of a dog going 2 meters from a tree to a fire hydrant, and then returning more quickly past the tree to a dog house that was 1 meter behind the tree. She especially liked students to begin with Difference Tables such as the one at the top of the figure. The middle is an example of a Number Line model and the bottom shows two Line Graph models (position v time and distance v time). Next to the middle diagram, there is a prompt that she used to show that motions can also be represented using arrows of different lengths and pointing in different directions

Some Different Models of Motion

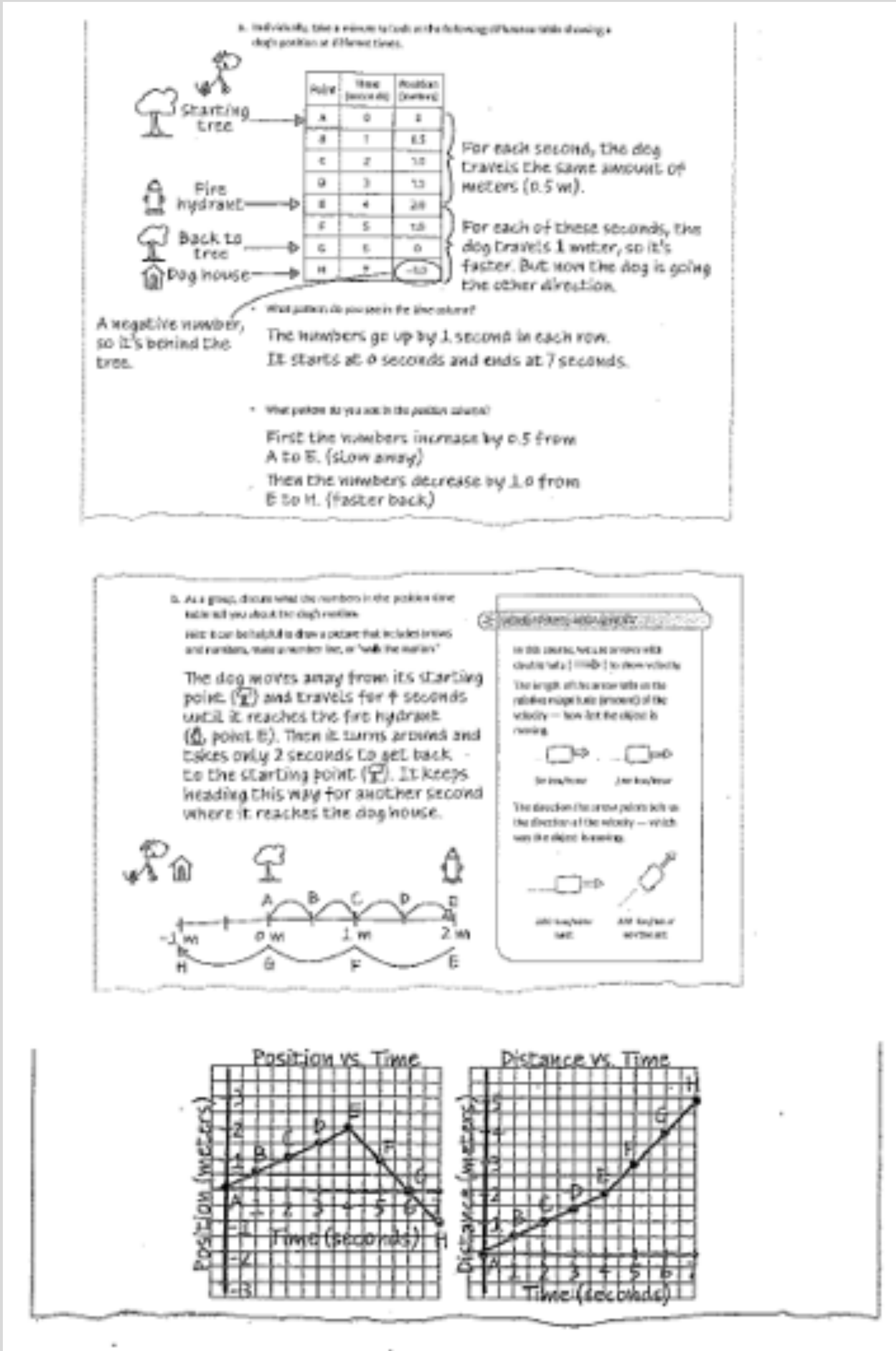

Figure 3: Different kinds of models can be used to analyze motion. (Illustrations from Making Sense of Science *Force & Motion* course, courtesy of WestEd)

Over the entire course of lessons involving motions, Ms. Z encourages students to **compare different models** of the same phenomenon, and **communicate** which model features help them understand the phenomenon better and which model features are not so helpful. Since this entire grade level involves many examples of ***systems thinking and system models***, students will often experience that "models are limited in that they only represent certain aspects of the system under study."[3] By comparing and expressing how particular model types do or do not help them understand a specific phenomenon, students gain insights into how the limitations of a model sometimes help them focus on a key concept and sometimes do not provide enough information.

In the case of the dog's journey, several students said that the line graphs confused them while other students said that they liked how the directions and slopes of the lines summarized key aspects of the motion scenario. Kanesha said that at first she did not like the line graphs, but after she figured out what the different vertical and horizontal axes represented, she liked them a lot better, and could use the line graphs to **explain** the scenario. Ms. Z took this opportunity to discuss common misconceptions about line graphs and introduce a way that the class as a whole could **communicate** about incorrect and correct conceptions (Figure 4).

Student teams and then the whole class discussed the correct conception that a graph is not a literal picture of motion. Kanesha pointed out that the correct conception statements all mentioned the reference point, but each of the three graphs actually started at a different x value for that reference point. She said that it would be better if they all started from the same point on the vertical axis at time zero. Other students said that in their math class, the x value was always on the horizontal axis, not the vertical axis. After this discussion, the students formed teams to make new versions of this incorrect/correct diagram, and compared their diagrams with each other.

[3] NGSS Crosscutting Concepts Middle School third bullet for "Systems and System Models."

Incorrect and Correct Ideas About Line Graph Shapes

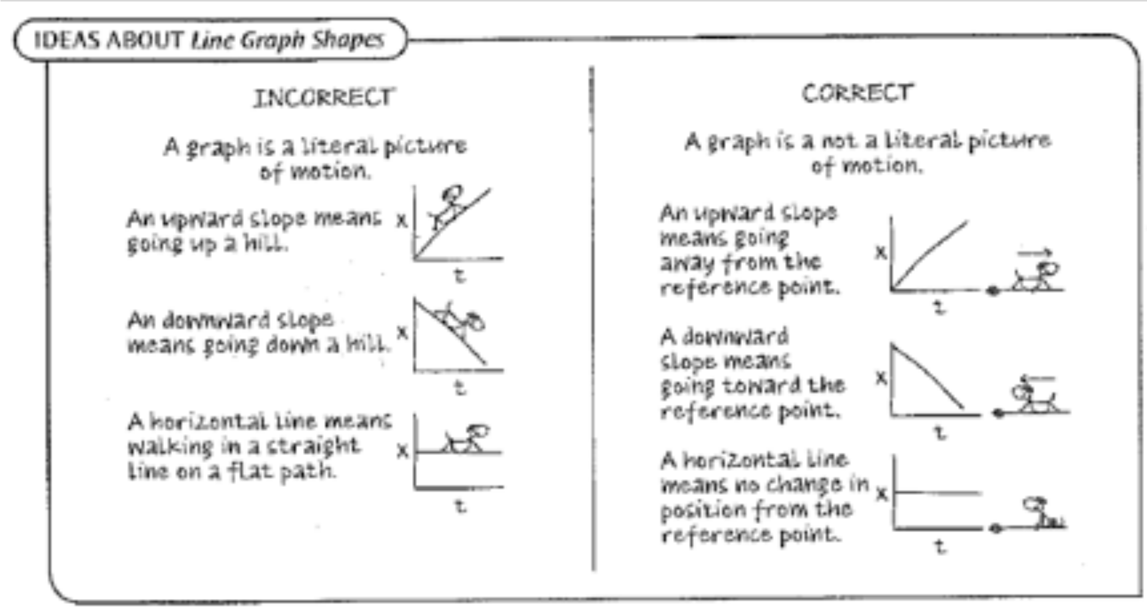

Figure 4: Comparing incorrect and correct ideas about a concept or a cognitive tool, in this case the shapes of line graphs. (Illustration from Making Sense of Science *Force & Motion* course, courtesy of WestEd)

This unexpected development perfectly supported Ms. Z's plan to have the students use this incorrect/correct diagramming as a way to solidify and summarize key motion concepts. She congratulated the students for effectively **developing and using models**, and then provided videos and animations that illustrated a wide variety of motions that included changes in position, speed and velocity. In each case students used multiple types of models to **describe, model and begin to explain** these motions.

This variety of experiences helped reveal key concepts as well as common misconceptions. Students used the incorrect/correct diagram format to **explain** the differences to themselves and each other. By the end of the investigations, students had decorated the class walls with many of these charts. In particular, there had been considerable discussions and revisions with respect to the concepts of speed and velocity, especially negative velocity (Figure 5). Students also developed diagrams that contrasted the incorrect conception that speed and velocity are identical with the correct conception that velocity includes direction as well as speed (Figure 6).

Incorrect and Correct Ideas About Negative Velocity

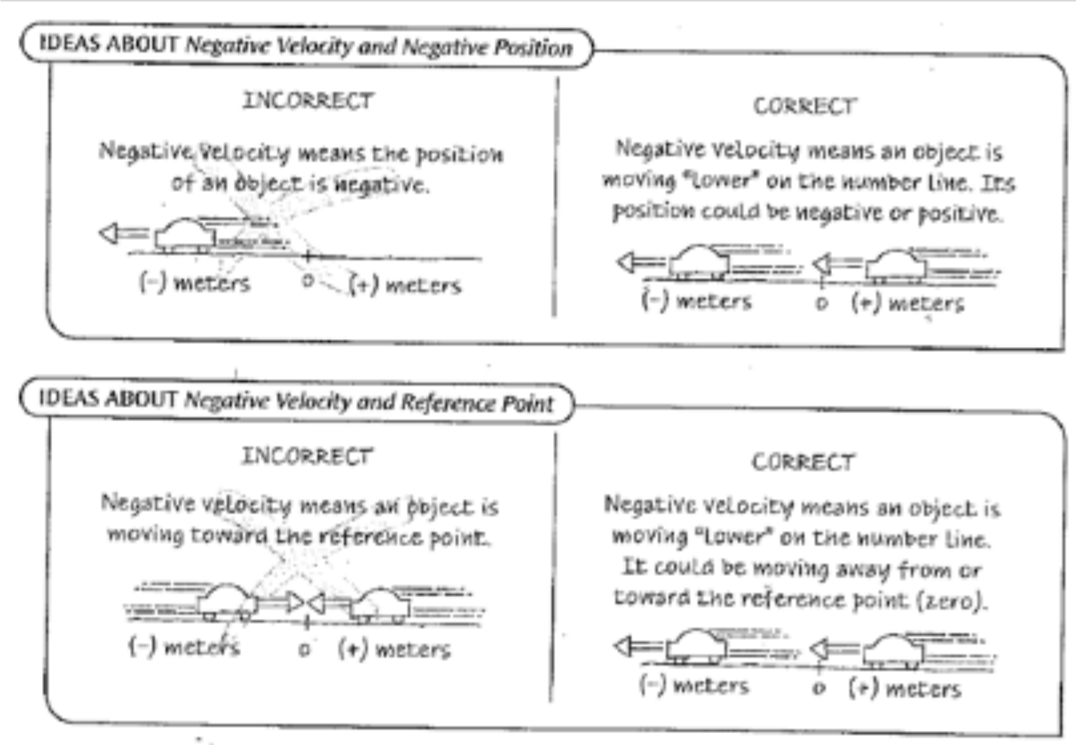

Figure 5: Comparing incorrect and correct ideas about negative velocity. (Illustration from Making Sense of Science *Force & Motion* course, courtesy of WestEd)

Constant Speed May Not Be Constant Velocity

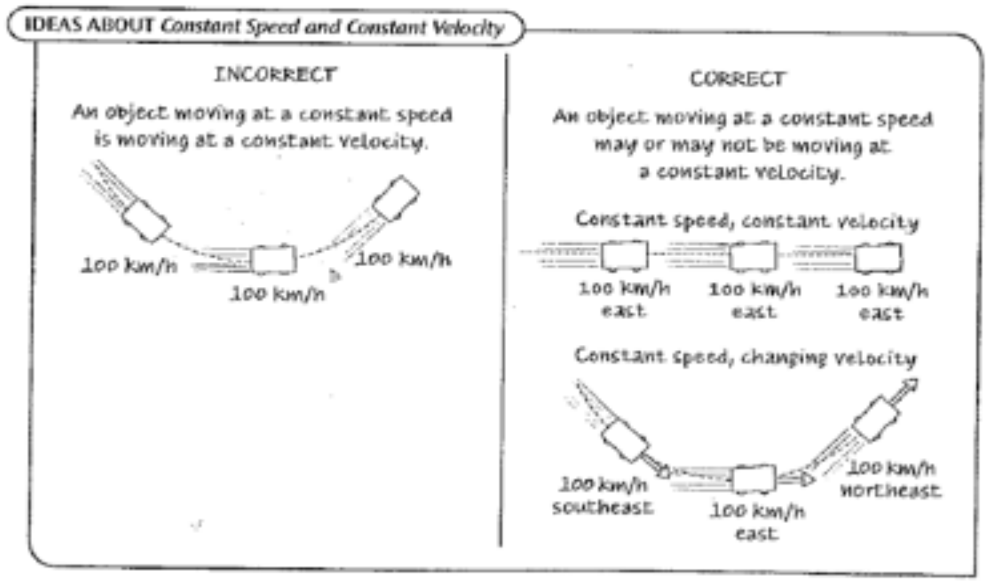

Figure 6: Object moving at constant speed may not be moving at constant velocity. (Illustration from Making Sense of Science *Force & Motion* course, courtesy of WestEd)

In the next series of lessons, students had many opportunities to **design and carry out investigations** on how the motion of an object varies depending on the amount of friction experienced by the moving object. Student teams could **design and do new experiments** only after they used their notebooks to show Ms. Z that they had accurately described their experimental procedures and results, and that they had used models to help **communicate their explanations and predictions**. Periodically student teams had opportunities to share and critique each other's work, and Ms Z also organized whole class discussions to help guide the investigations and explanations in the most productive directions.

Building on the preliminary conclusions from these investigations, Ms. Z began a class session by demonstrating the motion of a puck on an air hockey table under three conditions: table covered with a layer of paper towels, uncovered table with air off, and uncovered table with air on. She then asked what would happen if the table were very long and had zero friction. Students individually wrote their predictions, and then shared in dyads, larger groups, and finally as a whole class.

Ms. Z then had students work in teams to safely investigate the motion of a small chunk of dry ice. She told them that they could exert a force on the dry ice only by lightly pushing it with a pencil, and absolutely not letting it touch bare skin. Students immediately observed that dry ice seems to experience very little friction. This relatively quick and highly supervised activity helped support the prediction that an object in motion that experienced zero friction would indefinitely continue at the same speed. Ms. Z concluded the lesson with a homework reading about Newton's First Law and an introduction to the concept of forces. The reading showed how to illustrate different forces as arrows of different lengths that could also point in different directions. The students needed to use at least one of three different literacy strategies referenced in the handout.

Based on the homework, Ms. Z lead a class discussion that helped summarize that a force is a push or pull interaction among two or more objects. Student teams then had to use their notebooks to pick one of their motion investigations involving a push or a pull in the horizontal direction. For their selected investigation, the teams had to use arrows to **model the forces** that were acting in the horizontal direction at four different times:

A) before they pushed or pulled the object to initiate the motion;
B) at the instant that the object was pushed or pulled;
C) at an instant where the object was slowing down but had not stopped; and
D) at a time after the object had stopped moving.

Team sharing and whole class discussion then led to a consensus that there were no horizontal forces acting at instants A (before) and D (after). It took a little more time to get everyone to agree that at time C the only horizontal force was friction acting opposite to the direction of motion. By comparing C and D, some students **explained** that the force of friction was decreasing from the beginning of the motion to the end of the motion. The most extended and controversial discussion regarded instant B, the moment the object was pushed or pulled.

Ms. Z did not push or pull for a resolution of the Instant B discussion. Instead she asked the students to individually consider motion in a frictionless system such as outer space or an astronaut training facility. Their challenge was to **model** how an astronaut could maintain a constant velocity in the up direction while exerting one or more forces. The astronaut has two air guns, each of which can exert either 20 or 40 newtons of force. Ms. Z used this challenge to help solidify the notion that constant velocity can ***result from*** an absence of forces or from perfectly balanced forces.

From Constant Velocity to Acceleration

Ms. Z decided to use free Forces and Motion education animations[4] in transitioning the instructional focus from constant velocity to acceleration, from balanced forces/Newton's First Law to unbalanced forces/Newton's Second Law. She began by summarizing Newton's First Law, "When the total force on an object is zero its motion does not change at that instant." She solicited responses to why she had emphasized "at that instant."

Having established that background, she instructed the students to work individually or with a partner to explore their assigned animation, such that one-third of the class explored one of the three animations (Motion; Friction; Acceleration). They had to record in their notebooks what they did, any conclusions that they reached, and any questions that the animation raised for them.

In the succeeding days, class sessions focused on the animations in the order of Motion then Friction then Acceleration. As the students presented, they or Ms. V used the projector to manipulate the animation to support and extend what the students had recorded in their notebooks. After having reviewed the three animations as a whole class, the students collaboratively with each other and with Ms. Z agreed on specific questions or concepts to explore further within the animations, such as **obtaining and analyzing data** about the ***effects*** of mass and velocity on acceleration. These investigations and subsequent **analyses** resulted in a consensus statement of Newton's Second Law, "When the total force on an object is not zero, its motion changes with an acceleration in the direction of the total force at that instant."

Students had been surprised that the scientific meaning of the term "acceleration" includes speeding up, slowing down or changing direction. Some of the students

[4] https://phet.colorado.edu/en/simulation/forces-and-motion-basics

enjoyed telling people that vehicles actually have three accelerators: the gas pedal, the brake and the steering wheel.

Ms. Z completed this acceleration section of her instructional plan by challenging student teams to develop “incorrect/correct diagrams” related to the connections among forces, mass and acceleration. She wanted to help ensure that their take-away understandings remained deeper than repeating the F = ma equation. Students enjoyed returning to that diagram format, sharing their diagram models, and improving them. The most complex consensus diagram combined ideas about acceleration, motion and net force (Figure 7). The horizontal wavy lines represent air blowing from fans located on the top left and top right of each cart.

Acceleration, Motion and Net Force

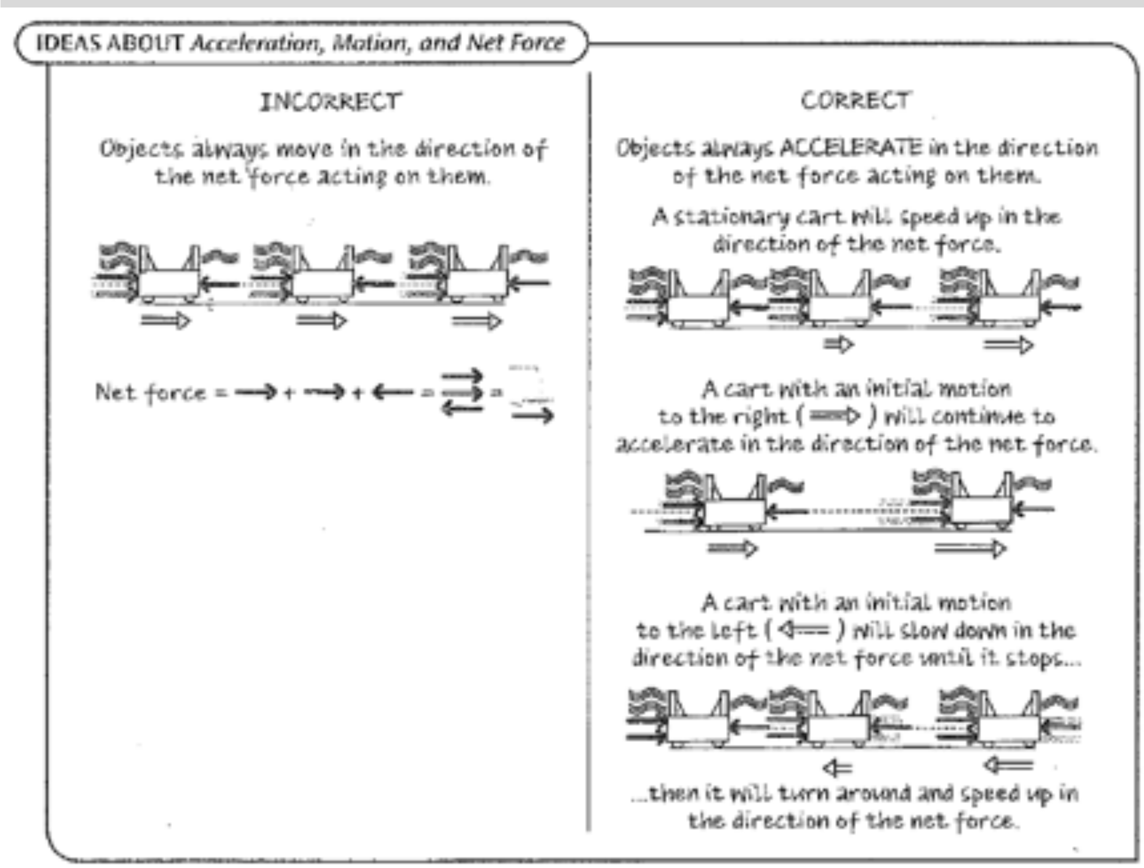

Figure 7: Objects always accelerate in the direction of the net force acting on them, but they do not always move in that direction. (Illustration from Making Sense of Science *Force & Motion* course, courtesy of WestEd)

Forces: Equal and Opposite

Ms. Z prominently displayed the incorrect/correct diagram about acceleration, motion and net force as a way to initiate a deeper discussion about forces. She asked students to talk about what they may have noticed about forces that is confusing to them, and scaffolded the discussion so it highlighted the "equal and opposite" nature of forces, a question about whether friction is pushing or pulling, and the role of gravity in their motion investigations. For example, she focused their attention on the carts with fans in Figure 7. What did they think about the force arrows that push in a direction that is opposite to the direction that the fan blows? The amount of force of those opposite pushing arrows seems to be directly related to the amount of force of the blowing fan.

This more theory-driven analysis of force and motion required more reading, modeling and discussing than hands-on investigating. Ms. Z provided different illustrated handouts that analyzed specific phenomena from the point of view of equal and opposite forces. She encountered three major conceptual issues for students: (1) the notion that only living beings or powered machines exert forces; (2) the rationale for why the forces have to be equal and opposite; and (3) the idea that objects can push and pull each other without actually touching.

For the purposes of Grade 8 students, Ms. Z honored the questions that the students raised but tried to keep the focus on the observable phenomena and how to explain these phenomena at the macroscopic level rather than theorizing about what could be happening at the invisible levels to cause the attractions and repulsions. She told students that physicists are still investigating and learning about the ultimate nature of gravity and electromagnetism.

Her main pedagogical goal for these discussions was to help students understand that a force is more than a push or a pull. A force is an interaction between objects that can result in a change in motion. When a person pushes on a wall, the wall pushes back with an equal and opposite force. When a balloon blows air behind it, the air pushes the balloon forward with an equal and opposite force. When a book presses down on a table top because of the force of gravity attracting it, the tabletop pushes up on the book with an equal and opposite force. If the tabletop did not push up, the book would go through the tabletop and fall to the ground. If the tabletop pushed back stronger than gravity, then the book would rise into the air.

Ms. Z reminded the students of the systems they had studied in grades 6 and 7. Forces provide yet another example of ***systems and system properties***. She concluded this part of the learning by having students revisit their investigations that involved objects sliding down ramps. Ms. Z handed out a paragraph about gravity to help guide their modeling:

"At the surface of Earth all objects experience a force due to gravity at every instant. This force, the weight of the object, is directed down towards the center of Earth. At the same time that an object's weight presses down on a horizontal surface, the surface pushes straight up with an equal and opposite force that is called the "normal force." On a slanted surface, this normal force pushes upward, perpendicular to the surface."

Forces Acting on a Sliding Sled

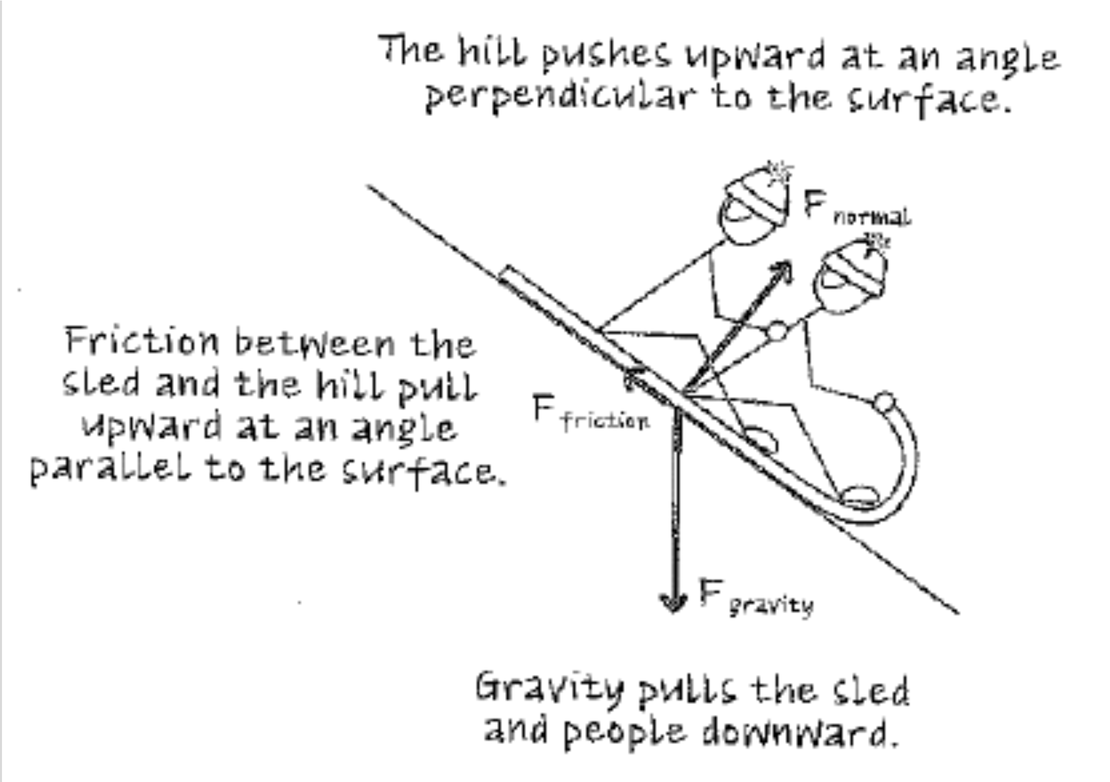

Figure 8: The net force on the sled causes it to slide down the hill. (Illustration from Making Sense of Science *Force & Motion* course, courtesy of WestEd)

This paragraph was accompanied by an illustration of the forces acting on a sled on a hillside (Figure 8). Ms. Z told the students to use this illustration as a guide in modeling their ramp investigation. She also told them that they would not be tested on determining the net force in these two-dimensional situations, but that this modeling was necessary for them to understand the interplay of forces in downward sliding motions. Ms. Z concluded this series of lessons by telling the students that their questions about gravity would be the focus of a later Instructional Segment on spooky forces that can act at a distance. However, before that Instructional Segment, they would have to play with objects that collided with each other. She smilingly apologized for having to make them play with collisions.

NGSS Connections and Three-Dimensional Learning

Performance Expectations

MS-PS2-1 Newton's Laws of Motion
*Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.**

MS-PS2-2 Newton's Laws of Motion
Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

Science and engineering practices	Disciplinary core ideas	Crosscutting concepts

Developing and Using Models *Develop and use a model to describe phenomena.* **Analyzing and Interpreting Data** *Analyze and interpret data to determine similarities and differences in findings.* **Constructing Explanations** *Construct an explanation using models or representations.*	**PS2.A Forces and Motion** *For any pair of interacting objects, the forces exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction. (Newton's 3* *The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion.* *All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared.*	**Systems and System Models** *Models can be used to represent systems and their interactions.* *Models are limited in that they only represent certain aspects of the system under study.* **Cause and Effect: Mechanism and Explanation** *Cause-and-effect relationships may be used to predict phenomena.*
Connections to the CA CCSSM: 8.EE.5–6, 8.F.1–3		
Connections to CA CCSS for ELA/Literacy: **RST.6–8.1, 4, 9; WHST.6–8.7, 8; SL.8.1**		
Connection to CA ELD Standards:		
Vignette Debrief		

The *CA NGSS* require that students engage in science and engineering practices to develop deeper understanding of the disciplinary core ideas and crosscutting concepts. The lessons give students multiple opportunities to engage with core ideas in space science (Moon phases and the solar system), helping them to move towards mastery of the three dimensions described in the *CA NGSS* performance expectations (PE's). Students continue to apply the crosscutting concept of ***Systems and System Models*** as they explore many situations involving the motions of objects. They also apply the crosscutting concept of ***Cause and Effect: Mechanism and Explanation*** to explain and predict the relationships among force, mass and acceleration. In their wide-ranging investigations students conduct the practices of **Developing and Using Models**, A**nalyzing and Interpreting Data**, and **Constructing Explanations**. Just quickly reviewing the figures within the vignette highlights the many models, analyses and explanations that connect the ideas and practices within this connected set of lessons.

Instructional Segment 1 Teacher Background and Instructional Suggestions (continued)

During the vignette, students investigated and measured motions of objects. The word "motion" in the NGSS implies both the object's speed and its direction of travel. While the Vignette included analysis of velocity (speed and direction), the assessment boundaries of PE's for 8th grade state that students will only be required in state/ national testing to add forces that are aligned, and deal with changes in speed that occur when the net force is aligned to the motion.

Speed is a ratio of distance divided by time. Students can **investigate** speed by **conducting experiments** where they measure both distance and time. Manual measurements of time in tabletop experiments using stopwatches are prone to large error, so there are several alternatives: students can pool multiple measurements using collaborative online spreadsheets and take the average, use an app to calculate speed from video clips[5], or use a motion sensor probe.

From a mathematics point of view, speed is the ratio of two very disparate quantities (distance such as meters and time such as seconds). Speed itself, the ratio, is also qualitatively different from the distance component and from the time component. This situation is typical in science where ratios are used in specific contexts to analyze phenomena. In order for these science ratios to make sense, students need to specify the units of measure for each component of the ratio and also of the resulting number, such as a speed or a density. This situation is very different from learning about ratios as an abstract relationship of two numbers that do not have units associated with them.

As noted in the Vignette, students often harbor the preconception that a moving object will naturally stop rather than keep moving. If I kick a soccer ball, it will roll along the ground, slow down and then stop. From a force point of view, the kick initiated the ball's movement and then friction, a very different force, opposed that movement. It requires a lot of experimentation and discussion before students internalize the understanding that without an opposing force, the ball would actually keep moving forever at the same speed in the same direction.

However, even after extended investigations and discussions, students can still retain misconceptions such as that the initiating force somehow remains associated with the moving object and keeps propelling it. As described in the Vignette, modeling the forces at different instants of time (before, during and after motion) can help address this kind of misconception. Another very powerful way to deepen understanding of motion is to provide an ***energy*** perspective in addition to the force perspective.

The ***energy*** perspective can help students understand why objects slow down. The kick transferred kinetic energy from the foot to the soccer ball. If no interactions remove kinetic energy from the soccer ball, it makes sense that the ball will keep moving at the

[5] Tracker: https://www.cabrillo.edu/~dbrown/tracker/

same speed in the same direction. The interaction with the ground transfers some of that kinetic energy to the ground (the grass moves and also becomes a little warmer because of being rubbed by the ball). Since the soccer ball has lost some of its kinetic energy to the grass, it naturally slows down and eventually stops.

Collision of a Moving Person with a Stationary Person

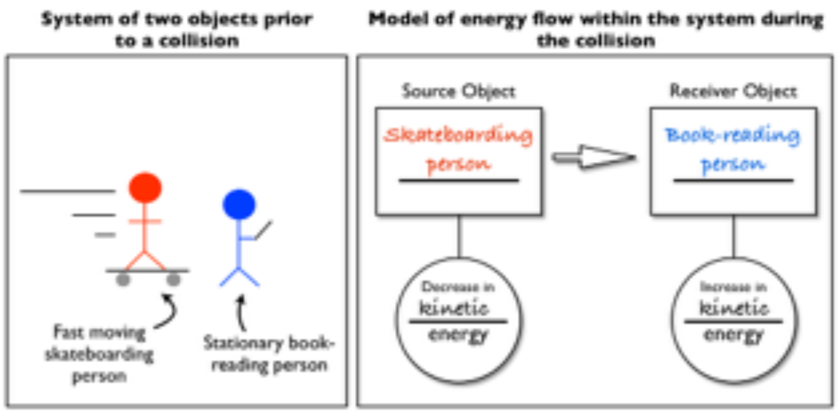

Figure 9. Model of energy flow within a system during a collision. Image credit: M. d'Alessio, released to the public domain.

Students can create a diagrammatic ***model*** of the ***flow of energy*** within ***systems*** as shown in Figure 9. This simple diagram of a collision is a model because it includes components (an energy source and receiver), an understanding of the way these objects will interact based on the laws of physics (energy is conserved, with one object decreasing in energy that is transferred to the other object), and it can be used to predict the behavior of the ***system*** (the object that decreases in kinetic energy slows down while the object that increases in kinetic energy should speed up). Students can use these types of diagrammatic models to illustrate transfers of energy.

Model of energy flow within a system that has friction

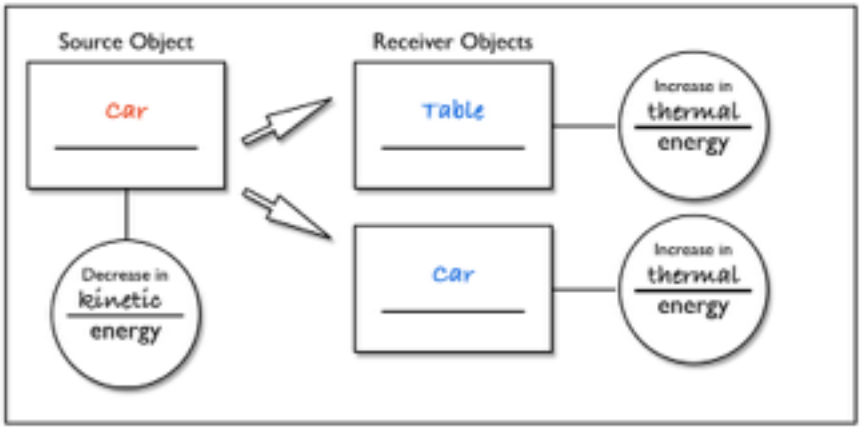

Figure 10. Model of energy flow including friction within an experimental system of a tabletop car. Image credit: M. d'Alessio, released to the public domain.

The force of friction is an interaction in which ***energy*** is transferred. Students must ***plan investigations*** to explore the ***effects*** of balanced and unbalanced forces on the motion of objects (*MS-PS2-2*). One such investigation could involve measuring the velocity of model cars with different amounts of friction by attaching sticky notes to the front and sides of the car to vary the amount of friction. Students should notice that when they push the car, they apply a force in one direction while friction is a force working in the opposite direction. The overall change in motion (and therefore change in energy) depends on the total sum of these forces. Using an energy source/receiver diagram to model the situation (Figure 10) helps draw attention to the fact that some of the energy must go somewhere. The car clearly decreases in energy but that means another component of the ***system*** must increase in energy.

With some simple analogies such as friction of hands rubbing together, students can conclude that the energy is likely converted into thermal energy. When rubbing hands together, both hands warm up even if one hand remains stationary during the rubbing. This observation gives rise to two related modifications to the previous simpler energy source/receiver diagram: 1) there can be multiple energy receivers in a ***system*** from a single energy source; and 2) an object (e.g., the car) can be both the source and the receiver of energy if that energy converts from one form (kinetic energy) to another form (thermal energy).

During an interaction when a force acts on an object, that object will gain kinetic energy. How much will the object's motion change during this interaction? Students asked similar **questions** in 4th grade (*4-PS3-3*), and now they will begin to answer them. The answer depends strongly on the target object's mass. This principle becomes easily apparent in collisions. Students can **perform investigations** by colliding the same moving object with target objects of different masses that are otherwise identical in shape (for example glass versus steel marbles of different sizes, cars with or without fishing weights attached, etc). In order to measure consistent ***patterns***, students will need to ***plan their investigation*** (*MS-PS2-2*) such that the source object has a consistent speed (by rolling down a ramp of a fixed distance, for example). This procedure will ensure that the initial kinetic energy is constant and lead to a consistent force initiating the collision interaction, if all other factors remain constant. Students can vary the mass of the target object and see how its speed changes as a result of the impact, plotting the results to look for a consistent pattern. This graphical representation should lead them towards a discovery of Newton's Second Law that relates the change in an object's motion ("acceleration") to the force applied and the mass of the object. *MS-PS2-2* does not require that students have a mathematical understanding of acceleration. Instead this PE focuses on the ***proportional*** relationship of motion changes and force.

When the source and target objects have equal masses and collisions transfer all of the ***energy*** from source to receiver, the speed of the target object should be similar to the speed of the source object. This phenomenon can be seen clearly in billiards when the cue ball comes to a complete stop after hitting another ball. Observations such as these provide evidence to make the **argument** that as one object loses kinetic energy during the collision, another object must gain energy, and vice-versa (*revisiting MS-PS3-5 from integrated Grade 6*).

In each collision so far, the target object always receives the same amount of ***energy*** from the source object. The effect of this energy transfer on the target object's speed depends on its mass. The motion of smaller target masses changes more (greater acceleration) than the change in motion of larger target masses. This kind of inverse relationship (bigger mass resulting in smaller change) can be confusing for students, so it can help to make that aspect of the Second Law very explicit. Students can explore this idea further by changing the kinetic energy of the source object. In that case, the relationship is direct rather than inverse. Keeping the target object constant, groups of students can predict and demonstrate that increasing the mass or the speed of the source object increases the change in motion of the target object. From the energy perspective, a faster moving or more massive source object can transfer more kinetic energy to the target object. From the force perspective, a faster moving or more massive source exerts a greater force on the target object. The animation investigations cited in the Vignette can complement these tabletop investigations very nicely, and the dual perspectives of force and energy can help **explain** the results of changing variables within the animations.

The crosscutting concept of ***energy and matter: flows, cycles and conservation*** is applied in many different contexts throughout the middle school grade span. One of the middle grade bullets used to describe this CCC states that, “the transfer of energy drives the motion and/or cycling of matter.” In Integrated Grades 6 and 7, the emphasis is on the role of energy transfer in driving the cycling of matter (water cycle, rock cycle, and cycling of matter in food webs). In Integrated Grade 8 Instructional Segment 1, the emphasis is on the role of energy transfer in driving the motion of matter.

Utilizing this CCC throughout the middle grade span serves at least three complementary purposes. As students gain experience in applying the CCC, it helps them connect with different DCIs and understand these DCIs and the related phenomena in greater depth. As students apply the CCC in different contexts, they get to understand the CCC itself in greater depth (e.g., transfers of energy can drive cycles of matter and motion of objects). Thirdly, students experience science as a unified endeavor rather than as a bunch of separate and isolated topics. Ultimately all of science works together as a unified whole system.

Engineering Design Challenge

Performance Expectation MS-PS2-1 provides a capstone project for Instructional Segment 1. Students are challenged to use what they have learned throughout the Instructional Segment to design a solution to a problem involving the motion of two colliding objects. The PE suggests examples of collisions between two cars, between a car and a stationary object, or between a meteor and a space vehicle. In order for this challenge to extend deeper into the design process, the suggestion here is to restrict the projects to situations that students can physically model and obtain data that can be used in iterative testing and refinement of their design solution.

The classic egg drop could be used but many of the solutions to that problem involve slowing the falling egg before the collision. The emphasis for the PE is on applying Newton's Third Law that objects experience equal and opposite forces during a collision. For example, a variation where students attach eggs to model cars and design bumpers will follow naturally from their prior tabletop experiments. At the conclusion of their testing and refinement, students should be able to use their models of ***energy transfer*** and kinetic energy to make an **argument** about how their design solution works. Bumpers tend to reduce the effects of collisions by two processes: 1) they absorb some of the source kinetic energy so that less of it gets transferred to kinetic energy in the target object and more of it gets converted to thermal energy; and 2) they make the collision last longer, so that the transfer of energy occurs over a longer time interval.

No matter what type of collisions students investigate, they will need to identify the constraints that affect their design as well as the criteria for identifying success (MS-ETS1-1). As student teams evaluate competing design solutions (MS-ETS1-2) and identify common features of successful models (MS-ETS1-3), they can identify and model the physical processes that are involved, using the dual perspectives of forces and energy transfers. Students should be able to discuss their bumper solution in terms of energy source/receiver diagrams such as Figure 10. Towards the end of their design challenge, students need to **explain** why certain choices they made actually work, and then use their more detailed ***models of their system*** to further refine their design.