# A Thrilling Roller-coaster Ride

## The Ups and Downs of Learning Force and Motion: A Fifth-Grade Learning Progression

By Dena Harshbarger and Joseph Wiechman

As a fifth-grade classroom teacher and a university science methods instructor who coordinates professional development opportunities for classroom teachers, we are always looking for ways to "move" students to learn and develop an understanding of motion and stability by exploring forces and interactions. The following force and motion unit spanned four weeks (50 minutes a day) in a fifth-grade classroom. The inquiry-based learning progression mirrors Piaget's Theory of Cognitive Development (1952) because it allowed students to manipulate materials and ideas as they actively constructed and reconstructed their knowledge of motion and stability based upon these experiences with forces and interactions. The learning progression aligned with the *Next Generation Science Standards*, as it enabled the students to plan, design, and test various systems as they applied their knowledge of all three laws of motion and the law of gravity (See Table 1). The teacher facilitated and offered guidance and scaffolding to ensure that misconceptions were addressed and students accurately learned the scientific concepts. Ongoing assessment data was informally gathered using checklists, recording forms, and rubrics (see Supplemental Materials). These formats enabled the classroom teacher to note misconceptions and record student questions in order to inform instructional decisions.

TABLE 1

Vocabulary terms.

| | |
|---|---|
| **Acceleration** | How the speed and direction of a moving object changes with time. |
| **Gravity** | An invisible force or attraction that pulls objects toward one another. |
| **Newton's First Law of Motion** | An object will stay in place or move in a straight line unless a force acts upon the object. |
| **Newton's Second Law of Motion** | The second law states that if an object has more mass, it will take more force to accelerate the object. This also means that the harder you kick a ball, the farther it will go. |
| **Newton's Third Law of Motion** | The third law states that for every action, there is an equal and opposite reaction. This means that there are always two forces that are the same. |
| **Speed** | How fast an object is moving. |

### THE FORCE AND MOTION LEARNING PROGRESSION

The unit followed a progression relating previously learned and new concepts. Those ideas were applied to a variety of activities, data collection, and class discussions. An outline of the learning progression is shown in Table 2.

### NEWTON'S FIRST LAW: OBJECTS IN MOTION, OBJECTS AT REST

Phenomena: Students watched a short video on the history of roller coasters to launch the learning progression (see Online Resources). While watching the video, students noticed how roller coasters changed over the years as knowledge of motion increased and the desire for thrill seeking changed. For instance, the students observed that the idea of a roller coaster was merely a variety of simple designs (slopes, turns, straights, and loops) and that when combined correctly, the complexity and enjoyment of the ride increased. To build on those observations, students were shown a working version of a simple roller coaster system using the materials they would later have available for designing their own rollercoasters (See Figure 1). This allowed the students to develop early thoughts and connections to the culminating goal of creating a functional rollercoaster.

To provide the background knowledge and experience that would help the students think critically about rollercoaster design, it was first necessary to determine their current level of knowledge as well as to provide a purposeful sequence of learning opportunities that would enable them to explore and learn about Newton's laws of motion and related scientific concepts. As shown in Table 2, this learning progression included five parts: (1) Dropping singular objects from a fixed height; (2) Dropping paired objects from a fixed height; (3) Pushing objects and pendulums and applying to PhET Simulations; (4) Measuring the distance and speed of objects on a tape measure track, and (5) Doing a coin slide activity. A description of each activity follows.

### *Part 1: Falling Objects—Dropping Singular Objects from a Fixed Height*

To preassess students' understanding of the DCI PS2.B Motion and Stability: Forces and Interactions, students predicted what would happen if objects were dropped as they completed the Prediction sections of the Gravity student handout (see Supplemental Materials). First, the objects were displayed for the students to see and interact with individually but were not paired with another item at this point. For Part 1 of the student handout, students predicted an outcome according to the mass and size of the object and justified their reasoning. Next, they tested the outcomes and recorded the results on the student handout. Students were asked to summarize what occurred and explain whether or not they changed their mind or if

**TABLE 2**

**Overview of learning progression.**

| | |
|---|---|
| Getting Things Moving with Newton's First Law: Potential energy, kinetic energy, balanced, and unbalanced forces | • Students observed the behavior of classroom objects, then applied forces to the objects, observing movement patterns, and then redefined inertia to basic terms.<br>• Students compared the mass of objects and the inertia of those objects, comparing a golf ball and a ping pong ball.<br>• Students learned that the loads on a lever relate to the amount of force they must apply to make the objects move.<br>• PhET simulations were used for students to interact with and observe multiple ways Newton's first law applies to objects at rest and objects in motion while removing other outside forces (friction). |
| Newton's Second Law: Speed, Velocity, Acceleration, and Momentum | • Students created a tape measure track and measured the time it took a ping pong ball and golf ball to roll a maximum distance of 25 feet when pushed on the floor and compared how mass affects acceleration, through calculating the speed of the object.<br>• Students observed and compared falling objects to make connections to gravity, objects, and the forces acting on those objects. |
| Keeping Things Moving With Newton's Third Law of Motion | • Students used a rubber band and weight-powered can to observe action and reaction forces.<br>• 5-Coin Slide: Students predicted what would happen when they flicked one, two, and three coin(s) at a line of coins without any supporting structures. |
| A Thrilling Rollercoaster Ride: Total Energy | • Roller coaster Observations: Students observe rollercoaster designs with design flaws. The observations relate to Newton's laws of motion and require the students to identify specific locations needing improvement.<br>• Roller coaster Designs: Students are given one hour to collaborate and design on paper a variety of ways to build a rollercoaster using the established materials and guidelines.<br>• Roller coaster Building: Students are given 2.5 hours to build a functioning rollercoaster using Quercetti marble coaster and classroom materials. |

they were having difficulties deciding based upon what they observed.

### Part 2: Dropping Paired Objects from a Fixed Height

In Part 2 of the Gravity handout (see Supplemental Materials), students again made predictions and explained their reasoning before they tested and compared pairs of falling objects. Students first dropped pairs of objects that were similar in size, including a tennis ball and a baseball, a ping pong ball and a golf ball, a glass and plastic marble, and/or a bearing and a glass marble. Dropping objects from shoulder height (i.e., arms straight out from body) allows students to efficiently complete the task. To add more structure and/or if classroom management is a concern, the teacher may lead this demonstration using the same shoulder height setup. Additionally, the teacher can choose to drop the items onto the floor or place a paper or second surface on the floor that will make a sound when the objects land. This also helps students hear which object landed first if there was a difference.

When predicting, students generally chose the "heavier" of the two objects to land first. To address this misconception, students selected objects of various sizes and masses to pair up and test to see if the size made a difference. Additionally, a video of a bowling ball and golf ball fall comparison was shown to the students (see Online Resources). The video confirmed that two objects of varying weights fall at the same rate; however, students were explicitly told that this should not be tried at home. See safety considerations in Table 3. During this process, students began to question size, mass, and design as they revisited and refined their understanding of gravity (an invisible force or attraction that pulls objects toward one another) and Newton's first law of motion (an object will stay in place or move in a straight line unless a force acts upon the object). For instance, one student shared, "It seemed like things that are bigger and heavier should fall faster, but I learned that things fall the same way because of gravity."

Part 2 of the student handout included self-reflection questions that asked students to explain whether their thinking was supported and/or redirected during the lesson. This type of questioning mirrors the growth mindset of a scientist/engineer and promotes CER responses (Claim, Evidence, Reasoning).

### Part 3: Pushing Objects, Pendulums, and PhET Simulations

Following the falling objects tests, students predicted what would happen when paired objects are *pushed*. As shown in Figure 2, a push was demonstrated as holding a meterstick at 50 cm or a half meter stick at 25 cm between the thumb and index finger. The object being tested was placed on opposite ends of the sticks (touching stick), 5 cm/45 cm on the half, 5 cm/95 cm on the full. Using the same object for the demonstration (a ping pong ball is my go to ball), the meterstick was slid along the floor extending the arm outward till the end of one's reach. This gave the students an idea of how they could determine whether an object took more push to move compared to another object. The students observed this when the stick tilted more toward one side since the object with greater mass needed more force to move. Students then predicted how much force would be

FIGURE 1

**Model roller coaster used to demonstrate design flaws and design styles to help students understand how the materials would be used.**

required to push and stop each object based upon the mass and size of the object. They also justified their reasoning before testing outcomes of paired items. Questions asked while facilitating the investigation:

- Why did your half/full meterstick flex to one side or the other?
- Which objects did not take much force to move? a lot of force to move?
- What happened when the objects stopped? Did any stop at the same time?

During this investigation, students made the connection that objects with less mass take less force to start and stop, while objects with more mass take more force to start and stop. One student noted, "The meterstick was flexing to the side of the golf ball before the stick was able to push the golf ball." Another student said, "The ping pong ball should have rolled farther, it started faster, but the golf ball didn't want to stop and the ping pong ball did." The following are suggestions for facilitating this portion of the learning progression:

- This lesson works best in an open area, gym, hallway.
- Display the objects for the students to see and interact with

TABLE 3

**Safety precautions.**

"Doing science through hands-on, process, and inquiry-based activities or experiments helps to foster the learning and understanding of science. However, in order to make for a safer experience, certain safety procedures must be followed" (NSTA, 2014, xviii).

| | |
|---|---|
| **Fire Extinguisher** | Make arrangements to have a fire extinguisher available whenever the slightest possibility of fire exists. Safety codes require training for use of portable fire extinguishers. Certificate of extinguisher training should be provided as part of the safety compliance approval. |
| **Supervised Investigations** | Students are never allowed to conduct any unauthorized investigation or to work alone or unsupervised. |
| **Practice Procedures** | Practice all procedures prior to presenting them to an audience or having participants try them. As a safety precaution for *any* of the learning tasks described in this article, be sure to have students sketch and show you their plans for approval *before* they test them out with electrical materials. |
| **Eye Protection** | Safety goggles are needed for all phases of a hands-on activity (i.e., gathering, working with, and cleaning up needed materials). Eye protection is to be sanitized in hot water and antibacterial dish detergent or using alcohol swabs. |
| **Accidents/Injuries** | All accidents and injuries must be reported immediately to the instructor, no matter how trivial they may seem at the time. |
| **Attire** | Dress appropriately for laboratory work by protecting your body with clothing and shoes. Tie back long hair and tuck into the collar. Do not wear loose or baggy clothing or dangling jewelry. Sandals or open-toe shoes are not to be worn. |
| **Allergies** | Teachers should check to see if any students have contact allergies associated with the science investigation.<br>*Check for latex allergies before using balloons. |

NOTE: Additional information on safety can be found at the NSTA Safety Portal at *http://www.nsta.org/portals/safety.aspx* and the "Safety in the Science Classroom" at *www.nsta.org/pdfs/SafetyInTheScienceClassroom.pdf.*

individually, but not paired with another item until testing time.

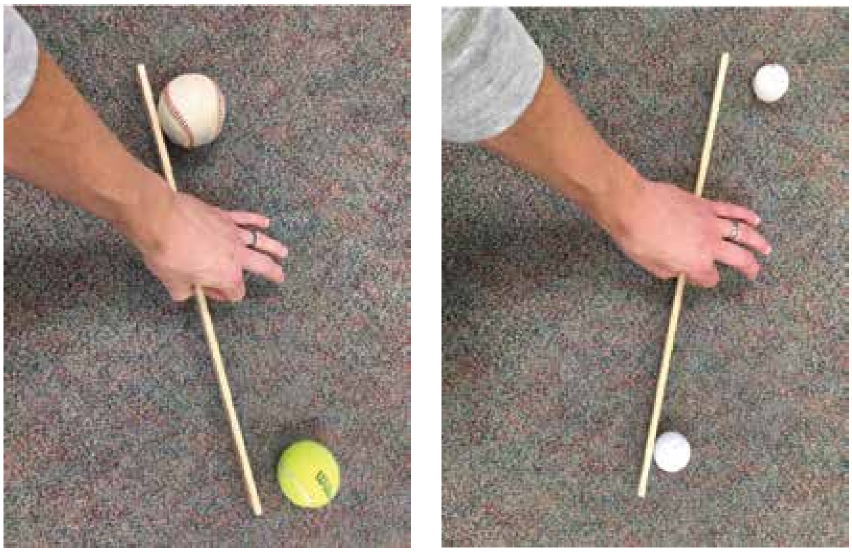
- As in Part 1, test objects of similar size (i.e., tennis ball and a baseball, a ping pong ball and a golf ball, a glass and plastic marble, and/or a bearing and a glass marble)
- Demonstrate using an easy push so the objects come to a stop relatively easily.
- When testing paired objects, the objects will flex the half/full stick to the heavier object indicating there is more force needed to make the object accelerate (how the speed and direction of a moving object changes with time).
- Demonstrate a "stop'" as watching for each object to come to a rest after being pushed.

Next, students observed multiple ways that Newton's first law of motion (an object will stay in place or move in a straight line unless a force acts upon the object) applies to objects at rest and objects in motion using an interactive online PhET simulation, Force and Motion: Basics and the Energy Skate Park Basics (See Online Resources). With teacher guidance and questioning, the hands-on investigations and simulations collectively provided students with the rationale to support an argument that the gravitational force exerted by Earth on objects is directed down (5-PS2-1).

FIGURE 2

***Newton's First Law***

**The meterstick demonstration showed students how the heavier mass object delays its start while the light object is pushed forward by the force of the meter sick.**



## NEWTON'S SECOND LAW: SPEED, VELOCITY, ACCELERATION, AND MOMENTUM

### *Part 4: Exploring Distance and Speed of Moving Objects*

Next, students created a "Tape Measure Track" to explore and develop their understanding of Newton's second law of motion (if an object has more mass, it will take more force to accelerate the object) in terms of speed (i.e., how fast an object is moving) and acceleration (i.e., how the speed and direction of the moving object changes with time). To do this, students measured the amount of time it took for a ping pong ball and a golf ball to roll a maximum distance of 25 feet when rolled down the tape measure track. Students compared how mass affects observed traveling speed and acceleration. For instance, one student said, "It takes more force to get the heavier ball to move as fast and as far as the other ball." Students defined acceleration in their own words, typically saying the balls start rolling slowly but pick up speed and travel faster upon finishing.

## NEWTON'S THIRD LAW: LAW OF CONSERVATION OF MOMENTUM ACTIVITY

### *Part 5: Coin Slide Activity*

To explore Newton's third law of motion (for every action, there is an equal and opposite reaction) students did a coin sliding activity. The students used eight pennies, two rulers, and tape to create a situation in which an action force caused an opposite reaction. The two rulers were laid flat on the table parallel to one another and taped down to the desk to form a "lane or track." Some of the pennies were lined up at one end of the lane, while a varying number of pennies were flicked toward those pennies from the opposite end of the lane. The reaction was measured and recorded on the students' data sheets. Students observed that the transfer of force relative to the number of pennies flicked was identical. If one penny was flicked, one moved; if two pennies were flicked, two moved and so on. This phenomenon demonstrated that when two objects collide, the total momentum of the objects before the collision is equal to the total momentum of the objects after the collision. Simply stated, the momentum is not lost but transferred through the pennies and sent in motion again.

## THINKING LIKE ENGINEERS: CONDUCTING ROLLER COASTER INSPECTIONS

After participating in this five-part instructional sequence, the students were ready to apply and extend their understanding of Newton's laws of motion in a roller coaster engineering challenge. Since roller coasters are constructed based upon knowledge of Newton's laws of motion, they provide an engaging way for students to take these concepts "for a ride" and further investigate. The teacher designed multiple models of three roller coasters in which a marble had to overcome unbalanced forces in order to travel completely through the roller coaster. As shown in Figure 1, the teacher deliberately designed each roller coaster so that it contained a faulty system such as ramps, hills, and overall design. To promote critical thinking and develop engineering practices, students were given opportunities to become roller coaster inspectors as they studied, analyzed, and tested the various roller coaster systems. Having two or three of the same model enabled the students to plan and conduct tests at their leisure. The students drew the corrections on a sticky note so it could be placed directly over the spot(s) that needed to be repaired. Once the class identified the problem(s), the students worked individually to draw out the roller coaster as best as they could, noting the problems. Students were encouraged to use scientific language when noting the problems (a word bank and definitions could be provided to students during this time).

Following the diagramming of repairs, the students fixed the problems encountered in these situations. They had materials at their disposal to remake sections of the roller coaster track they thought needed to be repaired. Note: You may need to scaffold the roller coaster challenge by adjusting the number of faulty systems or problems from one to four depending on your students' readiness levels and experience with inquiry-based instruction.

Using the models and drawings, the students demonstrated to the class what they believed was incorrect about the roller coaster and how/why the repair was made. These pairs gradually merged into groups having four or five students each. After a few days, groups were reconfigured so that students were able to share ideas and work with different people in the classroom. This allowed the class to come to a consensus of what may be wrong with the roller coaster. Based upon the class consensus, modifications were made to the system in order to make it operate correctly. As recommended by the *NGSS* (2013) engineering standards, further tests were performed to determine which solution best solves the problem.

FIGURE 3

**Students' create rollercoaster designs using Newton's laws of motion.**

## THE FINAL RIDE: A ROLLER COASTER CHALLENGE

Click, click, click… at this point, everything that students had experienced thus far involving Newton's laws of motion "clicked" together and was applied during the final roller coaster engineering challenge. Students worked in heterogeneous groups for the challenge. Groups were given Quercetti materials (see Online Resources) to build a marble roller coaster that demonstrated how the law of gravity and Newton's three laws of motion make roller coaster systems work. The Quercetti marble systems use a plastic marble. Students typically ask about changing the marbles out to see if a glass marble or a ball bearing will travel through the system when a plastic one does not. Quercetti materials/kits can be purchased for $25–$50 from various venues (i.e., Walmart, Amazon). Some specific options are included in the resource section. If funding is limited, DIY options also exist. A video is also included under Online Resources that demonstrates how a marble run can be created from household items such as a cardboard base, scissors, pen, marbles, tape, paper plates or paper towel tubes (see Online Resources).

For the challenge, students were required to identify areas of the coaster demonstrating gravity and the three laws of motion. Figure 3 shows one group's roller coaster design. Students used sticky notes to identify the track location of the vocabulary terms and law of motion. Students then provided an oral response to defend their stance and used scientific vocabulary to explain why the roller coaster worked the way it did. Questions asked while facilitating the investigation:

- What forces were at work in the system as the marble traveled through various parts?
- How did the system modifications impact the overall function of the roller coaster?
- Is there anything else we could have done to make the system operate more effectively?

The students' responses to these questions and their oral presentations indicated that they understood the following:

- A high starting point is needed to use gravity.
- A proper marble is needed for correct travel.
- The system should be strong enough to support the movement of the marble.
- The marble needs to travel the entire system without any help.

Since this was a performance-based project, a core rubric was used for assessment purposes (See Supplemental Materials). The rubric outlined the requirements for the project and designated point totals for both the engineering process and the students' understanding of the three laws of motion and related scientific concepts. A modification to assessment may include students photographing their roller coaster systems and/or developing a slide show or video presentation in which they can provide an oral explanation using scientific vocabulary terms.

We hope that you will put this learning progression "into Motion." Online, we have shared additional extension ideas. We know that you and your students will enjoy the ride! ●

## REFERENCES


Hibbing, A.N., and J.L. Rankin-Erickson. 2003. A picture is worth a thousand words: Using visual images to improve middle school struggling readers. *The Reading Teacher* 56 (8): 758–770.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states. http://www.nextgenscience.org/next-generation-science-standards.*

Piaget, J. 1952. *The origins of intelligence in children.* New York: International University Press.

Vygotsky, L.S. 1978. *Mind in society.* Cambridge, MA: Harvard University Press.


## ONLINE RESOURCES

A Brief History of Roller Coasters
*https://youtu.be/nLP1z6-nhZw*

Galileo Falling Bodies Gravity Demonstration
*https://youtu.be/Z789eth4lFU*

PhET Interactive Simulations - Physics: Force and Motion: Basics
*https://phet.colorado.edu/en/simulation/forces-and-motion-basics*

Quercetti Big Marbledrome Marble Run Toy
*https://tinyurl.com/e92z4pyf*

Quercetti Transparent Marble Run 45 Piece Basic Building Set
*https://tinyurl.com/4jnzm9p6*

How to Make a Marble Run
https://www.youtube.com/watch?v=OnjW_0kv5b0

## SUPPLEMENTAL MATERIALS

Download the data sheets, rubric, and extension ideas at *https://bit.ly/3mm4B1v.*


**Dena Harshbarger** (***harshbargedk@unk.edu***) is an associate professor at the University of Nebraska Kearney. **Joseph Wiechman** is a former fifth-grade teacher who is now an elementary school principal in Kenesaw, Nebraska.