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PhysicsQuest 2020

Science Kits for Middle School Classrooms

Katherine Johnson

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Welcome to PhysicsQuest 2020!

When most people think about gravity, they think about Sir Isaac Newton, who observed an apple falling straight down from the tree and wondered why its path was always straight. In this PhysicsQuest kit, you will explore the concept of gravity and the different forces that affect the path an object can take, also known as its trajectory.

Understanding trajectories is crucial to space flight, and is how Katherine Johnson made the invaluable calculations that enabled NASA to get humans into space and onto the moon. You'll learn more about Johnson's work in this guide. In this PhysicsQuest experiment kit you will learn about the fun and relevance of science and the physical world. Each kit provides you with materials and ideas to experiment with the concepts of forces and motion. Each activity builds into each other to support your learning as you become a scientist.

For Teachers

There is a Guide available online for teachers and/or parents with videos, additional resources, and supporting materials for the content presented in this guide. You can find it online at physicscentral.com.

About the American Physical Society (APS)

The American Physical Society is the premier professional society for physicists in the United States. APS shares the knowledge of physics by publishing journals, hosting scientific meetings, reaching out to the public, and promoting physics education.

PhysicsQuest is brought to you by PhysicsCentral, an APS program that communicates the excitement and importance of physics to people of all ages.

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Spectra's Science Hero: Katherine Johnson

Lucy Hene is a junior high school student, who becomes Spectra, a superhero with the powers of a laser. You can follow her adventures in physics in the Spectra comic series.

Lucy arrives at school for another—hopefully—normal day at Nikola Tesla Junior High.

“Hurry, we’re going to be late for physics!” Kas said.

General Leslie J. Relativity is at the board. “All right everyone, settle down. Today, we’re going to do something a little different.”

Lucy already could tell that today wasn’t going to be another normal day.

General Relativity explains. “When we’re learning physics, it’s easy to forget that there were real people behind all the things we’ve come to know about the world. It was individuals coming up with the experiments and writing equations down. I don’t think we’ve been talking about this enough, so what I’d like you all to do is to learn about a scientist or mathematician whom you admire. You have one week to write a short essay about their life and scientific accomplishments.”

Bell rings

“Who are you going to write about Kas?”

“I’m absolutely going to write about Brian May. Lead guitarist for Queen, AND an astrophysicist? Definitely my hero!”

“And you, Ruby?”

“I’m going to write about Jocelyn Bell Burnell! She’s a famous astronomer who helped discover pulsars.”

“Gordy?”

“I think I’m going to write about John Urschel. He’s a mathematician working on his PhD at MIT – but he was also an offensive lineman for the Baltimore Ravens. SO COOL!”

“What about you Lucy?”

“I’m not sure yet. I think this could be a good opportunity to focus on something new—maybe someone who doesn’t have anything to do with lasers.”

As soon as Lucy got home from school, she started doing some research. She eventually landed on a particular news story: “NASA Renames Facility In Honor of ‘Hidden Figure’ Katherine Johnson.”

“Hmmmm. Hidden Figures? What’s that about? And who’s Katherine Johnson?” Lucy pulls up the movie trailer on YouTube.

“Equilateral, trapezoid, isosceles, tetrahedron…”

“I’ve never seen a mind like the one your daughter has. You have to see… what she becomes.”

“Wow. This is amazing! I’ve decided—I’m going to write about Katherine Johnson.”

Lucy spent the next few days reading all she could about Katherine Johnson. She went to the library and checked out a copy of *Hidden Figures: The American Dream and the Untold Story of the Black Women Mathematicians Who Helped Win the Space Race* by Margot Lee Shetterly.

One week later, the essays were due. Lucinda stands in front of the class to read what she’s written:

“My Science Hero: Katherine Johnson”
By: Lucy Hene

Katherine Johnson was born on August 26, 1918 in West Virginia. At a very young age she demonstrated a special talent and interest in mathematics. “I counted everything. I counted the steps to the road, the steps up to church, the number of dishes and silverware I washed… anything that could be counted, I did,” she once said.

Because of her advanced mathematics skills, Johnson was able to graduate high school at only 14 years old! She then enrolled at West Virginia State University—a historically Black college. While in college, she took every math class that was available. In fact, she even ran out of them! New advanced math courses were designed just so she could continue taking advanced math. In 1937, she graduated from college with the highest honors, earning degrees in Mathematics and French.

Following her graduation, Johnson taught public school for several years before returning to school as a graduate student in the math program at West Virginia State, which was then recently integrated. After leaving the program to focus on her family, she returned to teaching until 1952 when she heard about open positions at the Langley Laboratory based at the National Committee for Aeronautics (which would later become NASA) in Hampton, Virginia. Johnson accepted the offer and officially began her career as a mathematician for NASA.

Johnson got right to calculating flight trajectories in the West Area Computing section of Langley Laboratory, where hundreds of African-American, female mathematicians were working as human computers—reading, analyzing, and plotting data. “Everything was so new—the whole idea of going into space was new and daring. There were no textbooks, so we had to write them,” Johnson said.

Everything changed after the 1957 launch of Sputnik. The United States was determined to reach the moon, so NASA was the center of all the action. Johnson undertook trajectory analyses for America's first human spaceflight, the Freedom 7 mission. In 1960, she co-authored a report laying out equations for orbital spaceflight; it was the first time a woman in the Flight Research Division helped author a research paper. This was only one of the 26 papers she would co-author throughout her career!

In 1962, Johnson did her most famous work—helping prepare for astronaut John Glenn's orbital mission. At the time, the new electronic computers were crunching numbers and producing equations for the flight, but the astronauts didn't trust them. Glenn specifically asked that Johnson would run the numbers herself to confirm that the programmed calculations were correct. "If she says they're good, then I'm ready to go," Johnson remembers Glenn saying.

After 33 years of service, Johnson retired from NASA and received many prestigious awards and honors for her exceptional service. In 2015, she was awarded the Presidential Medal of Freedom. At the ceremony, President Barack Obama said, "Katherine G. Johnson refused to be limited by society's expectations of her gender and race while expanding the boundaries of humanity's reach." In 2019, she was awarded the Congressional Medal of Freedom—the highest civilian award in the United States. In 2016, NASA dedicated the Katherine G. Johnson Computational Building at the Langley Research Center where she worked all those years.

Johnson's life was also a main focus in the biographical book *Hidden Figures: The True Story of Four African American Women Who Helped Launch Our Nation into Space* by Margot Lee Shetterly. The book was later adapted to the award-winning film Hidden Figures.

"Math. It's just there. You're either right or you're wrong. That's what I like about it," Johnson once said.

Katherine Johnson sadly passed away very recently, on February 24, 2020. But all that she accomplished over more than three decades at NASA—breaking boundaries, calculating trajectories, and supporting historic space missions—will never be forgotten. In fact, it's important that not only should we keep remembering and recording the stories of scientists that have been 'hidden' for so long, but we should continue to uncover more science heroes whose stories have yet to be recognized."

"That was a wonderful essay, Lucy! What did you learn from writing about Katherine Johnson's life?" General Relativity asked.

Lucy stopped to think. She thought about all the times she put on her super Spectra outfit so that she could help her friends when they're in danger and save the day. She thought about her special laser powers and how she tries to always use them for good. She also thought about how important science is for making the world a better place, and how happy she feels being able to contribute to doing so.

"Writing about Katherine Johnson taught me that it's important to embrace your talents and use them for the greater good. She became a hero for science by staying true to what she loved most—mathematics—and never giving up despite obstacle after obstacle. I think the most important thing I've learned from writing about Katherine Johnson is that it doesn't take wearing a cape to be a hero."

The new SPECTRA
now available for download:
go.aps.org/spectra-ligo

ACTIVITY 1

Falling Physics

What would happen if you dropped a hammer and a feather at the same time from the same height? Which one do you think will hit the ground first, the hammer or the feather? What about if two bowling balls, one 15 pounds and the other 8 pounds, were dropped off the Leaning Tower of Pisa at the same time. Which ball would hit first? What would happen if you repeat the same experiment on the moon? We need you to work with your classmates to design a couple of experiments to test what happens when an object falls. We want you to design experiments that can help find out if the mass or shape of things affects how objects fall.

KEY QUESTION

How does mass affect how fast an object falls?

EXPERIMENT 1

To start off, look at the materials we've given you and play with them a bit. What kind of things can you do with the stuff you have? With your classmates, design an experiment to test if two objects of the same mass but different shape hit the ground at the same time. Use the scientific method to guide the design of your experiment.

The scientific method has five basic steps, plus one feedback step:

- Make an observation.
- Ask a question.
- Form a hypothesis, or testable explanation.
- Make a prediction based on the hypothesis.
- Test the prediction.
- Iterate: use the results to make new hypotheses or predictions.

Getting Started

Before you start, think about the following questions and write some answers below. There are no right or wrong answers. You will use these questions to guide your experiment design and test the answers.

1. What do you think affects how objects fall? What are the possible variables that you can think of? Label each as independent variables (variables you change) or dependent variables (variables you measure after changing an independent variable).

2. How can you test the different variables that you think affect how objects fall?

Materials

- 2 equal-sized pieces of paper
- Chair or table (or both)
- A ruler or metric tape (optional)
- Beam balance (optional)
- A chronometer or something to measure the time (optional)
- A camera to record the experiment (optional)

Collecting Data

Before you start collecting data think about your hypothesis. Which objects do you think will hit the ground first and why?

Draw a diagram of how you are going to set up the experiment and explain how that experiment will help you answer the question: Will two objects with the same mass but different shapes hit the ground at the same time?

In creating the design, think about what data you need to collect and how many times you need to repeat the experiment to be sure of your results. What are the variables that you are going to test, which variables will you keep constant, and which ones would you change?

Work with your group to collect data. If you have a video camera, make sure your teacher or a classmate starts recording the experiment.

Record your data for each time you repeat the experiment below. Look at the video to confirm your observations and write them below. What was the result of the experiment? Did you get the same result every time? Why do you think that is? Any other observations? Share your results with the other groups in your class and with your teacher.

Experiment 2

For Experiment 2, we need you to design an experiment to test if two objects of different masses but similar shapes hit the ground at the same time. Below is a list of materials available to you for this experiment.

Materials

- 2 balls similar in size but different mass
- 2 aluminum tart pans
- Chair or table (or both)
- A ruler or metric tape (optional)
- Beam balance (optional)
- A chronometer or something to measure time (optional)
- A camera to record the experiment (optional)

Collecting Data

Before you start collecting data, think about your hypothesis. Which one do you think will hit the ground first and why? How will this experiment be similar or different from the first experiment?

Draw a diagram of how you are going to set up the experiment and explain how that experiment will help you answer the question: Do two objects with different masses but similar shapes hit the ground at the same time?

In creating the design, think about what data you need to collect and how many times you need to repeat the experiment. What are the variables that you are going to test, which variables will you keep constant, and which ones would you change? We are giving you balls of different materials, mass, and sizes. Think of all the possible combinations you can try with the different balls.

Work with your group to collect data for the experiment. If you are recording, make sure that your teacher or a classmate starts recording before the experiment starts so you do not miss the important parts.

Record your data for each time you repeat the experiment below. Look at the video to confirm your observations and write them below. What was the result of the experiment? Did you get the same result every time? Why do you think that is? Any other observations? Share your results with the other groups in your class and with your teacher.

ACTIVITY 2 Swinging Science

Most people enjoy going to playgrounds and playing on the swings. But did you know that the movement of swings—or pendulums—is one of the most studied problems in physics? Understanding their movement has helped people tell time, keep the beat or rhythm in music, and protect buildings against earthquakes. Do you know what causes a swing to move back and forth if you only raise it and release it? There are many variables that affect how a pendulum swings. In this experiment, students will learn what some of these variables are and design experiments to test them.

KEY QUESTION

How does mass affect how fast an object falls?

EXPERIMENT

Getting Started

Before you start, think about the following questions and write some answers below. There are no right or wrong answers. You will use these questions to guide your experiment design and test the answers.

1. Apart from a swing, what other examples of pendulums can you think of?

2. You just learned the definition of a period, what do you think you can use to measure the period of a pendulum?

3. What do you think affects how a pendulum swings? What are the variables?

4. Of the variables you could think of, which ones you would classify as independent variables (variables you change) and which ones you would classify as dependent variables (variables you measure after changing an independent variable)?

Materials

- 2 lengths of string
- 4 hex nuts
- A ruler or measuring tape (optional)
- A timer (optional)
- Sheets of graph paper (optional)

Designing the Experiment

To start off, look at the materials you have in front of you and play with them a bit. What kind of things can you do with the stuff you have? With your classmates, design an experiment to test what variables affect the swing of a pendulum and how. Remember to use the scientific method to guide your experimental design.

The scientific method has five basic steps, plus one feedback step:

- Make an observation.
- Ask a question.
- Form a hypothesis, or testable explanation.
- Make a prediction based on the hypothesis.
- Test the prediction.
- Iterate: use the results to make new hypotheses or predictions.

In the section above, you were asked to list some independent variables. List ways you might be able to change the variables with the materials you have in front of you. Using the information you wrote down, design an experiment to test how one variable affects a pendulum's swing. What will you change? How? By how much? What will you measure? How many trials will you do? (you should always do more than one) Once you have this data, what will you do with it? What will it teach you? How will you analyze it? Draw a diagram below of how you are going to set up the experiment and explain how that experiment will help you answer the question: How does a pendulum swing, and what affects its movement?

Work with your group to collect data from the experiment you designed. Write down the results each time you repeat it. Look at your video to confirm your observations.

Write your observations below. What was the result of the experiment? Did you get the same result every time? Why do you think that is? Any other observations? Share your results with the other groups in your class and with your teacher.

If you are still not sure what to do with your data, here are some suggestions:

1. Make a table where you have the values for your independent variable in one column and the corresponding values for the dependent variable in the other. For example, if you want to see how the pendulum movement changes when you change the length, then the period (the time it takes the pendulum to swing one way and back) should be on the dependent variable column, while the length of the string should be on the next column, as the independent variable. Take several measurements with the same length before you test a new length. Do you notice any patterns?
2. Try graphing your data. Remember, the independent variable always goes on the x-axis and the dependent variable goes on the y-axis. Do you see any patterns now?
3. Can you draw any conclusions about what affects the period of the pendulum?

ACTIVITY 3

Watch it Fly

In activities one and two we looked at what happens when things fall, both straight down and as part of a pendulum. Now we're going to look at what happens when something moves in two directions, down and out! For example, when you throw a ball, the action of throwing the ball will make it move away from you (horizontally) but gravity will also pull it down, so the ball is moving down and out.

KEY QUESTION

How does the mass of a projectile and its initial velocity affect how far it flies and how fast it drops?

EXPERIMENT

Getting Started

Before you start, think about the following questions and write some answers below. There is no right or wrong answer. You will use these questions to guide your experiment design.

1. What is a projectile?

2. When you throw a ball or launch something from a slingshot, what path does it take? Draw it.

3. When something is flying like a projectile, in how many directions is it moving?

4. Do you think a projectile moving forward very fast will hit the ground sooner or later than a projectile moving forward slowly?

MATERIALS

- 4 rubber bands
- 2 sets of chopsticks
- 4 different-sized wooden balls
- A roll of masking tape

Setting Up the Experiment

With your classmates, think about how you could test those ideas. To start off, look at the materials we have given you and play with them a bit. What kind of things can you do with the stuff you have? How would you design an experiment to see if a ball moving forward and down will hit the ground faster or slower than a ball dropped from the same height? How would you test if two balls moving forward, but from different initial positions, will hit the ground at the same time? Draw your design on below. In this experiment what do you think are the dependent variables and which are the independent variables?

Designing the Experiment

You are going to explore what happens when an object, in this case a wooden ball, moves in two directions at once. When an object is in free fall, it is moving in one direction (down) and this motion is caused by the force of gravity. To get our projectiles moving in two directions, we need to give them a kick off so that they will be moving forward as well as down. Think about how to provide a “kick” to the balls so they start moving and how to make sure you can provide the same amount of “kick” for different tests. Also consider how you could change the way you provide the kick so that you can make the balls move faster or start from different points on the table. Test balls of different sizes and at different horizontal distances. If possible, record the experiments so you can go back to the videos to confirm observations.

Make sure to measure each case more than once, and write down the results each time you repeat the experiment. Look at the video to confirm your observations. Write your observations on the next page. What was the result of the experiment? Did you get the same result every time? Why do you think that is? Any other observations? Share your results with the other groups in your class and with your teacher.

If you are still not sure what to do, here are some suggestions:

1. Label the balls 1 through 4 from largest to smallest and make a table with columns for each ball.
2. With the materials provided, build a slingshot. Place the slingshot at the edge of a table. It helps to use a bit of tape to make a handle in the middle of the rubber bands.
3. Place one of the balls in the chopstick slingshot.
4. Pull the rubber bands back and mark the launching position with a strip of tape and measure the distance from the starting point to the edge of the table. Let go, launching the ball, and time how long it takes for it to hit the ground. Put a piece of tape where the ball hit and label it with the ball number and the distance the rubber band was pulled back. Repeat the experiment with the same ball and conditions (distance from starting point to the edge of table) three times, marking with tape each time, and find the average distance traveled. It’s always important to do repeated trials to find the averages from the same conditions.
5. Now do the same thing, only pulling the rubber band farther back and mark the new starting point with tape. Again do this 3 times and find the average. Each time, note how long it takes to hit the ground.
6. Repeat steps 3-5 with each numbered ball. Repeat each trial three times with the same conditions. Keep track of the results in the space provide below.
7. Now, one at a time, drop the balls from table-height. Record the time it takes the balls to hit the ground. Video record each attempt to confirm your observations. Compare the times it takes the balls to hit the ground when they were dropped versus the times when they were sling-shot. Write your observations.

Analyzing Your Data

1. Draw the path a ball took as it flew off the table. Was it what you predicted?

2. Looking at what you recorded in your notes, did the distance the ball traveled forward affect how long it took to fall to the ground?

3. Did the balls with more mass take a longer or shorter time to hit the ground?

4. What can you say about the effect of horizontal motion on vertical motion? How does horizontal motion affect vertical motion?

Make a table to write down the results of all your trials, the mass of the ball, the initial position at which it was launched, the distance it traveled, and any other variables that you consider important. Then use the table to compare all the different cases. Discuss with other groups in your class. How did your results compare to the other groups? What conclusions can you draw from it? How does your data confirm or not confirm your initial hypothesis?

ACTIVITY 4 Circular Motion

We have already looked at motion of objects falling in one direction as when you drop them or in two directions as part of a pendulum. We have also looked at what happens when objects fall while also moving in the horizontal direction. In this last activity, we are combining all that knowledge to see what happens when objects move in a circular motion: there are constant changes in the horizontal and vertical direction at all times during the movement, making the object follow a circular path. Examples of circular motion are, carousels or merry-go-rounds in parks, a car going around a roundabout, the Moon orbiting around the Earth, or the Earth revolving around the Sun.

KEY QUESTION

What happens when the centripetal force is removed?

EXPERIMENT 1

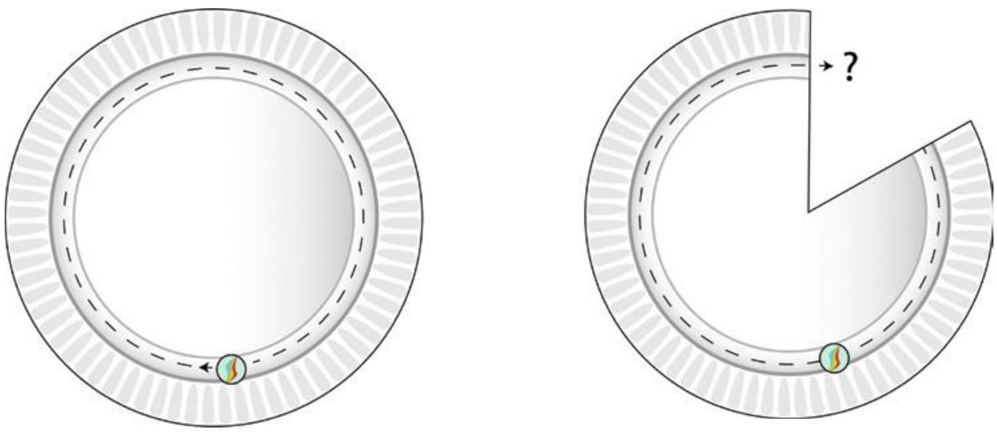
Getting Started

Before you start, think about the following questions and write some answers below. There is no right or wrong answer. You will use these questions to guide your experiment's design and test the answers.

What do you think happens when you give a little push to a ball while it is in a circular container? How will the ball move? What direction does it go?

After your push, what is the force causing this circular motion?

The picture below represents a marble going in a circle inside a plate. The marble is moving clockwise. What happens if you remove the force causing the marble to go in a circle? Draw with a marker the direction you think the marble will take



Setting Up

To start off, look at the materials we have given you and play with them a bit. What kinds of things can you do with the stuff you have? With your classmates, design an experiment to test how to get balls to move in circular motion, what forces are affecting the balls' motion, and what happens when you remove those forces. Draw diagrams to explain. Remember to use the scientific method to guide your experimental design.

The scientific method has five basic steps, plus one feedback step:

- Make an observation.
- Ask a question.
- Form a hypothesis, or testable explanation.
- Make a prediction based on the hypothesis.
- Test the prediction.
- Iterate: use the results to make new hypotheses or predictions.

Materials

- Different size and material balls
- Paper plates with a rim

Designing the Experiment

With your group and class, you discussed what the possible forces are that are acting on a ball rolling along the inside edge of a circular container. Write down which variables you will test for, how you will change the variables, and how many tests you plan to do. Make sure that your teacher or a classmate is recording the experiment.

Write the results each time you repeat the experiment. Look at the video to confirm your observations. Write your observations in your notes. What were the results of the experiment? Did you get the same result every time? Why do you think that is? Any other observations? Share your results with the other groups in your class and with your teacher.

If you are still not sure what to do, here are some suggestions:

1. In what direction is the ball moving when you give it a push? Think of the definition of force and indicate what forces you think are acting on the ball. Draw this in your notes.
2. What will happen if you cut a section out of the plate? If you give the ball a push near the top so that it travels along the plate counterclockwise, predict what path you think the ball will take when it exits the plate through the cut out section. Write down your hypothesis first, and explain why you think it will take that path. Draw arrows showing the direction of the force acting on the marble and the direction of motion of the ball when it leaves the plate.
3. Test out your hypothesis with the plate and ball. Do the experiment several times to make sure you know what actually happens and write the results each time. What path does the ball take when it leaves the plate? With your group try to explain why the ball took that path. Draw what you observe.

EXPERIMENT 2

Getting Started

For activity two, we need you to design an experiment to test what direction a Wiffle ball and string will fly if you let go of the string when you are spinning it. Before you start, think about what force or forces are acting on the Wiffle ball as you spin it, what is the specific force directly causing the Wiffle ball to follow a circular path? Hint: though you are applying a force to the string, you are not connected to the Wiffle ball. In what direction is this force? Draw a diagram on the next page to show the force and direction.

What will happen if you let go of the string? Which direction will the Wiffle ball go? Does it change direction depending on the point you release the string? What about if it is spinning vertically or horizontally? Draw some diagrams on the next page to indicate your predictions.

Setting Up

To start off, look at the materials we have given you and play with them a bit. What kinds of things can you do with the stuff you have? With your classmates, design an experiment to test how the balls will move in circular motion, what forces are affecting the ball's motion, and what happens when you remove the forces that confine it to a circle. Draw diagrams to explain your experiment, how you think the ball stay in circular motion and how it will move when you remove those forces. Remember to use the scientific method to guide your experimental design.

The scientific method has five basic steps, plus one feedback step:

- Make an observation.
- Ask a question.
- Form a hypothesis, or testable explanation.
- Make a prediction based on the hypothesis.
- Test the prediction.
- Iterate: use the results to make new hypotheses or predictions.

Materials

- String
- Wiffle ball
- A camera to record the experiment (optional)

You can substitute the materials with any small object you can attach a string to or even make your own from playdough.

Designing the Experiment

Test out your guess with the Wiffle ball. Do the experiment several times to make sure you know what actually happens and record it each time to verify your observations. While still maintaining circular motion, you'll want to spin the Wiffle ball as slowly as possible so that your group can actually determine the proper release point. Think about what release point is required to make the Wiffle ball fly straight up towards the ceiling.

Can you draw some conclusions from the two experiments about what direction the force and the velocity are for an object going in a circle?

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