{ } **LESSON**

The Science of Superpowers

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GRADES 5–8

TYPE
INFORMATIONAL
POETRY
STEM

COMMITMENT
4 SESSIONS: 2 HOURS EACH

Longer than a long weekend, more thorough than a thoroughbred, and more fun than a funhouse, it's … "The Science of Superpowers"! True to its subject, this is a super lesson, covering a wide range of STEM and poetry concepts in its four action-packed sessions. But don't feel like you need to be a hero—do as many or as few as you like.

We all know some heroes have special powers. But how exactly do their powers work? Do you know how Iron Man flies? Want to know how the Black Widow uses her superhuman strength? In this lesson, students explore the science and engineering behind superpowers and heroic adventures using DNA extraction, paper airplane construction, Q-tip tower building, and egg drop design. In addition to lab journal writing, each activity is paired with a different genre of poetry inspired by the session's theme and hands-on activity.

This is a very flexible lesson. Of course, it was designed to be taught as a series and while the science content is different in each lesson, there is a flow to the overarching themes. That said, it also works well as an abbreviated series—doing only sessions 1 and 2, or teaching only sessions 3 and 4.

SESSION 1: I AM FROM...(ORIGIN POEMS AND DNA)

In this session, students explore the heritable qualities (meaning characteristics that can be passed on from parents to offspring) of living things. Students look at the interplay between that inheritance and who a person becomes, sometimes discussed as nature versus nurture.

This session is adapted from "Strawberry DNA Extraction," http://seplessons.org/node/217.

YOU WILL NEED

- Water
- Dawn dish soap
- Salt
- Capped tubes (2 per student, holding at least 12 milliliters)
- Isopropyl (rubbing) alcohol
- Rubber bands (2 per student)
- Hero costume (completely optional, but cool)
- Computer with Internet access, to show video (optional)
- Digital projector, to show video (optional)
- Items that may or may not have DNA, like tortilla chips, a kiwi, and a flower
- Lab coats (completely optional, but cool)

- Safety goggles
- Copies of the “Secrets of Strawberries” handout (included with other handouts at the end of this lesson)
- Coffee filters (1 per student)
- Clear plastic cups (1 per student)
- Strawberries (1 per student, plus a few extras in case of strawberry catastrophes)
- Ziplock bags (1 per student)
- Plastic coffee stirrers (1 per student)
- Small (1.5 milliliter) Eppendorff microcentrifuge tubes (1 per student)
- Copies of the “Supercookbook” handout
- An example of a “Where I’m From” poem

BEFORE YOU START

Before the first session, you’ll need to prepare the chemicals the class will use to isolate strawberry DNA. Each student will need his or her own tube of Lysis buffer, which is easy to make. This formula makes enough for thirty students. Combine the following:

- 360 milliliters (1½ cups) water
- 40 milliliters (2 tablespoons plus 2 teaspoons) Dawn dish soap
- 8 grams (1¼ teaspoons) table salt

Transfer twelve milliliters of mixture to each tube and secure it with a cap. (Measurement tip: twelve milliliters is about 2.5 teaspoons.)

You’ll also need to prepare a ten-milliliter tube of isopropyl (rubbing) alcohol for each student. Wrap these tubes with a rubber band to identify them (rubber band, rubbing alcohol—easy to remember!). If you’ll be doing the experiment on a hot day, you’ll probably have better results if you can keep the alcohol tubes cool until you need them.

A Note on Sections Titled "FOR YOU TO KNOW (AND YOUR STUDENTS TO DISCOVER)"

This lesson comes from the published 826 collection *STEM to Story*. Lessons in the collection cover a wide array of science, technology, engineering, and mathematics topics, and we recognize that few educators will be comfortable with all of them. The lessons were designed to focus on discovery and exploration, so we encourage you to explore and learn alongside your students. To bring you up to speed quickly, each lesson from the publication includes a section or sections titled "FOR YOU TO KNOW (AND YOUR STUDENTS TO DISCOVER)", which provides some background on the subject at hand. This is to give you a solid foundation before you teach. Because it's all very interesting, this section is also useful at parties, letting you dazzle your fellow guests with your knowledge of STEM facts and trivia.

This section is for you—and not the students. You shouldn't feel like you have to read it, and you certainly shouldn't feel like you have to teach it. If you do choose to teach this material to students, we've found it's best not to introduce these ideas or vocabulary words at the beginning of a lesson. As a lesson progresses and students are sharing their observations and ideas, it will usually become clear that they have discovered many of these concepts for themselves. You can then help them by providing labels (the vocabulary words) to hang on the scientific ideas they have already described in their observations. As you do this, try to draw on students' own language in connecting their observations and ideas to the "scientific" language. If, at the end of the lesson, your students haven't learned what they were "supposed" to, resist the urge to give it to them. Their questions and curiosity will do a better job of motivating learning over the long term. Waiting is powerful—and you will see the results in what your students do and learn.

HOW TO BEGIN (10 MINUTES)

Begin class with an official welcome to the science of superpowers. Brief the students on your mission: You will create and explore together. You will extract real DNA, learn some physics, and engineer solutions to superchallenges. In the process, you will envision heroic adventures for your hero and use poetry to communicate the science of superpowers.
If you are awesome, you will give this welcome wearing a hero costume yourself.

The first session focuses on origins and what makes us (and heroes) who we are. Your students will reflect on and explore the dimensions of their identity, from the parts they control to the parts they don't. Ask the class:

- What are some of the traits or characteristics of a hero?
- Can you think of examples of traits that a hero is born with?
- What about characteristics that are shaped by a hero's environment—where she lives, what he

learns from his parents, some sort of conflict or dilemma she experiences?

Make a T-chart on chart paper or the board documenting students' ideas of hero traits, noting which are heritable and which are environmental.

The distinction between the two types of traits parallels the nature versus nurture debate that is prevalent in biology and in particular in the study of animal, including human, behavior. Some heroes are shaped by their environment, others by their genetics (or a change to those genetics), and still others by a tool or agent that conveys power (such as Green Lantern's ring).

Ask students for some examples of heroes and their traits, both inborn and environmental. Following is a sample list in case the discussion gets off to a slow start, though students will probably know more:

- Spider-Man undergoes a genetic change when bitten by a spider (but is also shaped by his uncle's values: "With great power there must also come great responsibility").
- X-men are born mutants.
- The Hulk experiences a change to his genetic makeup caused by exposure to radiation (and exacerbated by anger control issues). Is this a heritable change or an environmental change?
- Superman's powers derive from his origin on another planet and the differences in physiology (how the body works) due to differences in gravity between Krypton and Earth. It is likely that his powers are heritable, as his cousin, Supergirl, has similar abilities. That said, Superman's, or Clark Kent's, adoptive parents had a strong value system they shared with their son.

STEP 1 (10 MINUTES)

What About You?

Authors create a backstory to explain the history of a character before the story begins. A hero's backstory—often called an origin story—explains how and why the hero came into being, the origin of her superpowers, what experiences and influences shaped him into who he is in the comic series, and so on. Essentially the hero's backstory explains the role of nature and nurture in making her who she is.

Unsurprisingly, as most heroes are people, these stories mirror our own. This session helps students investigate their own backstory. Ask them, "What makes you who you are?"

It's fine if there are lots of different interpretations of the question. Record student responses on the board, and start moving the discussion toward genetics. What makes you you, a cat a cat, and Spider-Man Spider-Man? (You'll return to the nurture bit eventually.) Write their responses on the board. When students introduce more complex ideas, encourage them not to just state a label (for example, "It's because of genes"), instead asking them to explain, in their own words, their understanding of what that label means to ensure that everyone has the same understanding of the word or concept.

STEP 2 (10 MINUTES)

What is DNA?

At this point, explicitly ask students if they have ever heard of DNA. We like to introduce the concept with a music video from They Might Be Giants. Next, show students a variety of objects, and ask them if DNA can be found in them: a kiwi, tortilla chips, and a flower (these can be substituted out for anything else you might have on hand).

> **GENETICS**

Although this topic of genetics is covered in much more detail in this session's "For You to Know" section, there are a few key ideas that may come up in this discussion:

- Offspring (babies) are similar to their parents. Humans give birth to humans, elephants to elephants, and mice to mice. The same idea holds true with plants, bacteria, and so on
- The instructions to make a creature are encoded in a chemical compound called **d**eoxyribo**n** ucleic **a**cid (DNA). DNA is chemically the same in all organisms—thus either with your naked eye or with a microscope, DNA from a strawberry looks the same as DNA from a human
- DNA in a cell makes up a structure called a **chromosome.** Different organisms have different numbers of chromosomes
- An offspring receives one set of chromosomes from its (biological) mother and another set from its (biological) father
- The complete set of genetic information inherited from your parents is called your **genome**
- One analogy to explain how DNA works is to think of the whole genome as a cookbook and the DNA as the language (or code) that the cookbook is written in. Most cookbooks have similar recipes (for example, breakfast recipes, cookie recipes, and vegetable recipes), but the actual recipes in the cookbook are different because they use different amounts of the same ingredient or different ingredients entirely. The variations in genetic cookbooks are what make different organisms who or what they are. The cookbook for monkeys and the cookbook for humans are fairly similar, but there are a lot of differences between the cookbooks for humans and plants
- Much like a cookbook, the genome is broken into smaller units of information—the recipes (or **genes**). Some recipes provide the instructions for a complete dish (a **trait**)—for example, to make pancakes you only need one recipe. For other dishes (that is, human characteristics) you may need two recipes (spaghetti with tomato sauce requires a recipe for spaghetti and a recipe

> for tomato sauce), and a cake may require many recipes (one recipe for the batter, one for the filling, and one for the frosting)
>
> - With the exception of mature red blood cells—which don't play a role in the activity today—every cell in your body has the complete set of instructions (cookbook)—though each cell may only use a subset of the instructions (recipes) to help it specialize. (In other words, eye cells are not using the same recipes as skin cells.)

Reinforce the idea to students that some traits are inherited (for example, eye color), some relate to learned behaviors (for example, being polite), and others are a combination of what is often called nature (inherited) and nurture (learned or in some way supported by your environment)—like height, which is dependent on both the height of your parents and your access to nutrition.

STEP 3 (35 MINUTES)

DNA Extraction Experiment

Tell the students it's time to put on their lab coats and see actual DNA. If you don't have lab coats, don't worry. All the materials used in this session are common household materials. (If lab coats aren't available and your students want to wear *some* kind of uniform, invite them to make hero capes out of towels or jackets tied around their shoulders. Scientists are heroes, too!) Nothing here is inherently dangerous. Real science requires real protocols, however, so you'll want to remind your students of the following:

- Strawberry juice will stain—so don't wipe fingers on your clothes, and try to avoid splashing, spilling, engaging in flying strawberry battles, and so on.

- Don't eat or drink anything while doing the strawberry experiment. This will prevent you from mistakenly drinking the Lysis buffer, or some other mishap. This is also a very critical laboratory safety practice to get used to.
- Wear safety goggles. Even though everything being used in this experiment can be found in either your kitchen or your medicine cabinet, getting into the habit of wearing eye protection is good science.
- Wash your hands thoroughly when finished—another good laboratory practice.

Break students into groups of two or three (although ideally, even in these small groups, each student will extract DNA from his or her own strawberry). Distribute the supplies: copies of the "Secrets of Strawberries" handout, coffee filters, clear plastic cups, rubber bands, strawberries, ziplock bags, test tubes of Lysis buffer and isopropyl alcohol, stirrers, and Eppendorff tubes.

If adult helpers are available, have each helper oversee a few groups as they work through the extraction (step-by-step instructions are on the "Secrets of Strawberries" handout). If helpers are not available, go over the instructions with the class as a whole group before handing out materials. Then set them loose to conduct the procedure as described on the handout, circulating to help as necessary.

Note that students will be able to see a *mass* of DNA (and it looks like a big clump of snot), not individual strands. They will *not* be able to see the double helix shape. (Scientists cannot see the double helix either, even using a microscope. With a very special and powerful type of electron microscope that magnifies more than twenty thousand times, scientists can see a single strand of DNA, but they still cannot see the helix shape. That takes an indirect visualization technique called X-ray diffraction.)

STEP 4 (20 MINUTES)

Origin Stories

Gather students back together. Explain to students that DNA is the ultimate origin story, because the DNA code in every organism on Earth tells a complete history of the organism. When isolated and decoded, the DNA can reveal who the organism's parents are and who it is related to, both its recent ancestors and those from the very distant past. Understanding the DNA story has helped us to figure out how life evolved on our planet, to better understand where diseases originate, and to develop new treatments that save lives.

Now you want to shift to creating *new* heroes that will encounter a series of adventures and scenarios. Let students know that you want to understand how their new hero became super—the hero's origin story, which students will write in poetry form.

Because DNA is a cookbook for an organism, students will use the "Supercookbook" handout to develop their hero. An important part of this work is thinking about the powers the hero will have. Where did these powers come from? How does she use them? How does his environment shape how he uses his powers? Does he have a moral code for how the powers are used? Where did this code come from? What types of pressures influence the hero, for good or bad?

STEP 5 (10 MINUTES)

Brainstorm Breakout

Have students use the “Supercookbook” handout to begin developing a description of their hero.

STEP 6 (15 MINUTES)

Personifying Your Hero

Once students have filled out the “Supercookbook” handout, it’s time to use their powers for poetry.

After making some time for questions and sharing, task students with writing a “Where I’m From” poem in the voice of their hero that explains who the hero is, as well as the origin of his or her powers and abilities. In doing so, they’re writing a **persona poem**, or a poem that is written from the perspective of another character—in other words, you step into the shoes of someone who is not you!

Read an example of a “Where I’m From” superpower poem with the group. George Ella Lyon’s poem “Where I’m From” is a fantastic introduction to the form. We highly encourage instructors, when introducing a superpower spin on this type of poem, to share one they have written. Creating your own hero will be helpful throughout the workshop.

Have students find a quiet space to write their own “Where I’m From” poem in response to the following prompt:

> Imagine that your hero has to leave his or her home, and venture out into the world to fight evil. How will your hero explain to strangers where he or she is from? What powers will your hero carry with him or her? What was the role of genetics in shaping your hero? What about his or her environment? How did your hero get those powers? Was there some event that led him or her to

> develop the powers? Be sure to use some of the traits outlined on the “Supercookbook” handout to tell your hero’s story.

“Where I’m From” poems are often open ended and quite personal, even in comic book persona form. In poet George Ella Lyon’s original “Where I’m From,” which inspired the form, lines like “I am from Artemus and Billie’s Branch, / fried corn and strong coffee” evoke strong images of southern heritage and rough mornings, but they don’t often suggest future directions. We recommend challenging your students with an additional twist. Have them think back to the concepts of nature and nurture, and consider how these relate to personal choice. Students should think about possible choices for their hero, and how these might be informed by any moral responsibilities that come with the hero’s powers. Toward the end of their poem, students can envision their hero’s future actions as they move from “I am from” to “I am going.” “Owl Girl” written by 826NYC student Athena Murray, is attached to this lesson as an example.

> **THE SUPERPOWER OF IMAGERY**
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> Poets—and writers in general—can create powerful mental pictures in their readers’ minds by using imagery. One of the most basic and most effective ways to do this is by using the five senses: touch, taste, sight, smell, and sound. How does a hero experience these things? Brainstorm a few lines beginning with “I feel,” “I taste,” “I see,” “I smell,” and “I hear.”

STEP 7 (10 MINUTES)

Wrap-Up

As students finish writing their poems, ask them to help clean up the materials left over from the DNA extraction activity. Note that the capped tubes can be saved and reused. (If you plan to repeat this workshop in the near future, simply refill the tubes with the Lysis buffer and rubbing alcohol, and you’re ready to go!)

Once cleanup is completed, gather students together and build excitement for the next session by summarizing this session and foreshadowing the next. Now that they are beginning to understand how humans and heroes develop their traits, they’ll begin to go a little deeper—or should we say higher? In the next session, students will continue their study of heroes by exploring why—and especially *how*—they fly. Many heroes use flight to help them protect a city, rescue an innocent civilian, or battle a supervillain. How do they do it? Are they able to fly naturally (without assistance), or do they get help from an engineered system (a plane or rocket suit)? What are the structures in these devices that help them fly, and what can we learn about flight by studying these structures?

STEP 8

FOR YOU TO KNOW (AND YOUR STUDENTS TO DISCOVER)

Locked away in every cell of every living thing is a molecule with the tongue twister of a name, deoxyribonucleic acid (DNA). DNA is the ultimate origin story—written in a secret code. For within the code of DNA are not only the instructions to build a living thing (whether a bacterium, plant, dog, human, or something else), but also a genetic history of the organism—whom the individual is related to, who the species’ closest relatives and ancestors are, and how the species has changed and evolved. DNA is a remarkable molecule.

A Spiral Staircase

The DNA of all organisms is made of the same chemical stuff. It is impossible to tell the difference between the DNA of a strawberry, an elephant, or a human by just looking at it (either magnified or unmagnified). Because all DNA is made from the same ingredients, it all looks the same.

At the molecular level, the structure of DNA is like a spiral staircase—it is a twisting ladder that is made of a sugar phosphate backbone (the railings) as well as nitrogen-containing “bases” (the stairs). But this structure is so small that it is impossible to see using a microscope. To discover the structure of DNA, scientists used a technique called X-ray diffraction. This technique provides information about the positions of atoms in a molecule. Figuring out the structure of DNA was one of the great aha moments in modern science. Particularly exciting was the fact that identifying the structure led immediately to hypotheses about how some very important cellular processes might work—and to experiments that could test these ideas. This information led to a biological revolution through which researchers have unlocked many secrets of cells, helping us to better understand and treat diseases, among many other benefits.

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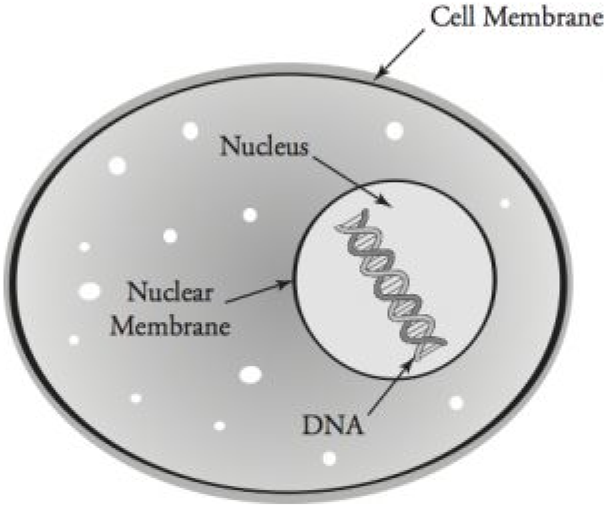
Recipes for Life

As discussed in the lesson, a helpful analogy for explaining DNA is to think of DNA as a cookbook. All organisms have their own unique cookbook—and that book is full of recipes (genes) to make the complete organism. There are, of course, similarities between cookbooks. The human cookbook and the monkey cookbook are fairly similar (both need recipes for eyes, hearts, intestines, and so on), whereas there are huge differences between the human and plant cookbooks. This is of course an imperfect analogy because the genes in DNA encode the *building blocks* of parts, not entire parts. It takes many recipes (genes) to make an eye.

Another important idea to understand is that every cell of a human being contains the complete cookbook for making a human. Said differently, a skin cell does not only have the recipes (genes) for making skin. It also contains all the information to make eyes, kidneys, blood, and so on, but it's only making use of the skin cell information (just like you might only look at the spaghetti recipe when cooking dinner, even though it's contained within the larger collection of recipes inside the cookbook). Specialized cell types only use the DNA instructions they need (if you want to make a cake, you don't also use the spaghetti recipe in your cookbook) at any given time.

Why Can I Extract DNA with Dish Soap, Salt, and Rubbing Alcohol?

It's pretty cool and unbelievable at the same time that simple household ingredients can enable you to hold DNA in your hand.



The ingredients used to extract the DNA take advantage of some simple biological chemistry. DNA is found in the cells of living things (and in multicellular organisms, the DNA is kept in a special compartment within the cell called the nucleus). Cells and the nuclei are each surrounded by membranes made of fats. Detergents (like those in dish soap) break up fats (this is why they are helpful for cleaning greasy pans). Scientists take advantage of this. When they add soap to a mixture containing cells, it breaks down the cell and nuclear membranes, releasing the DNA into the solution. The detergent and salt also help separate other cellular components (proteins from the DNA), but just adding detergent and salt would not be enough for you to see the DNA. To do this, we add rubbing alcohol (isopropanol). This takes advantage of another cool bit of chemistry: different materials can be dissolved in different liquids. Both DNA and salt, for instance, can be dissolved in water. However, DNA is insoluble (cannot be dissolved) in rubbing alcohol. So … if you add alcohol to a solution with DNA, the DNA becomes insoluble and precipitates (comes out of the solution). You see the DNA precipitate as a cloudy (snotty-looking) mass in your tube.

SESSION 2: UP, UP, AND AWAY! (SECRET POWER POEMS AND FLIGHT)

Humans have been fascinated by flight and have longed to fly for hundreds of years, with recorded attempts at human flight appearing as early as the ninth century. No surprise, then, that we love to give our heroes the power of flight. In this session, students will explore flight and engineer a flying vehicle for their hero. During all of this, students will grapple with the idea of structure-function relationships and the important roles they play in both natural and engineered systems. Along the way, students will continue their hero's narrative in verse, writing about the way their hero anticipates and overcomes obstacles—just as engineers make their job easier by looking ahead and preparing for expected challenges.

This session is adapted from "Take Off with Paper Airplanes":
https://www.teachengineering.org/lessons/view/cub_airplanes_lesson06.

YOU WILL NEED

- Images of various flying things (such as planes, birds, gliders, and fictional flight devices)
- Science journals (optional)
- A ball
- Prefolded paper airplane
- Paper airplane templates (available online)
- Paper of varying weights and types for making airplanes
- Tape measures
- Rulers for plane design stations
- Copies of the "Paper Airplane Tech Specs" handout

- Stopwatches (or smartphones or other devices with stopwatch functionality)
- Masking tape

BEFORE YOU START

Before class, set up two or three airplane testing stations. At each station place a tape line on the floor (this is the start [or launch] line). Ideally, there will be a clear path leading from the launch strip so there are no obstructions that might get in the way of a test flight. Each station should also have a tape measure for students to measure the flight distance, and a stopwatch to measure flight length. You many need to set up stations in the hallway, if the classroom isn't conducive.

HOW TO BEGIN (15 MINUTES)

Display some images of flying things (natural and engineered, real and fantastic). You could include birds; butterflies or other flying insects; planes; gliders; Icarus; Da Vinci flying machines; heroes who fly on their own; and the devices that support the flight of others (rocket suits, helicopters, or planes, for example).

Prompt the students to think about what helps each of these items (animals, heroes, or vehicles) fly. If your students are using science journals, they can take notes of their ideas there.

After a few minutes, ask students to think specifically about the shapes of the items. How does the shape help an item fly? Does it have any other qualities—size, weight—that also help it fly?

At this point, it's useful to define what a **structure** is—for example, bridges and houses are structures. And each serves a **function**—bridges help you cross over something (a highway, a river, a canyon), and houses provide shelter. Structures can also be components of an item: doors are a structure on a house, and their function is as an entry way and exit from the building; and the head of a nail functions as a surface for a hammer to connect with (to either push in or pull out the nail). What about in natural systems, such as a human? Ask students to name some structures on a human, and to describe their function (you could record responses in a T-chart). Structures could include legs (for mobility), thumbs (for grasping), eyes (for seeing), teeth (for chewing), and many, many others.

Today’s function: flight! The ability to get off the ground has been pursued by heroes and humans since ancient times. Most of the time, they have failed. Icarus flew too close to the sun and came crashing down. The eleventh-century British monk Eilmer didn’t do any better when he fashioned wings for his arms and feet and jumped off a tower. And in Judy Blume’s *Tales of a Fourth Grade Nothing*, when Fudge tries to fly off the monkey bars, he ends up with two fewer teeth.

But some heroes overcome gravity and genetics to become airborne. Sometimes superpowers let them, and sometimes their supergear does. Superman can fly unassisted, Spider-Man can swing from building to building using his web, and the modern Batman has all manner of nifty black vehicles to get him off the ground to where he needs to go. These flight devices (themselves structures) often comprise several component structures, which students will investigate here. (And later, they’ll see how writing structures can be combined into superstructures as well.)

Continuing from the preceding discussion of structure and function, ask students what structures in birds, heroes, or vehicles make flight possible. Are there parts of any of the objects that help them fly? What about particular shapes that are common in many different flying things? Are these structures? How do the structures contribute to the function (flight)? Students might have difficulty answering this last question. That a wing may be important for flight is something many students will know intuitively, but the science behind this idea is much more complicated. Fortunately, your class is about to do some exploration that will help students develop their ideas about how things fly.

Also ask students what things might hinder flight. Students may have a variety of responses to this question—from the lack of wings (or more generally structures to support flight) to gravity (which pulls things back to Earth).

STEP 1 (55 MINUTES)

Engineering Flight

Throw a ball into the air and let it fall to the floor. Ask students if they are surprised that it fell; why or why not? Then ask why an airplane, which is much heavier than a ball, doesn’t fall out of the sky. Take a paper airplane and then drop it. Ask students why this didn’t fly, and what you’d need to do to make it fly. Students will suggest throwing rather than dropping the airplane. Test their suggestion by throwing the plane. Ask them why throwing it makes a difference. Collect student ideas on chart paper or on a blackboard.

Now it’s time to give the students their mission:

> You have been challenged to engineer a vehicle for your hero to fly in. You have just discovered that the world’s greatest supervillain has a hideout in Antarctica, and you need a fast way to get there. Because of the cold, it has to be enclosed—jetpacks, capes, and flying carpets won’t cut it. As engineers, you have decided to use paper airplanes as your model system.

Believe it or not, aerospace engineers also use paper prototypes, which let you plan, prototype, test, and refine designs quickly. Each student will design and test two different plane models in the session today.

Provide students with paper airplane templates and rulers. Use of the templates is optional; however, if students choose to use a template, encourage them to refine the template design for their second plane rather than picking an altogether new template to test. We want them to be involved in some of the design decisions and to experiment with how changing a plane design changes how it behaves in flight.

Students should use the “Paper Airplane Tech Specs” handout as they design and test their planes. Encourage students to test their planes with at least two—and hopefully three to four—trials so that they can calculate the average flight length, duration, and speed.

Once students have designed and folded their first plane, they can move to a testing station. They’ll need to work in pairs: one person will launch a plane while the other records the duration of the flight in seconds. After the plane has landed, the partners should measure the flight distance, or the distance from launch line to landing site.

This is also a good time to talk with students about isolating variables. The more consistent they are with their flight launches during trials, the more reliable and informative their data will be. Time permitting, you can have students brainstorm possible variables that might affect their flight tests and encourage them to limit and control them as much as possible.

After they have tested their first plane, have students reflect, using the “Paper Airplane Tech Specs” handout, on the strengths and weaknesses of that plane. Challenge them to refine their design to result in a plane that can fly either longer or farther (or both!). Have students use the handout to repeat all design and testing steps with their second plane design.

Have students compare and contrast the two planes on the handout. Ask students how they might further improve their plane. Are there structures that hindered their flight performances? What would they change? Add? Remove? Why?

STEP 2 (15 MINUTES)

Understanding Flight

Have the class think back to the demonstration from earlier, when you dropped a plane and it fell without flying. Why didn't it take off? Gravity, they might answer. But gravity still acts on planes (and heroes) when they are in the sky. There must be some other force that can counteract gravity. What other ideas do students have about why throwing the plane helped it fly and overcome gravity? Now that they have experimented some more, have their ideas changed or developed further?

We hope a student will say that the plane flew because you gave it a push. This is an important point. This pushing force is called **thrust**. Ask them why thrust makes a difference. What is happening when the paper airplane is pushed (thrust) forward? Why does a forward push on a plane keep it from falling down? Thinking beyond planes, what gives a bird thrust? Or a hero beginning an unassisted flight? Though all of these fliers' thrust comes from different mechanisms, they have something in common. It has a lot to do with what is going on around the flying thing, as well as with the design of the flying thing itself.

Ask students what they feel on their face when they ride a bike, a scooter, or even a roller coaster. Does the feeling change if they are going faster or slower? Alternately, you could ask students if they have ever flown a kite. What type of weather is best for flying kites? The answer: windy! How can you get a kite "started" or in the air if it is not a very windy day? Students may offer the suggestion of starting by running with it. There's a lot to consider here!

Now is a good time to circle back to thrust. Thrust pushes flying machines through the air (in a plane, the thrust is created by the engines; in a paper plane, by the launcher's push; in a kite it may be created initially by running, but it can also be caused by the wind). The thrust causes air to move over the wings (a structure designed for a specific function), just as when you ride a bike or a scooter, you feel the air moving past your face. This is where the science gets really interesting. When there is a rock in a river, the water flow changes to go around the rock. In the same way, air must flow around any object, whether it's your face as you ride your bike, or the wing of a bird, plane, or kite. As Isaac Newton noted, for every action there is an equal and opposite reaction. The wing pushes and pulls the air around it in a very particular way, and the air pushes and pulls back up on the wing. This upward force is called **lift**, and good wing structures are shaped in a way that maximizes it. The lift generated by air flowing over the plane's wings creates enough force to overcome the downward pull of gravity and carry a huge aircraft loaded with passengers into the air. If the thrust stops or decreases, the speed of the aircraft decreases, so the flow of air over the wings slows, decreasing the lift—and gravity can then pull the plane back down.

There are some cool things you can do to have your students experiment with lift. The first involves a strip of paper. Have students tear a length of scratch paper at least an inch wide. Ask them to hold the strip by a narrow end and ask for observations about what happens when you hold it from that side. (It droops.) Now, ask students to hold the strip to their lips and blow over it. What happens? (The paper lifts up.) Ask students to experiment a bit further—What happens if you blow under the paper? (Not much.) There is a second experiment they can possibly try, with their parents' permission. Ask students to stick their hand out the car window (when the car is in motion) and experiment with changing both the shape of their hand (flat versus cupped, fingers open versus held closely together, and so on) and the angle of their hand in relation to the wind. Their hand can pretty closely approximate the shape of a wing. Lots of cool discovering to be done!

STEP 3 (25 MINUTES)

If I Could Fly …

As your students have seen, flight isn't all that easy—and neither is being a hero, superpowered or not. Before engaging in all sorts of daring adventures, heroes have to hone and harness their abilities. Think Peter Parker in the 2000s Spider-Man movies, Bruce Wayne in

Batman: Year One (the graphic novel), the many X-Men who literally go to school to learn to control their powers, or even Violet and Dash Parr in Pixar's *The Incredibles*. And once their talents are under control, things can still go wrong, like when Tony Stark's armor runs out of power or Superman encounters some Kryptonite.

Heroes must persevere, and planning ahead helps them do so, just as anticipating challenges helps engineers create structures that function according to their plans. If a civil engineer is overseeing a bridge being built in an earthquake zone, he can plan ahead and use materials and designs that are flexible but strong. Or if she's in charge of a skyscraper along the stormy tropical coast, she can think of building designs with high wind resistance.

Whatever a hero's goals, it helps to predict obstacles in an effort to overcome them. Here, ask your students to consider what their hero wants to do, and what might be in the way. Then, give them time to write a poem whose stanzas each describe an obstacle and how it's overcome. Your students can write about how their hero becomes a hero in the first place (and has to build equipment, control powers, or both), or how their hero uses his or her preparedness and ingenuity to survive a power- or equipment-related disaster. Students could even include how their hero had to revise his or her plan either midcourse or before attempting to overcome an obstacle a second time—persisting and succeeding!

STEP 4 (10 MINUTES)

Flying Out the Door

Before students fly off, you want to wrap up today's session and build excitement for the next one. Ask students to share what they have learned about how structures serve specific functions in living and engineered systems (they can use flight as an example) and how they might like to continue to refine their plane design at home. (Are there any structures they would like to adapt or change at this point, to see how those changes affect flight?) Encourage them to continue their flight engineering—this is a particularly accessible activity to take home and keep exploring and discovering. Connect back to heroes, saying, “Heroes who fly without mechanical assistance often have capes. Using what you know about structure and function—and how flight works—what do you think the cape might be doing? Do you think it helps or hinders flight? Why?” If there is extra time, invite them to share some of their poetry.

Next session, students will continue their focus on engineering by designing a safe place for their hero to fly to: his or her secret lair.

SESSION 3: QUICK, TO SAFETY! (SECRET LAIR BUILDING AND HAIKU)

Shelter is one of the basic needs of most animals. Shelter provides protection from extreme weather (heat, cold, precipitation) and predators. Shelter provides a safe place to sleep, to care for young, and to rest and recover from injuries. Human shelters are the most elaborate in the animal world. They are engineered to meet the needs of those who live in them with specialized rooms for different functions, though other creatures like bees and ants also build specialized structures (or rooms) within their shelters. Heroes have some of the most amazing shelters around—secret lairs that conceal their secret identity, protect them from supervillains, and allow them to rest and recuperate (and sometimes study or invent) between adventures. In this session, students will design shelters and explore structures through hand-on secret lair building and writing haiku.

YOU WILL NEED

- 8.5-by-11-inch paper to fold, accordion-style, into drying racks (2 to 3 per student)
- Cotton swabs (40 to 60 per student plus extra for demonstration, possibly including some extra-

long swabs for variety)

- Clear rubber cement (at least 1 bottle for every 2 students)
- Newspapers, scissors, and tape (optional)
- Sample haikus
- Copies of the “How to Be a Superengineer!!!!” handout
- Copies of the “Secret Lair Blueprint” handout

BEFORE YOU START

Before class, make some drying racks for the cotton swabs by folding paper accordion-style. You’ll also want to build a simple structure with cotton swabs predipped in rubber cement to give students an idea of how this building material works.

For this session, the students will also do a little prep (and be sure to see note on rubber cement at the end of these preparation instructions). As soon as students walk in, have them start prepping their cotton swabs. Preparing cotton swabs is quick—simply dip each swab end in rubber cement and set it on the accordion-folded drying rack to dry. Students will want to wipe the dunked swabs on the edge of the glue jar when pulling them out. If there is too much glue on the end of a swab, it will take a long time to dry (drying time is typically ten minutes). Once the swabs are “tacky”—dry but sticky—they can be used for building. *Tip for instructors:* If time allows, we recommend that you try this activity in advance of the workshop to get a sense of the right amount of dipping and tackiness.

Cotton swab prep can be done at stations with small groups of students working with adult helpers. In the absence of helpers, teach the early arrivers how to dip the cotton swabs in the rubber cement and place them on the racks to dry. Ask students to share how to prepare cotton swabs with any students who join their table later. Each student will need about forty to sixty prepared cotton swabs.

A note on rubber cement: It can get a little fumy, so you’ll want to **be sure you’re working in a well-ventilated room**. If your classroom is on the small side, crack some windows. Keep an eye on the students to make sure they’re not hovering over the jars of rubber cement too much, and instruct them to screw the caps back on once they’re done.

A Note on Sections Titled “FOR YOU TO KNOW (AND YOUR STUDENTS TO DISCOVER)”

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This section is for you—and not the students. You shouldn't feel like you have to read it, and you certainly shouldn't feel like you have to teach it. If you do choose to teach this material to students, we've found it's best not to introduce these ideas or vocabulary words at the beginning of a lesson. As a lesson progresses and students are sharing their observations and ideas, it will usually become clear that they have discovered many of these concepts for themselves. You can then help them by providing labels (the vocabulary words) to hang on the scientific ideas they have already described in their observations. As you do this, try to draw on students' own language in connecting their observations and ideas to the "scientific" language. If, at the end of the lesson, your students haven't learned what they were "supposed" to, resist the urge to give it to them. Their questions and curiosity will do a better job of motivating learning over the long term. Waiting is powerful—and you will see the results in what your students do and learn.

HOW TO BEGIN ()

In the first session, students used the "Supercookbook" handout to design a new hero. They then used their understanding of structure-function relationships to engineer a flying vehicle to help their hero get where he or she needs to go. Today, students will continue engineering to fill an important need of every hero: a secret lair. When that's done they'll engineer a haiku that mirrors the secret lair's structure.

The session starts out with a discussion of retreats. Humans, like many other animals, need a place to feel safe and protected. Ask your students where they go to feel safe. Many will say they go to their home; ask them where specifically in their home. Others will say school or church, or a friend's house, or the neighborhood park or library. Whatever the response, make sure students are as specific as possible, and then ask what about that place appeals to them. Some will say they like the solitude; others will say they enjoy the company. Some will like that they can relax; others will look forward to challenge and excitement. Heroes have all the same reasons and more.

Move on to the next bit of the discussion, asking, "Where do you think a hero goes to feel safe and hide out?"

Discuss some well-known hero lairs. Where are they, what do they look like, what are the essential elements? What unique features do they have that help the hero be successful? Examples might include Superman's Fortress of Solitude, Batman's Batcave, the X-Men's Xavier's mansion, and the Teenage Mutant Ninja Turtles' sewer hideout.

Brainstorm the elements that make up a "secret lair," writing the results on the board. Students ideally will mention the following:

- Location: Secrecy and camouflage
- Solitude: A place to rest, heal, and think
- Space: A command center for learning, practice, planning, inventing, and storing the hero suit
- Entrance/exit: Easy accessibility

Unfortunately, most superfolks are not also superbuilders. They need someone else to design and create their secret lair: an engineer. And engineers have superpowers, too: they can design solutions to important problems, making the world better. There are engineers who design airplanes so that they can safely take hundreds of passengers from one point to another, engineers who study the flow of traffic and design streets (and time traffic lights) to reduce traffic jams, and engineers who design and build video games that you enjoy playing.

Heroes need engineers to help them solve a variety of problems. They need engineers to design gadgets that help them evade supervillains. They need engineers to design high-tech fabrics that protect them from their enemies' onslaughts (and their own derring-do), and they need engineers to build their secret lair—a safe place where they can work, plan, practice, and recover from their stressful adventures.

Give students their task:

> Today you will design a secret lair for the hero you created in the first session. Your hero needs you—to be an engineer.

Distribute the "How to Be a Superengineer!!!!" handout and spend a few minutes going over it. Engineering is like a superpower, and it's what will help them—and their hero client—succeed in their assignment.

STEP 1 (75 MINUTES)

Display some images of flying things (natural and engineered, real and fantastic). You could include birds; butterflies or other flying insects; planes; gliders; Icarus; Da Vinci flying machines; heroes who fly on their own; and the devices that support the flight of others (rocket suits, helicopters, or planes, for example).

Prompt the students to think about what helps each of these items (animals, heroes, or vehicles) fly. If your students are using science journals, they can take notes of their ideas there.

After a few minutes, ask students to think specifically about the shapes of the items. How does the shape help an item fly? Does it have any other qualities—size, weight—that also help it fly?

At this point, it's useful to define what a **structure** is—for example, bridges and houses are structures. And each serves a **function**—bridges help you cross over something (a highway, a river, a canyon), and houses provide shelter. Structures can also be components of an item: doors are a structure on a house, and their function is as an entry way and exit from the building; and the head of a nail functions as a surface for a hammer to connect with (to either push in or pull out the nail). What about in natural systems, such as a human? Ask students to name some structures on a human, and to describe their function (you could record responses in a T-chart). Structures could include legs (for mobility), thumbs (for grasping), eyes (for seeing), teeth (for chewing), and many, many others.

Today's function: flight! The ability to get off the ground has been pursued by heroes and humans since ancient times. Most of the time, they have failed. Icarus flew too close to the sun and came crashing down. The eleventh-century British monk Eilmer didn't do any better when he fashioned wings for his arms and feet and jumped off a tower. And in Judy Blume's *Tales of a Fourth Grade Nothing*, when Fudge tries to fly off the monkey bars, he ends up with two fewer teeth.

But some heroes overcome gravity and genetics to become airborne. Sometimes superpowers let them, and sometimes their supergear does. Superman can fly unassisted, Spider-Man can swing from building to building using his web, and the modern Batman has all manner of nifty black vehicles to get him off the ground to where he needs to go. These flight devices (themselves structures) often comprise several component structures, which students will investigate here. (And later, they'll see how writing structures can be combined into superstructures as well.)

Continuing from the preceding discussion of structure and function, ask students what structures in birds, heroes, or vehicles make flight possible. Are there parts of any of the objects that help them fly? What about particular shapes that are common in many different flying things? Are these structures? How do the structures contribute to the function (flight)? Students might have difficulty answering this last question. That a wing may be important for flight is something many students will know intuitively, but the science behind this idea is much more complicated. Fortunately, your class is about to do some exploration that will help students develop their ideas about how things fly.

Also ask students what things might hinder flight. Students may have a variety of responses to this question—from the lack of wings (or more generally structures to support flight) to gravity (which pulls things back to Earth).

STEP 2 (20 MINUTES)

Lair-Upon-Lair Haiku

After students have done a bit of engineering, bring them back to writing, and highlight some similarities between writing and engineering. There's a purpose to things people write, like there's a purpose to things people engineer. And in both there are constraints to work around. Engineers may have size constraints (as with earlier in this session) or cost constraints (which, as already suggested, aren't necessarily monetary—the amount of available resources, such as cotton swabs, is another kind of cost). Writers have constraints as well. A writer may only have a limited amount of time for a radio or TV commercial, or may have to hold back on complicated vocabulary so an audience can understand. Sometimes, these constraints are more codified or formalized—five hundred words on a statement of purpose for a college application, or an ABABCDCDEFEFGG rhyme scheme for a Shakespearean sonnet.

Here, students will further explore the client-engineer relationship, as well as structure and form, in their writing. Ask if they know what a haiku is; they probably do, but if they've forgotten, remind them of their five-seven-five syllable structure. Show some traditional and nontraditional examples of haikus (maybe show an example of your own haiku you've written about a hero, or see a student's example in the "Acorn Avenger" attached to this lesson). If need be, go over what a syllable is and have students practice counting how many syllables are in their own name to get warmed up for writing.

To give the students a little more structure, ask them to write a client-engineer haiku. The first two lines will be a client request from a hero. For example, "Help build my lair, please. / I need to heal after fights." or "I need to hide out / Where the Fox Man can't get me!"

And the last line will be by an engineer, in response to the request. For the previous examples, finishing lines might be "Look, infirmary!" or "Have these iron walls!"

Encourage your students to write as many first and second lines as possible, taking on the persona of their hero client. Ten or more is not unreasonable to ask for.

Once that's done, have them hand their partial haiku to a partner, who, as the engineer, will write final lines with resolutions to the problems. The completed haiku should be returned to the first author, the client.

Finally, the client will take a look at the completed haiku and decide which of the engineer's solutions they like best. If time and awesomeness permit, students can revise their cotton swab model. For major bonus points, they can use the haiku as walls.

STEP 3 (BONUS)

Want to Keep Writing? Optional Additional Writing Prompt!

For more writing, give your students the following prompt:

Imagine that your hero has to get a quick note to the rest of his or her friends about being safe and hidden. Using the haiku structure, write a "secret lair haiku" from the perspective of your hero that also acts as a secret message to his or her friends and family. How can you reveal your location and surroundings without giving away too much? How will they know you are safe? Go!

STEP 4 (10 MINUTES)

Safe, for Now …

After students have assembled their haiku, bring them back into a large group discussion. Have students share some of their writing, and marvel appropriately at the solutions they came up with and the clever concrete haiku arrangements.

Ask them to talk about how they made their choices about which resolutions they chose to include or not include in their lair poems. It’s likely that several chose to leave out certain resolutions because things didn’t fit—an ice hero might melt going through a hidden volcano entrance, or jet engines would ruin the stealth capability of a submarine. Note that sometimes structures don’t work well on their own, and that sometimes they work well on their own, but don’t make sense with other structures. Can your students think of structural designs on paper airplanes that work well by themselves but not with each other?

To finish, let your students know that the final session in the lesson will continue the engineering focus: students will design a safe vehicle to help their hero save the day.

FOR YOU TO KNOW (AND YOUR STUDENTS TO DISCOVER)

The focus of this workshop session is on students designing a secret lair for the hero they created during the first session. Engineers in general and your lair design engineers specifically have to base their design solutions on the expressed needs of their clients. In this lesson, the expressed needs are the fictional needs of their hero. In addition, the lair design engineers also have to work within the constraints of the lesson’s design challenges. This is a big idea in engineering—responding to client needs and working within constraints. Although students won’t complete a full engineering design cycle in this session, they will focus this very important piece—how to make sure their design is relevant to the problem that needs to be solved. Be sure to read the “How to Be a Superengineer!!!!” handout to brush up on your engineering principles.

The Shape of Stability

Note: What follows is a brief description of the stability of different shapes, and some examples that you can use with students if they bring up these ideas. Beware of giving spoilers. It’s best if the ideas are discovered by your students in their building and their discussions, and then reinforced by you, the instructor.

Children building with blocks often build towers and—even at a very young age—are thrilled by the wobbliness of a tall tower and the challenge of balancing just one more block on top (then one more, and one more) until the whole thing comes crashing down. It’s a primitive exercise in the field called structural engineering, in which different shapes serve different purposes.

Over time, those same children building block towers are likely to discover that they can build taller if they give the tower a wide base and the tower narrows as it goes up. The Empire State Building is a particularly elegant real-life example of this principle. Students with experience riding on trains, buses, or subways (or skateboards and surfboards) may have some relevant personal experience with this notion … they will probably know that, when standing, they are more stable if they have a wide base (if they have their legs spread apart, as opposed to standing with their legs together).

Triangles are the most stable shape for building because of the way they distribute forces. The ancient Egyptians built the tallest buildings in the world (at the time) using the triangle as their base shape. The result was the Great Pyramids—still standing after four thousand years. (Try this out: create a triangle out of rubber cement and cotton swabs, then try and deform it. You’ll only be able to do so by bending the cotton swabs. But if you were to assemble, say, a square, it would be very easy to deform at the joints without bending the cotton swabs at all.)

Even when modern structures are not shaped like a triangle, you can probably find many triangles in their “skeleton”—the framing that keeps them stable. Bridges offer a great example of this—look at old railway bridges and trusses and notice the number of triangles in the frame. Even buildings will be cross-braced for added stability against wind or earthquakes.

One architect, whose primary concern was hurricane damage, built a house in the shape of a dome. This was unconventional, certainly, but the shape allowed tall waves and strong winds to flow smoothly around the house, and in storms in which conventional houses were destroyed, the

> dome house survived essentially unscathed. Dome homes are a fantastic example of how engineers apply scientific principles to solve problems.

SESSION 4: SAVING THE DAY (PROSE POEMS AND THE GREAT EGG DROP)

Whether it's an invisible plane, a flying silver surfboard, or a custom van, safety is an important consideration when creating a hero's vehicle. In this session, students will explore principles of physics while designing safety systems for a super vehicle that will get the hero to the scene without a scratch. To end the lesson, students will write a prose poem in which their hero confronts his or her greatest challenge, and tells the tale of whether he or she succeeds or not.

YOU WILL NEED

- A balcony, window, or ladder (10 feet tall or more) that the egg vehicles can safely be dropped out or off of
- Waterproof tarp, tablecloth, or large garbage bags to cover the floor area where drop testing will occur
- Masking tape
- Copies of the "Saving the Egg" handout
- Assorted packing materials (cardboard boxes, cups, disposable takeout containers, Styrofoam, Bubble Wrap, newspaper, balloons, air-filled packaging, shredded paper, toilet paper or paper towel tubes, and so on)
- Eggs (1 per student)

BEFORE YOU START

This session has a pretty big materials list. All students will not use all materials—but you do want to have a good selection available so students can have access to what they need and have planned for. It's helpful to send a note home with students (or speak directly with parents) after the first session, asking them to collect recyclables and other supplies to use in this session. When it's time to build, we encourage you to ask students to show you their design plan before they grab their materials from the available supplies. Once the plan is approved, they can take what they need, rather than hoarding a bit of everything. You can make sure materials are distributed fairly by not approving plans that require all of the Bubble Wrap, for example.

Students will be using these materials to build vehicles to safely convey an egg from a height, so you'll also need someplace to drop the vehicles from. There are a number of options for this. If you have access to a balcony or window (ten feet or more off the ground—but no higher than a second-floor window), you can drop them from that position. Drops can also happen indoors, from the top of a ten-foot ladder (only adults should be on the ladder). Tape down a disposable tarp—a large disposable plastic tablecloth or several large garbage bags—to make cleanup of broken egg mess easy.

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HOW TO BEGIN (10 MINUTES)

All heroes, and those with superpowers in particular, are known for their dedication and commitment—their willingness to put themselves in harm’s way. But you don’t need to have superpowers to help someone in distress. Even little actions (offering to have lunch with another student who is sitting alone, volunteering to do a chore or task at home before a parent asks) can do a lot. Ask students to go around and tell a short story about a time when they chose to be a hero (by helping someone or doing a good deed). Ask, “What happened? How did it make you feel? How did the other person respond?”

Today, they'll have a chance to be a hero again. Their task: to engineer a vehicle that will get their hero to the scene quickly and safely; safely most of all.

Ask students to think about their experiences with various modes of transport (cars, planes, bicycles, and so on). What types of safety devices are either in place as a part of these vehicles or worn while riding them? Let students brainstorm a list of as many safety structures as they can think of, listing their responses on the board. (If you like, you can give the students a couple of minutes to jot down their ideas first; you'll get more fleshed-out ideas, and the pause is helpful to English language learners.)

> **SAVING THE DAY … ON MARS!**
>
> NASA engineers are the heroes behind rover expeditions to Mars. Engineers designed a complex sequence of events to correctly orient the rover, slow its descent, and absorb the energy of impact, so the rover would land intact on the surface of Mars with all of its delicate scientific equipment in working order. There are several good online videos produced by NASA that describe the landing sequence and how the rover's "safety" features work together for a successful landing.

Next, ask students what the function of these safety structures is. At this point, convert the list on the board to a T-chart. The headings "Safety Structure" and "Function" may be helpful. If the students need some clarification, remind them that the function is what the structure does and how it contributes to safety.

STEP 1 (70 MINUTES)

Designing an Escape

It's time for each student to start building his or her vehicle. At this point you can let the students know who will be playing their hero today: an egg. Yes, they'll need to design and create a vehicle that will safely get the fragile cargo from point A to point B, with point A being very high, and point B being the ground.

Encourage students to think about how they will integrate safety features. Revisit the list of safety structures and group them into themes based on their functions. For example:

- Reducing momentum: Brakes (slowing the vehicle and reducing the chance of impact or momentum at impact)
- Restraining passengers: Seat belts (preventing passengers from being thrown from the vehicle and from hitting objects in the vehicle, and positioning them correctly to be protected by airbags)
- Absorbing and distributing impact: Crumple zones, airbags
- Protecting passengers: Strong passenger compartment, roll cage, and so on

Discuss prototyping, or building a model to test a design, and ask students what they know about how the safety of vehicles is tested. Have they heard of crash test dummies? Why do they think these are used? What do car manufacturers do to test the safety of a vehicle?

Explain that students each will use a crash test dummy in their vehicle—a raw egg. The goal is for their egg to survive the crash unbroken (and ideally uncracked).

Remind students that engineers plan before they begin building. They draw a design plan, and perhaps even conduct some small-scale tests along the way before building the complete prototype. Distribute the “Saving the Egg” handout and give the students about fifteen minutes to complete their design plan. Tell students that they should bring their plan to an engineering supervisor (you) for approval prior to gathering materials.

Once students have completed their design plan and have approval to gather materials, provide approximately twenty minutes for building their prototype vehicle.

After the structures are built — and the eggs are secure inside — it's time to put them to the test and drop them from the drop station. Allot ten minutes or more. Note that an adult should do the dropping, and that drops of different vehicles should be as consistent as possible (that is, a simple release from the same height—do not throw or otherwise accelerate the vehicle). Students should stand around the perimeter of the drop area at a distance where they will be unlikely to get splashed by broken egg mess. Assign a student or volunteer to "collect" each vehicle after its test and put it to the side so other students' vehicles are not landing on top of those already dropped.

After everyone's dropped his or her egg, give the class about ten minutes to record what worked and what didn't work on their "Saving the Egg" handout. Once that's done, assemble the group for a discussion. Ask students to share how their passenger fared. Then move to a more reflective discussion about what they learned from their prototype and what they would do differently next time. Were there particular types of safety features that seemed to provide the most protection? Things that didn't work at all? Is there a way to combine different features from different students' designs to create an optimal passenger safety experience? Put up a piece of chart paper or use the board to collect students' ideas and collaboratively draw a revised super vehicle that, based on students' experiences in this session, should be supersafe.

STEP 2 (25 MINUTES)

Writing a Prose Poem

A prose poem lives between standard verse and standard prose. You can think of it as a paragraph of prose that uses poetic style, language, rhythm, and flow. Or you can think of it as a poem that's arranged in sentences and paragraphs instead of verses and stanzas. The end result should look like a standard paragraph, but sound like a poem. (For more on prose poems, there are a wealth of resources online, including this one.)

After testing the egg drop devices, whether they've succeeded or failed, students should have a heightened sense of the stakes associated with choices. They'll mainly at this point consider the choices of the engineer (the design of the vehicle), but you should also ask them to consider the choices and challenges facing the hero.

After a little bit of discussion on this, task your students with writing a prose poem about their hero's most colossal challenge. This prose poem should …

- Describe the challenge the hero is facing. Is it the Decimator, another villain, an impending natural disaster, or something else entirely?
- Explain why the challenge is too big for our hero right now. Our hero at this point shouldn't be able to successfully confront the challenge head-on, or get everyone to safety (or both).
- Describe the outcome. Students may write this based on the outcome of their egg drop, but it's okay if they write about a success here even if their egg drop failed (or vice versa). In any case, students can still draw on aspects of their egg drop as inspiration (for example, even if the landing legs on the egg drop fell off entirely and the egg was obliterated, in the poem the hero might be able to escape the wreckage with only a broken arm).
- Include vivid descriptions and figurative language throughout.

STEP 3 (15 MINUTES)

Teach-Backs and Close

Time permitting, have students share shorter or longer bits from their prose poem. Discuss, with the class, how the heroes' choices affected the ends of the stories. More indirectly, how did engineering design choices affect the egg drop experiment, and how were those reflected in the prose poems?

What other choices were there, and how might things have changed as a result of making different choices?

To end the lesson, have students reflect on all the choices their hero has made. How do those choices relate to the hero's natural abilities and nurtured tendencies? How do those choices affect the client-engineer relationship, and the quality of everything the students built? How do those choices affect the hero's world?

Bring the idea of choice back to the students' world. How can your choices influence who you are and where you are going?

Remind students that although we can't change our nature and nurture up to this point, we still do have choices, and our own choices are powerful determinants of who we become. Persisting through challenges and overcoming adversity are hallmarks of successful heroes, scientists, and engineers—but continuing to move forward and not giving up are choices that these real and imagined heroes make, on various scales, every day.

FOR YOU TO KNOW (AND YOUR STUDENTS TO DISCOVER)

Automakers spend huge amounts of money engineering systems within cars to keep the occupants comfortable and to protect them in the event of a crash. Similarly, NASA engineers carefully design systems that enable the Mars rovers to fall safely to the planet's surface without damaging the sensitive (and very expensive) components that will be crucial for a successful mission.

In designing a landing pod for their egg, your students will be engaging in a very similar task, and using the principles of physics will help them be successful.

What's Going On in a Crash

There are several important physics concepts at work in a collision:

- Although it is almost too obvious to state, objects tend to stay where you put them unless a force acts on them to change their state of motion (this is really Newton's first law). If you put a cup on the table, it will stay on the table until someone picks it up or pushes it over. The act of picking up or pushing over is a force acting on the cup. The converse—namely, that objects in motion stay in motion until a force acts on them to change that motion—is also true. It is, admittedly, harder to see, because there is always a force—friction—acting on forces in motion. The tendency of objects to resist a change in motion is called **inertia**.
- **Momentum** is essentially a measure of the amount of motion an object has. It is dependent on both the **mass** (a measure of how much stuff the object is made of—or on Earth, its weight) and its **velocity** (speed and direction).
- An **impulse**—a force acting over a period of time—changes the momentum of an object. If a car driving down the road runs into a brick wall, it comes to an abrupt stop. There is a large force that acts on the car over a short period of time. If the same car traveling at the same initial speed (and with the same mass) runs off the road into a sand pit, it comes to a stop much more slowly—there is a smaller force acting on the car over a longer period of time. The change in momentum in these two situations is the same—the car comes to a stop, but the effect on the vehicle and its occupants is dramatically different.

What does this all mean when we put it together? If you are sitting in your chair in your dining room, it is obvious that you are not in motion, unless someone pushes the chair (or you stand up and walk away). If you are sitting in a car moving at fifty-five miles per hour, although you perceive that you are sitting still, your body is moving at the same velocity (speed and direction) as the car you are traveling in. In this example, the system (the entire car and you) has momentum that is equivalent to the momentum of the car plus the momentum of the passenger.

Most of the time, when all is going smoothly on a drive, the momentum of the passenger and the momentum of the car act as a single system. When you brake your car to come to a stop, the slowing wheels apply a force to the car, and the car applies a force to you via friction or the pull of seat belts—and your momentum and that of the car decrease roughly simultaneously. If something forces the car to stop abruptly, however, like hitting the brick wall just mentioned at fifty-five miles per hour, the force has acted on the car, but you'll still keep moving. You still have momentum because of inertia (if you're not wearing a seat belt, the low force of friction in the car hasn't had enough time to stop you—that is, there has not yet been a sufficient impulse acting on you to stop your motion). Your body (and your internal organs) continues to travel at speed until a force changes your motion (brings you to a stop). You will slide forward in your seat until something stops you (and your organs will continue to slide forward until something, such as your rib cage, stops them—not good). Hopefully you are wearing your seat belt and have other safety systems in your car, as all of these safety systems are designed to either (1) absorb or distribute the force of the impact or (2) increase the time over which the force is acting, thereby decreasing the impulse.

That's the Way the Car Crumples

Newton's second law states that the size of a force depends on how quickly an object changes speed. If a car stops quickly, there must be a very large force acting on the car. If it can be slowed down at all before impact, the size of the force necessary to stop it decreases. That is, the longer the car takes to come to a stop, the bigger the decrease in the force needed to stop it. The brakes in a car help slow it (ideally enough so that an impact never takes place). Car manufacturers have also built what are called crumple zones, which harness the power of Newton's second law, into the body of the car surrounding the passenger compartment. If you hit a brick wall in a car with a crumple zone, the front end comes to a stop at the wall, and the body of the car continues to move forward, collapsing or crumpling the body of the car between the front and the passenger compartment. This takes time and absorbs energy—meaning that the force experienced by the passengers is reduced.

Once upon a time, car manufacturers made car bodies very rigid. This meant that there was little crumpling, and the passengers felt the full force of impact (the car may have been less damaged than in accidents with modern cars, but passengers did not fare so well and were terribly injured). Modern cars couple crumple zones with rigid passenger compartments (to limit intrusion of, say, the engine into the passenger area), and together these two improvements (with those described in the following paragraphs) have greatly improved passenger safety.

Don’t Burst My Airbag

Just like how crumple zones decrease the force of the impact by slowing the car, airbags decrease the force of impact experienced by the passenger by slowing the passenger. An airbag inflates as a passenger is sliding forward in his or her seat as a result of the impact. The passenger then hits the airbag, rather than a rigid structure like the dashboard, and the airbag deforms (much like how a pillow changes shape when you hit it). This deformation absorbs some of the energy of impact and slows the passenger so he or she does not come to an abrupt stop (big force, short time).

In addition, because airbags cover a large area, they distribute the force of impact. You probably have experience with this carrying a heavy backpack. If your backpack strap is twisted, it quickly becomes painful as the weight of the backpack (the downward force from gravity) is only distributed over a small area on your shoulder. If you untwist the strap, the weight is distributed over a greater area, and although the backpack is still heavy, it is less painful to your shoulder. Before airbags, drivers would hit the steering wheel, and the force of the impact was distributed over a very small area on the driver’s body. By distributing the impact, the passenger is less likely to experience a severe injury.

Use Restraint

Seat belts serve several functions. Seat belts connect you to the car, so in a crash, you are no longer a separate body moving independently of the car. This allows you to benefit from safety features like crumple zones that slow the car (and you) and decrease the force of the impact you feel. Seat belts are designed to stretch a little, and so, like the other safety features just described, seat belts slow a passenger and thereby reduce the force of impact. Seat belts also prevent a passenger from hitting objects inside the car, like the dashboard, steering column, or windshield, and prevent the passenger from being thrown out of the car altogether. Finally, like airbags, when worn properly, seat belts distribute the force of impact over the passenger's body.