Smithsonian Latino Center

¡DESCUBRA!

Meet the Science Expert

¡DESCUBRA! CREATE-IT POCKET SCIENCE HANDOUTS

INKA ENGINEERING IN A GRASS BRIDGE

1. Overview:

As they build a suspension bridge, students will understand basic engineering concepts such as "tension" and "compression." In addition, they also will learn of the extraordinary engineering prowess of the Inka Empire.

- Age level: 7–12 years
- Time frame:
    - o Preparation: 30 minutes
    - o Activity itself: 30-40 minutes

2. Background:

General background on the Inka Empire and Inka engineering is given below. For more information, please refer to the Smithsonian Institution's NMAI website: http://americanindian.si.edu/inkaroad/

- ***Tawantinsuyu*—the Inka Empire:** Between 1438 and 1533—in fewer than 100 years—the Inka built Tawantinsuyu[1] (tah wahn teen SOO yoo). In that time, the Inka transformed their small Andean kingdom into one of the most sophisticated and diverse empires the world has ever seen, an empire that was made possible through an advanced engineering and social infrastructure. Today, more than seven million *Quechua* and *Aymara* indigenous people are the direct descendants of the Inka Empire.

[1] Tawantinsuyu means "four parts together" in the Quechua language.

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- **Inka Road System and Inka Engineering:** The Inka built a system of roads that began in Cusco's main plaza and then radiated to the four regions of the Tawantinsuyu. The *Qhapaq Ñan* (KHAH pahk NYAN), as the Great Inka Road system was known, was the largest construction project in the Western Hemisphere at the height of Inka power. The Qhapaq Ñan's network of 25,000 miles (40,000 kilometers) of roads spread throughout the Empire, allowing the Inka to oversee and manage a territory of more than 772,000 square miles (2 million square kilometers)—the equivalent of California, Nevada, Arizona, New Mexico, and Texas combined. Monumental architecture, terraced agriculture, sophisticated water-management and food-storage infrastructure, and the domestication of thousands of varieties of potatoes and hundreds of varieties of quinoa and corn are some of the other amazing accomplishments of the Inka. The extraordinarily capable Inka engineers were able to design and build different sorts of bridges to fit the varied terrain of their Empire.

  The Europeans who first set foot in the Inka Empire had never seen a suspension bridge, and were amazed to find hundreds of them in active use all along the Inka Road system. Suspension bridges did not exist in Europe at that time; instead, Europeans built stone arch bridges. Despite the fact that suspension bridges can span longer distances, it took European engineers another 300 years to build a suspension bridge.

  Today, indigenous Andean communities are proud of their heritage and continue to live sustainably and in balance with their natural environment.

- **The Q'eswachaka Bridge:** Q'eswachaka[2] is the last remaining Inka suspension grass bridge in use. It stretches 100 feet (30 meters) across a gorge, 50 feet (15 meters) above the *Apurímac* River in Peru. The bridge, made of grass fibers, vines, and other organic material, has been in continuous use for the past 500 years. Every year, 1,000 villagers from four neighboring Quechua communities gather native grass, twisting and braiding it by hand to make 10 miles (16 kilometers) of rope. Then the members of the four communities work together over four days to rebuild the bridge. As they rebuild Q'eswachaka, they ask permission of the Apus (sacred mountains) and make offerings to *Pachamama* (Mother Earth). At the end of the repairs, the communities hold a feast to celebrate the new bridge.

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[2] *Q'eswachaka* (khes wah CHAH kah): in the Quechua language, *q'eswa* means braided grass and *chaka* means bridge.

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- **The Engineering of Q'eswachaka:** The Q'eswachaka bridge is an wonderful example of sustainability, both environmentally and in terms of engineering. The bridge is built of strong, locally harvested, and fully biodegradable materials. The Inka understood the characteristics of a variety of fibrous materials, such as grasses, cotton, and the wool of llamas and guanacos (camelids). So it was natural for them to find an engineering solution that used a locally abundant grass fibers that could be woven to make rope. While individual grass fibers may easily break and tear, the Inka knew that by twisting and braiding them into thick ropes, a far stronger and more flexible material could be made. Strength increases as more elements become available to share the load, or the forces, acting on them. So, what better way to solve the problem of crossing a deep gorge over a river than to weave a grass bridge!

  In suspension bridges, including the Q'eswachaka, cables work through tension, or through the stress resulting from a pulling force—these are called ***tension forces***. However, if you pull a cable too much, it will eventually break. The Inka understood and utilized the engineering concept of tensile strength. The tensile strength of the grass cables, or how much they can be pulled from opposite directions before they break, is critical. Inka bridge builders also knew how much stretching the cables could tolerate from the weight of the expected foot traffic on the bridge. The tensile strength of a grass rope depends on the type of grass, how much grass is used to make it, and how it is twisted and braided together with other ropes. Can you guess how big a load the largest cable of the Q'eswachaka can hold before it breaks? Each main cable, as thick as a man's thigh, can hold 5,175 pounds (or 2,347 kilograms)—more than the weight of an average automobile or the combined weight of 12 llamas!

3. Preparation:
Materials

- For each **bridge exploration station** (each station has a six-child team)
  - Two chairs
  - Rope
  - One rectangular piece of cardboard about 4 feet long by 1 foot wide
  - Duct tape
  - Books for weight (four-to-five heavy books)
  - Two pieces of rope, each about 9 feet long
  - 8–12 pieces of string, each about 2 feet long

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- **For all the participants**
  - Printed English and Spanish Tawantinsuyu posters (optionally mounted on FoamCor)
  - Two sets of laminated photographs for context on Inka culture to play "memory game"
  - One set of laminated Activity images
  - Projection of a 3:15 minute TRT video of the Q'eswachaka construction process (https://www.youtube.com/watch?v=dql-D6JQ1Bc)

<u>Adult Preparation</u>

- Gather all materials
- Lay out the materials for each bridge exploration station
- Lay out the materials for the whole group of participants

4. Making and Doing:
Adults may begin by engaging the children in a "memory game" with the two sets of laminated images; adults should have the "key" to the images, so they can explain what they are. This activity can be done by the younger children or by all the participating children, depending on how many there are. The purpose here is to provide a background on Inka culture and Quechua Andean communities, so that the bridge activities can be better appreciated.

Let's Experience Tension and Compression Forces!

Definition of Tension and Compression

Tension forces pull and stretch material in opposite directions, allowing a rope suspension bridge to support itself and the load it carries. **Compression forces** squeeze and push material inward, causing the rocks of an arch bridge to press against each other to carry the load. Both types of bridges rely on **abutments**, the components of the bridge that take on pressure and dissipate it onto the Earth. In the Q'eswachaka bridge, the abutments are made from massive rocks where the bridge's main cables are anchored.

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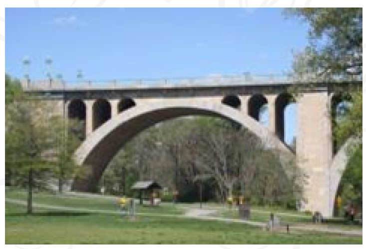
Point to the **Force 1** and **Force 2** laminated images to show the “push” (Force 1) and “pull” (Force 2) principles. Ask students to work in pairs to demonstrate **Force 1** and **Force 2**, as shown in the illustrations below. As the students push and pull, they will feel which way the forces are directed. Based on the definitions on tension and compression provided, ask the students which force they think is tension and which they think is compression?

	
Force 1	**Force 2**

Point to the laminated images of the two bridges—Q’eswachaka and the Taft Bridge in Washington, D.C. Ask the students to look at the two bridges and have them match “Force 1” and “Force 2” to each bridge type. Ask them to identify which bridge acts primarily on compression forces and which bridge acts primarily on tension forces. Ask the students to explain and justify their choices.

	
Q’eswachaka Bridge. Photograph by Doug McMains, NMAI	**Taft Bridge in Washington DC.** Photograph by Dan Davis, NMAI

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Ask the students to think about how it felt to experience these forces. When pulling apart from their partner, what shape did their bodies resemble? How about when they pushed against their partners' hands? When pulling apart from the partner, the students' bodies form a suspended curve, much like the Q'eswachaka bridge; when pushing towards their partners, the students' bodies form an arch, much like the Taft bridge.

Let's Build a Suspension Bridge!

It is interesting and fun to explore how a suspension bridge works. What kind of bridge could be built with the following materials?

- One rectangular piece of cardboard about 4 feet long by 1 foot wide
- Two chairs
- Four or five heavy books

Students can start by setting the two chairs facing each other, then placing the cardboard so it "bridges" the space between the two seats. They have just made a "beam" or "plank" bridge—a type of bridge that is not very strong. Ask the students to test its strength by placing a heavy load on it (one book at a time from the stack of books). How many it can hold before it collapses? Ask the students to consider which are the main forces at play in this type of bridge. Compression? Tension?

To strengthen the plank bridge, have the students modify it so that it becomes a suspension bridge. Use the following materials:

- Two pieces of rope, each about 9 feet long
- Eight pieces of string, each about 2 feet long
- Duct tape

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Have the students stretch the ropes above the cardboard over the backs of the chairs, and have two other students pull the rope ends tight by sitting on the floor behind each of the chairs (see illustration below).

Then ask the students to tie the tops of at least four pieces of string to one of the ropes, at equally spaced intervals along the cardboard; the process should be repeated with the other rope. Ask the students to secure the loose ends of the strings with duct tape to the underside of the cardboard.

The students have now modified the plank bridge and converted it into a suspension bridge. Ask the students sitting on the floor to pull on the ropes behind each of the chairs as another student starts piling books on top of the bridge. Students can experiment with the pulling force and with various loads to test the strength of the bridge. Ask the students to consider what forces are primarily at play in this type of bridge. Compression? Tension? Where are the students pulling on the ropes feeling the forces as their friends add more books? Ask the students to look at images of Q'eswachaka and consider how their bridge is similar to and how it is it different from the Inka bridge.

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My Notes and Observations

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