Grade 3
Unit: Invisible Forces
Lesson 2: “What makes bridges so strong?”

VIDEO TRANSCRIPT

EXPLORATION VIDEO 1

Hey, it's Doug! Today, I want to tell you a true story about a place—right here in this picture—and about a guy whose name was Charles Ellis. Charles built something right in this spot, and what he built is world-famous. You'll see by the end of the Mystery that you'll probably recognize it. For this story, we have to go back in time. We're going to go to the year 1929, almost a century ago. And here is Charles Ellis. Charles was an engineer—that's someone who uses science in order to build things. And Charles faced a challenge. You see, he had been called to help two cities on the West Coast of North America. Between the two cities was this wide channel of water. The two cities often traded goods with each other, and some people even went between each city to work each day. But there was only one way to get across this stretch of water: by boat. It wasn't great. A boat ride took over 45 minutes to get from one side to the other. The people in the two cities wanted Charles to build a bridge across the big channel of water, so they could drive their cars and trucks from one city to the other. And they didn't want just any bridge: they wanted a bridge that would be beautiful—really nice looking, something the whole world would admire, something that could be famous. A lot of experts said a bridge couldn't be built there. They said the distance was too great. It was more than a mile across. They also thought that the water in the channel was too deep. And it was really deep. If you sucked out all the water in this spot, like that, you'd see it was almost 400 feet down to the bottom. And what's more, lots of huge ships needed to get through the channel of water—big ships like cargo ships, cruise ships, Navy ships. Any bridge that was going to be built couldn't have a lot of pillars or supports underneath it because those would block the passageway for huge ships like these. So, how could a bridge meet all of these challenges? Today, just like Charles, you're going to design your own bridge. You'll compete for fun with some of your classmates to see who can make their bridge the strongest. Now, unlike Charles, you don't need to worry about your bridge being able to carry people or cars. You just have to worry about your bridge holding some pennies on it for weight. For this, you're going to make a bridge out of paper. But since you might not have thought much about designing bridges before, let me tell you a little bit more about the story of Charles Ellis, the engineer, so that you can learn something about designing bridges. Now the first question any bridge designer might ask is: well, what's wrong with just a really long board? After all, that's the simplest kind of bridge. Like, imagine all we had to do were cross this little stream or creek. It's just wide enough that you probably don't want to jump. So you might lay down a board to walk across, like this one right here. But see, if this creek were even a little wider, like this one, you start running into problems with putting a board across because the board now has to be longer in order to reach the other side. The longer a board, the more it weighs. And the more it weighs, the more it sags under its own weight. See? And now, if you add a weight on top of that, like a person walking, then the sagging downwards gets even worse. If you put too much weight on it, it might sag down into the water or even snap. So what could you do with a bridge like this? How could you keep it from sagging?

EXPLORATION VIDEO 2

You can see that this is the idea they used for this, the Lake Pontchartrain bridge, in Louisiana, USA. Where the bridge would have been sagging, they put these big pillars underneath to support it. The pillars are like the stick we put under our board. The weight of the road and any cars or trucks driving on it pushes it down, so something is needed to push back up. Otherwise, the bridge will fail or break. So, these pillars help push back up on the weight, keeping the bridge from sagging or breaking. Now, as long as you have lots of supporting pillars, it's possible to build a bridge as long as you want it to be. The Lake Ponchartrain bridge is really long—it's one of the longest bridges in the world. Now, when you build a paper bridge, maybe you could try building pillars out of paper. But poor Charles can't just build a bridge with pillars all along it because, as you recall, Charles has to deal with a really deep channel. Plus, he has to have space for really big ships to get through. So, what options does Charles have? Well, thinking back to our board across a stream, suppose we had a situation where the bridge is going over something really deep, like this. You can't easily just put a stick or a pillar to support a bridge in the middle because the middle is too far down. But you can put two pillars off to the sides, like this. Now you're supporting the middle of the bridge. Notice where the force of the weight is pushing? It's pushing off to the sides. This is what some bridge designers have chosen, here, and here, and here. You can probably guess what this kind of bridge is called. It's an *arch bridge*. Arch bridges are a very popular design for bridges. Maybe you even have one near where you live. So could Charles use an arch bridge design? This definitely would make a beautiful bridge and it wouldn't have any pillars underneath, so that's great for his problems. But, unfortunately, Charles can't use an arch bridge design because arch bridges can only be so long. If they're too long, the sides won't support the weight of the bridge. The longest arch bridge in the world, this one, is just over 550 feet across. Now remember, the gap of water Charles Ellis needs to cross here is over 5,000 feet—that's a mile—across. So an arch bridge might be good for you to try out today with your design out of paper, but this wouldn't work for Charles Ellis—he needs a different design. There is a third design that's possible. Now, in the pillar bridge, remember, you're supporting the weight of the bridge by pillars that are pushing up on the bridge from below. And in the arch bridge, you're supporting the weight of the bridge by putting two pillars off to the sides. So, pushing up on the bridge from the two sides beneath the bridge. But in both of these designs, notice they're pushing up on the bridges. What if you didn't have anything pushing up to support the bridge? Could the bridge pull down from something instead? Well, it can. This kind of bridge is called a *suspension bridge*. If you know the word *suspenders*, that's easy to remember. It's called that because the bridge *suspends*, or hangs, from these two towers up here. It's a pulling force. The road is here, and the weight of it, plus anything driving on it, is supported by these ropes made out of steel, which are attached up here to two towers on either side. This is the design that Charles Ellis chose to cross the channel of water. And when he did this, he created the most famous suspension bridge in the world. In fact, all this time I haven't told you the names of the towns he was connecting. The city on one side is San Francisco, California, and the city on the other side is a town called Sausalito. By now, you might be able to guess what the bridge is that Charles Ellis designed. It's this: the Golden Gate Bridge. The suspension bridge design solved all of Charles's problems. It was able to cross the wide gap of water, but without needing any pillars in the middle where the channel is so deep. That kept the channel free for large ships to come through. In order to make a suspension bridge, Charles and the construction crew had to construct two large towers to hang the bridge from. This is an actual photo when they were doing construction. Both of these towers were placed in the fairly shallow waters off to the side of the channel. Then they hung the bridge itself, the roadway, from the towers by making use of incredibly strong cables made out of steel—that's these. When it was completed in 1937, the Golden Gate Bridge was the longest suspension bridge in the world, and it still makes the top 10 list. But even if it's not the longest suspension bridge anymore, it's still the most famous, probably for its beautiful design and its striking dark orange color, and the incredible views from almost anywhere near the bridge. People often ask: why is it called the Golden Gate Bridge? I mean, it's orange, not gold. Well, the channel of water underneath is called the Channel of the Golden Gate. So, the bridge is named for the channel of water that it crosses, not because of its color. If I look through binoculars, I can even see this bridge from my neighborhood in San Francisco where I live. So, that's the story of Charles Ellis the engineer and the bridge that he built, San Francisco's Golden Gate Bridge. Now would be a good time to stop and think about the different kinds of bridge designs you've just seen, and what makes a bridge strong.

EXPLORATION VIDEO 3

Now, there's actually one little extra thing you can do to make a bridge very strong. This is something you might want to know about before you go designing a paper bridge. If we go back to that very first example of the world's simplest bridge—this one, a simple board across a stream—remember, we saw how if the board were very long, it would sag in the middle. And if you walked on it, it might even break or dip down into the water. But, notice something here: if you take this board and now you turn it so that it's on its side, it's much stronger. If you were to walk on it now, it wouldn't sag. It can support a lot more weight. So, if you take two boards on their sides like this, and then put a flat board on top for walking over, this bridge will be much stronger than that single flat board alone. So, what's crazy is that this bridge doesn't even have to be turned this way. If you nailed this all together so all three boards were connected, and then you turned them so it's facing upwards, it still has the same strength. The two boards that are pointing up make this bridge stiff—they keep it from sagging. This shape is really strong. In fact, you can see it in everyday life. With really large bridges, like this of course, they're not made of wood—this is made of steel since steel is even stronger. But there's a drawback to that: steel is also much heavier than wood. So bridge builders thought about, how could they make a shape like this, but keep it light? And they realized it doesn't have to be one giant, flat piece of steel all along the sides. You could just as well have steel beams, or poles, and it would be just as strong, but a whole lot lighter. They call this type of bridge a *truss bridge*, from the French word for bundle, since it's like a bundle of beams or poles. But all it is is just a lighter weight version of this: a design that makes a bridge stronger. If you look around, you can spot truss bridges everywhere, like this one. And here's a truss bridge. And here. And here. And here's another one. They're all over the place. Sometimes, you can even find truss bridges within other bridge designs. Like, look at the Golden Gate Bridge. So, that's a suspension bridge, right, but look at the roadway, the roadway under the Golden Gate Bridge—it's made of a truss. So you may want to use this knowledge when you think about how to make a strong paper bridge.

ACTIVITY INTRODUCTION VIDEO

It's time for you to be your own Charles Ellis. You and a partner are going to build a bridge. Now, the one thing you're limited by—the thing that's going to make this a challenge for you—isn't a wide deep channel of water like the Golden Gate Bridge was designed across, but instead, the materials that you're using. And a little bit of your time too. In terms of time, you've only got the rest of the class period to work. And for the materials, your bridge will use only paper. So, you and a partner are going to work together and it's your job to create a bridge between two stacks of books. The books should be about six inches apart, and your bridge must be at least three inches wide. And then here's what you should do: you'll test your bridge by stacking pennies on it, and you should stack pennies on it until the bridge fails, like this. Ready? It failed, collapsing under the weight of all the pennies there. Now, I know that's a weird idea: you want to make the bridge fail? But that's exactly right—you do. Because by making it fail, and then by watching how it fails, that's going to lead you to ideas for how to improve your bridge and make it stronger. The bridge that holds the most pennies is going to be the winning design. For the bridge materials, you can only use paper, nothing else, not even tape. Now, I know that might seem hard, but we're making it difficult on purpose because being creative, coming up with ways to solve problems, is like a muscle—you have to exercise it in order for it to get strong. And so, not having tape is going to make you have to exercise your creativity muscle. Think about all the things that you can do with paper. There's actually a lot you can do with it. You can fold it, you can roll it, you can twist it. Now, do any of these things make the paper stiffer or stronger? Think about that. Can any of these things help you do something you'd otherwise use tape for? Now, I should tell you: you will have scissors. You can make any cuts you want, so you can slice the paper up into smaller pieces if you'd like. And if you experiment, I'm sure you'll find a lot of ways to build a bridge. You can think about, how could you copy any of the designs you've learned about? You can use as many pieces of paper as you like when you're experimenting, as long as your final bridge uses just two pieces of paper. Now, to do the job right, I recommend you make at least three different bridge designs to see which one works best. You'll draw your designs here on the worksheet. So, to get started, you're going to need these things: a pencil, a "Bridge Challenge" handout, a "Bridge Designer's Notebook" where you can keep track of what you do, and then you'll also want a ruler, a pair of scissors, two stacks of books, and, of course, paper. And I shouldn't forget, of course, you'll need pennies too. Now, how many pennies you need, that's going to depend on your bridge. I hope you'll need lots of pennies. So go ahead, follow the instructions on the “Bridge Challenge” handout. And when you're done building, your class can get together and talk about what you all did, and which bridge held the most pennies. Good luck, and have fun, everyone!