NATIONAL MUSEUM OF THE AMERICAN INDIAN

EDUCATION OFFICE

Q'eswachaka

A LIVING LEGACY OF INKA ENGINEERING

Q'eswachaka

A LIVING LEGACY OF INKA[1] ENGINEERING

GRADE LEVELS: 5–8 | RECOMMENDED TIME: TWO CLASS PERIODS

Overview

This poster focuses on the *Q'eswachaka*[2] grass bridge—a key component of the Great Inka Road system and a living engineering legacy of the Inka Empire.

Poster features include:

- General introduction to the Inka Empire and the Great Inka Road network
- Student activities highlighting the engineering aspects of a suspension bridge
- Q'eswachaka as a unique example of sustainability from environmental, engineering, and cultural perspectives
- Profile of the only living bridge master, Victoriano Arizapana Huallhua, who leads four *Quechua* communities in the annual renewal of the grass bridge
- Rationale for the importance of preserving Q'eswachaka for future generations

Native Knowledge 360° | Framework for Essential Understandings about American Indians

- NMAI Essential Understanding 3 | People, Places, and Environments
- NMAI Essential Understanding 8 | Science, Technology, and Society

National Science Education Standards

- E1.1 Abilities of Technological Design, including evaluate completed technological designs and products; communicate the process of technological design
- F5.4 Science and Technology in Local Challenges, including science and engineering work in many different settings

Next Generation Science Standards

- Practice 2: Developing and Using Models
- Practice 6: Constructing Explanations (Science) and Designing Solutions (Engineering)

Student Objectives

Students will:

- Learn a general overview of the Inka Empire and the Great Inka Road system
- Explore the engineering concepts of tension and compression
- Test the load capacity of two bridge designs: plank and suspension
- Understand the cultural significance of Q'eswachaka

[1] In an effort to preserve and honor indigenous languages, NMAI chose to use the Quechua spelling, Inka, instead of Inca.
[2] Q'eswachaka (*q'eswa* meaning "braided grass" and *chaka* meaning "bridge" in the Quechua language) is pronounced khes wah CHAH kah.

Procedure

I. Display the poster in the classroom. Explain to the students that they will be learning about the engineering and cultural practices related to a grass suspension bridge of Inka design.

II. Use the "*Tawantinsuyu*—The Inka Empire" and "*Qhapaq Ñan*—The Great Inka Road" reference material in this poster to provide the students with an overview of the Inka Empire and the Great Inka Road network. Ask the students to use Google Earth™ and the map provided in the poster to identify the historical span and topography of the Inka Empire. A complete **lesson plan, discussion questions,** and list of **resources** can be found at http://AmericanIndian.si.edu/nk360/resources/inka-poster-lesson-plan.pdf

III. A pdf of this poster can be found at http://AmericanIndian.si.edu/nk360/resources/inka-poster.pdf

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I *Tawantinsuyu* —The Inka Empire

In less than 100 years, from 1438 to 1533, the Inka built *Tawantinsuyu*[3] (tah wahn teen SOO yoo), one of the most sophisticated empires in the world. Today, more than 7 million *Quechua* and *Aymara* people are the direct descendants of the Inka Empire, which grew from a small kingdom in the Andes in the early 13th century to become a thriving civilization. Through peaceful assimilation and warfare, the Inka expanded their empire to include large territories in present-day Peru, Bolivia, Ecuador, Colombia, Chile, and Argentina. A system of government based on the redistribution of resources and the Andean principle of *ayni*, or reciprocity, allowed the empire to flourish until the Spanish conquest in the middle of the 16th century. The city of Cusco was the administrative and religious center of the Inka world. The Inka built a system of roads that stretched from Cusco's main plaza to the four regions of Tawantinsuyu. The *Qhapaq Ñan* (KHAH pahk NYAN), or the Great Inka Road system, was the largest construction project in the Western Hemisphere at the height of Inka power. Monumental architecture, terraced agriculture, sophisticated water management and food storage infrastructures, 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. Today, indigenous Andean communities are proud of their heritage and still live sustainably and in balance with the natural environment.

Map of South America showing the Tawantinsuyu, Cusco, the Qhapaq Ñan road system, and the contemporary political boundaries and capitals of the six countries that were historically part of the Inka Empire.

Machu Picchu in the Andes of Peru. One of many cities of the Inka ruler. Photograph by José Barreiro, NMAI, 2008.

Above: *Hatunrumiyoc*, an Inka-engineered wall in Cusco, Peru, showing meticulously carved stones that fit perfectly together without the use of mortar. Photograph by Doug McMains, NMAI, 2014.

Left: Many potato varieties at the market in Pisac, Peru. Photograph by Doug McMains, NMAI, 2014.

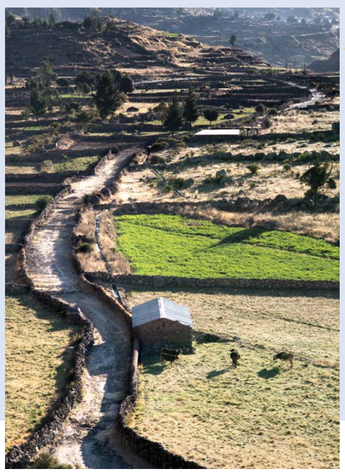
[3] Tawantinsuyu means "four parts together" in the Quechua language.

II *Qhapaq Ñan* —The Great Inka Road

"The Inka built roads everywhere to unite the villages of the world. The road is a rope that binds communities and allows us to live as one family."

—Panfilo Sulca (Quechua)
Sarhua, Ayacucho, Peru, 2010

The Qhapaq Ñan was built without the use of metal or iron, the wheel, or stock animals to pull heavy loads and spanned 25,000 miles (40,000 kilometers) throughout the Tawantinsuyu. The road system allowed the Inka to oversee and manage a territory the equivalent size of California, Nevada, Arizona, New Mexico, and Texas combined. This extraordinary network of roads meanders down the Pacific coast of South America, from Quito, Ecuador, to Santiago, Chile, traversing one of the most extreme physical geographies on the planet, from snowcapped 16,000-foot (4,900-meter) peaks to the coast, passing through rain forests, grasslands, and deserts. Parts of the road system were built by cultures that preceded the Inka Empire, but the Inka perfected the road network into an engineering marvel that supported transportation, communication, and trade. Inka engineers understood water flow, gravity, and wind erosion, and optimized the road design for human and animal foot traffic. It is estimated that 6% of the Inka road system is still visible, and the existing roads, which continue to be used and maintained by indigenous Andean communities today, are being studied to understand Inka engineering techniques and their application to contemporary projects.



A section of the Qhapaq Ñan meanders between agricultural fields and towns in Peru. Photograph by Doug McMains, NMAI, 2014.

A family walking along the Qhapaq Ñan in Jujuy, Argentina. Photograph by Alex E. Nielsen, 2007.

Since Inka times, the Qhapaq Ñan has been used by people and llamas. Photograph by Alex E. Nielsen, 2011.

III The Q'eswachaka Bridge

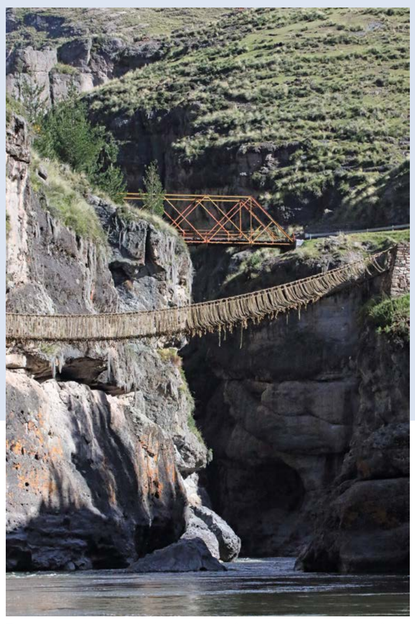
"The Q'eswachaka is the most sustainable bridge I know. It's completely renewable and made from local biodegradable materials that are washed away by the river every year… it treads very lightly on the Earth."

—Dr. John Ochsendorf
Professor of Engineering,
Massachusetts Institute of Technology.

Spanish explorers admired the variety of bridges along the Qhapaq Ñan. In particular, Europeans had never seen a suspension bridge and were amazed to find hundreds of them along the Inka Road system. Q'eswachaka, the last Inka grass suspension bridge, stretches across a gorge high above the Apurímac River in Peru and has been in continuous use for 500 years. The bridge is 100 feet (30 meters) long and is suspended 50 feet (15 meters) above the river. It is made of grass fibers, vines, and other organic materials. Every year, 1,000 villagers from four neighboring Quechua communities gather, twist, and braid by hand a native grass to make 10 miles (16 kilometers) of rope and then work communally over four days to rebuild the bridge. Asking permission of the *Apus* (sacred mountains) and making offerings to *Pachamama* (Mother Earth) are important activities that take place in concert with the rebuilding of the bridge. The community also holds a feast to celebrate the new bridge. Q'eswachaka is a key component of the Qhapaq Ñan and a masterpiece of Inka engineering. It also serves as an important example of sustainable engineering—a living expression of the knowledge, practice, and traditions that have been transmitted through generations of Quechua people in the Andes for the benefit of the community.

"We found bridges like nets over a very large and powerful river . . . which was a marvelous thing to see."

—Francisco Xérez
Assistant to Francisco Pizarro, 1534



The modern bridge seen in the background is used by cars to cross the river. Q'eswachaka in the foreground is used by local people. Photograph by Jeremy Cornejo Moscoso, 2015.

Drawing of Inka suspension bridge over the Pampas River in Ayacucho, Peru, 1877 by Ephraim George Squier (1821–1888). Peru: Incidents of Travel and Exploration in the Land of the Incas. Courtesy of the Smithsonian Libraries, Washington, D.C.

IV The Engineering of Q'eswachaka

Suspension bridges represent original and unique Inka engineering technologies. Q'eswachaka is an important example of sustainability from environmental and engineering perspectives.

Building Material: 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 grass, cotton, and llama and other camelid wool. So, it was natural for the Inka to find an engineering solution using a locally abundant grass fiber that could be woven to make rope. Individual grass fibers can break and tear easily, but twisting and braiding them yields a stronger and more flexible material. This is because strength increases with more elements to share the load, or the forces, acting on them.

Tension Forces: In suspension bridges, including Q'eswachaka, cables work through tension, or the stress resulting from a pulling force. However, if you pull a cable too much, it will break. The Inka understood this and used 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. The bridge builders also knew how much the cables could be stretched by 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!

In modern suspension bridges such as this bridge in Kobe, Japan (top, image #13120131, iStock by Getty Images), the roadway hangs from cables suspended from towers. The floor of Inka suspension bridges such as Q'eswachaka (bottom, photograph by Jeremy Cornejo Moscoso, 2014) is formed by the cables themselves.

V Be a Bridge Maker / Tension vs. Compression

Suspension bridges did not exist in Europe at the time of the Inka Empire; instead, Europeans built stone arch bridges. Suspension bridges can span longer distances, but European engineers did not build this type of bridge for another 300 years. In suspension bridges, tension forces are most important, while in arch bridges, compression forces are what matter. Tension forces pull and stretch material in opposite directions, allowing a rope 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 case of Q'eswachaka, the abutments are made from massive rocks where the bridge's main cables are tied.

STUDENT ACTIVITY:
Let's Experience Tension and Compression Forces!

Ask a partner to work with you to demonstrate Force 1 and Force 2 as shown in the illustrations to the right. As you work with your partner, can you feel which way the forces are directed? Based on the definitions given earlier, which force is tension and which is compression?

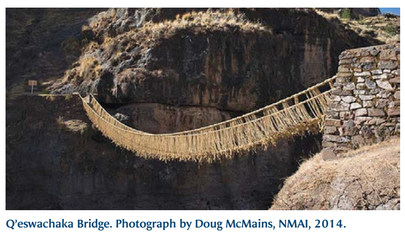
Force 1

Force 2

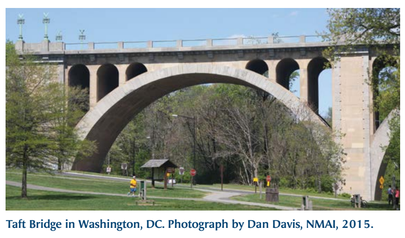
Look at the bridge images on the right. Can you match Force 1 and Force 2 with each bridge type? Which bridge acts primarily on compression forces? Which bridge acts primarily on tension forces? Explain why and justify your choices.

Now think about how it felt to experience these forces. When pulling apart from your partner, what shape did your bodies resemble? How about when pushing against your partner's hands?

Notice that when pulling apart from your partner, your bodies form a suspended curve much like the Q'eswachaka bridge, and when pushing toward each other, your bodies form an arch much like the Taft Bridge.



Q'eswachaka Bridge. Photograph by Doug McMains, NMAI, 2014.



Taft Bridge in Washington, DC. Photograph by Dan Davis, NMAI, 2015.

STUDENT ACTIVITY:
Build a Suspension Bridge

What kind of bridge would you build with the following materials?

- 1 rectangular piece of cardboard about 4 feet (1.2 meters) long by 1 foot (0.3 meter) wide
- 2 chairs

For example, you can place the two chairs facing each other and span the cardboard between the seats. This is called a beam, or plank, bridge. This type of bridge is not very strong. Test it out by placing a heavy load (a stack of books) on it, and see how many it can hold before it collapses (Fig. 1). What forces are primarily at play in this type of bridge, compression or tension?

To make the plank bridge stronger, modify it so that it becomes a suspension bridge. Include the following materials:

- 2 pieces of rope, each about 9 feet (2.75 meters) long
- 12 pieces of string, each about 2 feet (0.6 meters) long

Stretch the ropes above the cardboard, over the backs of the chairs, and have two friends pull them tight by sitting on the floor behind each of the chairs (Fig. 2).

Tie the tops of 6 pieces of string to one of the ropes, at equally spaced intervals between the two chairs. Do the same with the other lengths of string, but on the other rope. Secure the loose ends of the strings with duct tape onto the cardboard below (Fig. 3).

Now you have a suspension bridge. Ask your friends to pull on the ropes behind each of the chairs as you start placing books on top of the bridge. Experiment with the pulling force and with various loads to test the strength of your bridge.

What forces are primarily at play in this type of bridge, compression or tension? Where are the forces felt as you add more books? How is this bridge similar and how is it different from Q'eswachaka?

Fig. 1

Fig. 2

Fig. 3

VI Meet a *Chakacamayuc*

"Of course we teach our children and youth everything we do and what our bridge means to us. I ask them to continue with our tradition, and not to let any of this go away."

—Victoriano Arizapana Huallhua,
Chakacamayuc (Bridge Master), 2015

Victoriano Arizapana Huallhua—Chakacamayuc (chah kah kah MAH yook), a Quechua word meaning "bridge master"—is a 51-year-old member of the community of Huinchiri in Peru. Don Victoriano, as he likes to be called, is a Quechua descendant of the Inka. His people's culture is vibrant and strong, and has evolved and adapted for the past 500 years, since the time of the Inka Empire. Language, tradition, and a deep connection with the surrounding natural landscape continue to shape their worldview. Don Victoriano organizes four nearby communities to participate in the annual renewal of the Q'eswachaka grass bridge. He directs and supervises all aspects of the bridge-building process and plans the culminating feast. Don Victoriano inherited the responsibility for the maintenance and annual renewal of the bridge from his father and his grandfather. Now Don Victoriano is passing this knowledge on to his son. Q'eswachaka is thus an important example of cultural continuity.

The Chakacamayuc (Bridge Master) depicted here, fulfilled a role during Inka times quite similar to the responsibilities of Don Victoriano today. Drawing from The First New Chronicle and Good Government, 1615 by Felipe Guamán Poma de Ayala (Quechua, ca. AD 1535–1616). The Royal Library, Copenhagen (GKS 2232 4°).

Don Victoriano Shares a Story of Q'eswachaka

How Q'eswachaka Punished the Spanish Invaders

"This is a story that my grandfather told me when I was a child. Our bridge is over 500 years old and at that time the Spaniards had arrived in these lands and were chasing and killing our Inka ancestors. Then, our clever Inka ancestors got organized to counter and hold back the Spanish conquerors. My ancestors ran across Q'eswachaka with the Spaniards in close pursuit. When the Spaniards were crossing the bridge, our ancestors cut the ropes and the bridge fell into the river far below, punishing and killing many of them. This is, in effect, what my ancestors did and this is how they saved themselves using our bridge. After a while, they rebuilt the bridge."

Chacacamayuc Victoriano Arizapana Huallhua. Photograph by Jeremy Cornejo Moscoso, 2015.

"Q'eswachaka inkanchispa wayrampas animunpas kanman hinaya noqaykupaq kay chakayku."

"Q'eswachaka is the soul and spirit of our Inka ancestors, touching and caressing us like the wind."

—Victoriano Arizapana Huallhua, Chakacamayuc (Bridge Master), 2015