Title: Bridge the Gap

Description: What mathematics is involved in building different structures? Student civil engineers learn how to use geometry and physics to design, build, and test bridges.

At a Glance
Grade Level: 6-9
Subject sort (for website index): Mathematics
Subject(s): Geometry, Civil Engineering, and Physics
Topics: Properties of shapes; Triangulation; Structural Analysis, Scale Factor
Higher-Order Thinking Skills: Cause and Effect, Problem Solving
Key Learnings: Properties of Polygons, Triangle Inequality, Triangulation and Structural Stability of Designs
Time Needed: 3-4 weeks, 45-minute lessons

Unit Summary

Student groups of civil engineering firms design and construct a bridge that will hold the most weight for a given span. In preparation for their project, students build different structures; investigate properties of triangles and rectangles; take a virtual bridge field trip to learn about various types of bridges and examine famous bridges from around the world; and conduct several design and strength tests.

Curriculum-Framing Questions

Essential Question

How can math help me understand my world?

Unit Questions

Why is geometry important to building structures?
How can geometry help us build a better world?
What factors influence bridge strength?

Content Questions

What is triangulation in geometry?
How do side lengths determine the shape of a triangle and a quadrilateral?
What are the basic bridge types?

Assessment Processes

View how a variety of student-centered assessments are used in the Bridge the Gap Unit Plan. These assessments help students and teachers set goals; monitor student progress; provide feedback; assess thinking, processes, performances, products; and reflect on learning throughout the learning cycle.

Instructional Procedures

Prior to Instruction:

This unit of study makes use of the *Seeing Reason* and *Visual Ranking Tools*. Examine both the *Seeing Reason* and *Visual Ranking Tools* prior to planning instruction to learn about them and how to use them with students.

Set the Stage (1 day)

Begin the lesson by asking students the Essential Question: *How can math help me understand my world?* Break students into small groups and have them discuss the Essential Question and record their initial thoughts. Tell the students that they are going to begin a unit about bridges in which they will explore how math, specifically geometry, is an important part of designing and building bridges and structures.

Use the following spaghetti tower task to set the stage for the unit. The objective in setting the stage is to recreate some of the challenges bridge builders face and to introduce the bridge-building unit. Introduce the unit by asking students to complete the following task in small teams:

- Design and build a tower structure using uncooked spaghetti that will support a can that sits 30 cm (about 1 ft) above the floor or the desktop.
  - The base of the structure should be no wider than the diameter of the can.
  - The spaghetti can be cut into any length.
  - The spaghetti can be taped at the top and bottom only.
  - The can must be positioned with the open end facing up so weights can be added to it.
  - The structure must support the most weight possible.
- Have students record the number of noodles used, the number of taped joints, and the maximum weight the structure can support before collapsing.
- Have students stop adding weights when it starts to wobble.
- On a separate sheet of paper, direct students to sketch the design and point out its strengths and weaknesses. Have students identify various geometric shapes in their towers. When done, have students compare their design with others in the class and write down two things they would do to improve their structure.

Materials needed per team:

- 75 uncooked spaghetti noodles
- Masking tape
- Can
- Rocks/marbles/other weights

Have groups discuss their towers describing what worked and what didn't. As a class, discuss the following Unit Question: *Why is geometry important in building structures? What did you learn by doing this activity?*

Explore Properties of Polygons (2 days)

In preparation for the following activities, ask students to think about the questions they discussed after the previous activity: *Why is geometry important in building structures? What did you learn by doing this activity?* If they haven't discussed it already, lead students to the fact that certain polygons in geometry are stronger than others. Tell them that they will be exploring properties of polygons during the next few days.

Ask students the following Content Questions: *What is triangulation? How do side lengths determine the shape of a triangle? Or a quadrilateral?* Elicit student ideas about these questions. Tell them that they will explore these questions during today's and tomorrow's lessons. Students will spend one lesson on triangles and one on quadrilaterals to explore the ways that side length determines the shape of polygons.

Triangles Lesson: Students investigate the questions: Suppose you are given three numbers to be lengths of sides of a triangle. *Will it always be possible to make a triangle with those side lengths? Can you make two or more different triangles from the same side length?* Have students use straws and string to explore various combinations of side lengths. They can roll three dice to determine the lengths to use in the triangle. They should sketch and label their results.
Materials needed per team:

- A variety of straws cut into lengths of: 1,2,3,4,5,6 inches
- 3 dice per group
- String
- Scissors

When they have completed the problem, have them look back over their examples and use the straws to explore: *What combinations of side lengths create triangles that you often see in designs and buildings?*

Return to the Content Question posed at the beginning of the lesson and ask students if they have new insights into the questions: *Do side lengths determine the shape of a triangle? What is triangulation?*

Quadrilaterals Lesson: Begin the lesson reminding students of yesterday's lesson, telling them that today they will investigate the Content Question: *Do side lengths determine the shape of a quadrilateral?* Ask students to make conjectures. Students use this lesson to investigate the problem: Suppose you are given four numbers to be lengths of sides of a quadrilateral. *Will it always be possible to make a quadrilateral with those side lengths? Can you make two or more different quadrilaterals from the same side length?* Have students use straws and string to explore various combinations using four dice and sketch and label their results. Have them compare their results to the triangle lesson yesterday. Ask, *How are the results similar and different?*
Materials needed per team:

- A variety of straws cut into lengths of: 1,2,3,4,5,6 inches
- 4 dice per group
- String
- Scissors

When they have completed the problem, have them look back over their examples and use the straws to explore: *What combinations of side lengths create quadrilaterals like those you often see in designs and buildings? How does this compare to what you noticed about triangles yesterday?*

Structures Scavenger Hunt (2 days)
Groups of students go on a scavenger hunt of various structures and use presentation software to teach the class about their findings. Go over Structures Scavenger Hunt handout and discuss the details of the assignment. In brief, groups of students search several pre-determined Web sites that show various building structures and bridges. Each of the eight groups are given different topics: beam and truss bridges, suspension bridges, arch bridges, cantilever bridges, skyscrapers, airports, their school, and stadiums. Research on the structures needs to include:

- its definition
- its characteristics
- the types of polygons used
- combinations of side lengths and structural strengths and weaknesses
- how geometry is part of that structure in the world

This helps students answer the Essential and Unit Questions, *How can geometry help us build a better world*? as well as *How can math help me understand my world?*

Students create a slideshow and teach the rest of the class about their structure. Use this sample student presentation to demonstrate the above elements. Students need to include definitions and visual images of new terms and ideas they encounter on the scavenger hunt such as*:* truss system, lateral stabilization, and degree of arch curve (these will emerge in various Web sites as they examine the characteristics of the different structures).

Have students take notes during each group's presentation so that they can use the new information in their upcoming bridge experiments. Keep a chart paper of new terms and definitions that emerge from students presentations as a public document for all students to use over the course of the unit. If some important terms and ideas do not emerge from the presentations, introduce them as they relate to the student presentations. This will help prepare students in developing their *Seeing Reason* causal map.

Simple Bridge Experiments (2 days)
In order to investigate the Content Question: *What are some factors that influence bridge strength?,* students use spaghetti to design and test beam and arch bridges to determine which of the two structures holds the most weight.

Testing Beam and Arch Bridges
In brief, students use bricks and cardboard to build a beam and arch bridge and determine which of the two structural designs holds the most weight.
Each group will need:

- 2-4 bricks
- Cardboard
- Weights
- Lab procedures handout

Redesigning the Spaghetti Tower
Have students design and build a tower structure using uncooked spaghetti that supports a can that sits 30 cm (about 1 ft) above the floor or the desktop. This task requires students to use what they have learned so far about triangulation and structure strength. It gives them a chance to go back and redesign the tower they built on the first day of the unit and to try out and test new ideas about structural design and strength. Students should use the following specifications to redesign their tower:

- The base of the structure should be no wider than the diameter of the can.
- The spaghetti can be cut into any length.
- The spaghetti can be taped at the top and bottom only.
- The can must be positioned with the open end facing up so weights can be added to it.
- The structure must support the most weight possible.

Have students record the number of noodles used, the number of taped joints, and the maximum weight the structure can support before collapsing.

- Have them stop adding weights when it starts to wobble.
- On a separate sheet of paper, direct students to sketch the design and point out its strengths and weaknesses. Ask students to compare their new designs with their initial designs and write about the improvements they made.
- When done, have students compare their design with others in the class and write down two things they would do to improve their structure. Ask them to reflect on the following questions:
    - *Why is it important to redesign?*
    - *How can past designs improve future designs?*

Materials needed per team:

- 75 uncooked spaghetti noodles
- Masking tape
- Can
- Rocks/marbles/other weights

Discuss as a class the characteristics of strong and weak towers. Have students identify and discuss what they know about shapes and relate how those shapes have affected the towers they built.

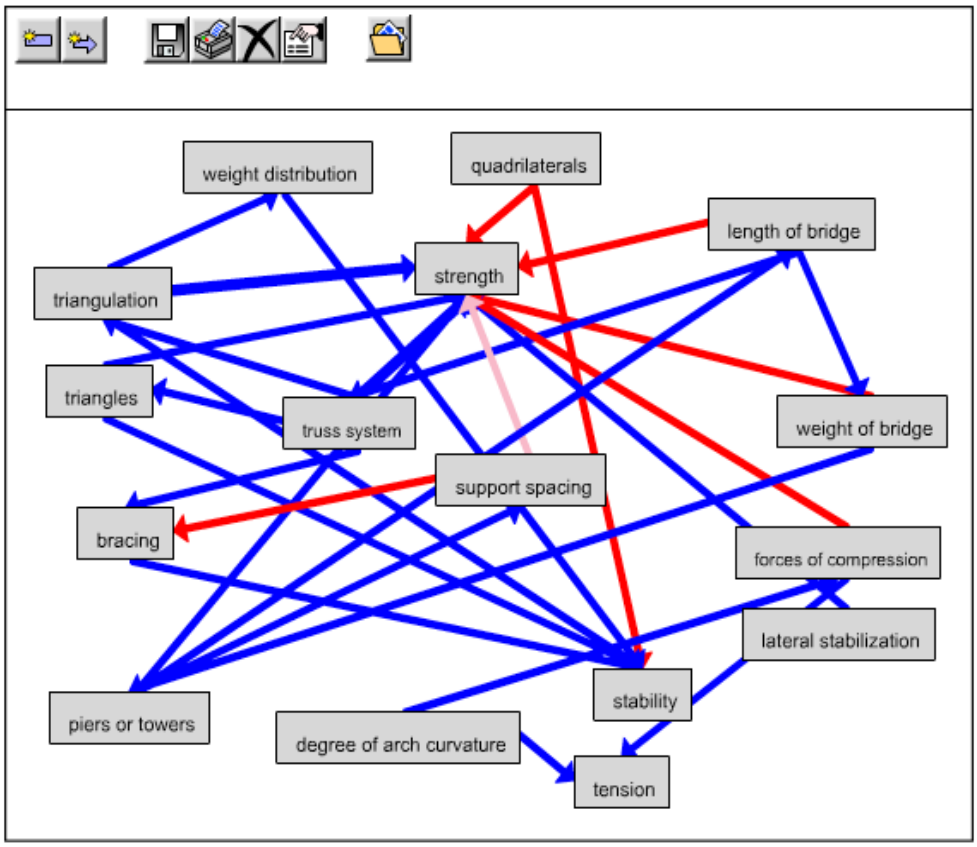
Use Seeing Reason to Study Factors that Influence Bridge Strength (2 days)
In the next phase of instruction, use the *Seeing Reason Tool* with the class to identify factors that influence bridge strength. Before having the students use the online tool themselves, follow these steps for introducing *Seeing Reason* to your class.

Place students in grou[s and ask them to use *Seeing Reason* to respond to the Unit Question: *What factors influence bridge strength?* Students need to include data from previous work in this unit to support relationships and factors such as those shown in the following map. Encourage them to use the description feature of the tool to explain their thinking and the relationship

between factors. This activity serves as a midpoint unit performance assessment, whereby readiness for the bridge building task can be determined. Use the midpoint scoring guide to determine students' readiness.

Examine the Seeing Reason Activity
The *Seeing Reason* space below represents one team's investigation in this project. The map you see is functional. You can roll over the arrows to read the relationships between factors, and double-click on the factors and arrows to read the team's descriptions.

Project Title: Bridges
Prompt: What factors influence bridge strength?



*If students need more experiences, ask students to look back over their notes and work on the previous lessons: polygons activities, structures scavenger hunt, and bridge experiments to look for relationships between bridge design and strength. Discuss the characteristics of strong and weak bridges. Ask them to re-evaluate their maps and adjust factors, relationships, and descriptions to fit anything new they have learned.

Bridge Building Task
Provide the following scenario to the students:
Your civil engineering firm has been hired to design and build a model of a bridge to replace the old bridge in your city. Your task is to design the bridge, build a model, and create a portfolio to present before the town council for approval. As a first task, each team needs to decide on your civil engineering firm's name.

Your model will be tested for strength and must meet the following specifications:

1. *You can only use spaghetti noodles and masking tape to build your bridge*
2. *The bridge must have a span of at least 30cm long*
3. *A roadbed of at least 5 cm wide and a clearance of at least 10 cm in height*
4. *The distance between the bridge supports should be at least 10 cm apart, unless the bridge has only one tower or support structure*

In addition to presenting your model, your portfolio to the town council needs to provide clear and convincing evidence for your choice of design, blueprints of your model bridge, and other supporting documentation such as: concept webs, graphs, charts, and photos.

Distribute the presentation scoring guide to the students to help them understand the expectations for the project. Review and answer any questions they might have. Ask students to refer to the scoring guide as they work on the project.

Prepare to Rank Bridge Design Factors

Before proceeding with the next activity, build a project in the *Visual Ranking* Teacher Workspace.

- Set up a project called: Designing Bridges
- Add each engineering firm to the project
- Describe the project and include this prompt: *What is the most important factor in designing your bridge?*
- Hold a discussion with the class as to what they think the most important factors are in building a bridge. Possible factors might include: length of bridge, weight of bridge, amount of beams, truss system, types of shapes used, stability, or triangulation.
- Populate the list with the most common 8-10 factors established by the class.

Use Visual Ranking to Rank the Most Important Factors in Designing Your Bridge (1 day)

Introduce the *Visual Ranking Tool* using the demonstration space at Try the Tool. Show students how to rank and compare lists, and how to describe items and explain their relative merit using the comments feature. Point out the meaning of the correlation coefficient (the degree to which rankings agree or disagree). A coefficient of 1.0 is perfect agreement, and a coefficient of –1.0 is a perfect disagreement.

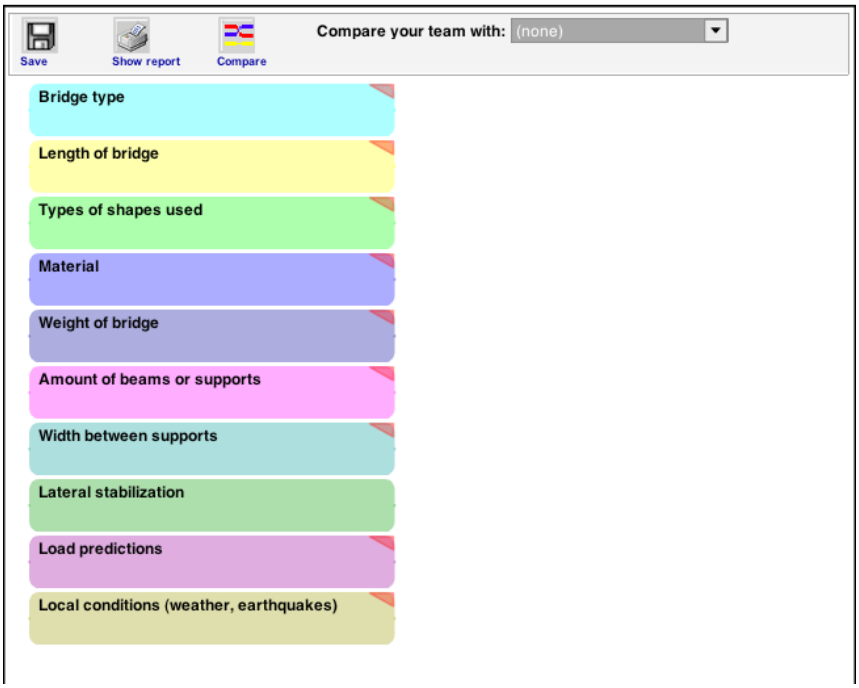
- Have students log in to their *Visual Ranking* team space. Point out the prompt that guides their ranking: *What is the most important factor in designing your bridge?* Have each civil engineering firm rank the items with this in mind, and explain the relative merit of each item using the comments feature of the tool. As students sort their lists, listen to their discussions and ask questions to help groups negotiate, make choices, and express their thinking.

- Once the groups have finished ranking and commenting, have them compare their lists with the lists that were ranked by the other firms. They should read each other's comments about the relative merit of each factor. Have students discuss why their lists are alike and different. Suggest that they identify the firms that ranked items most and least like they did. Have similar and dissimilar firms meet to discuss their rankings and rationale behind the order. Some firms may want to revise their thinking based on the things they learn from other firms.

Examine the Visual Ranking Activity

The *Visual Ranking* space below represents one team's ranking on this project. The view you see is functional. You can roll over the red triangle to see the firm's comments and click the compare button to see how different firms ranked the items.

Project Title: Designing Bridges
Prompt: What is the most important factor in designing your bridge?



Inform and Persuade Others
Once firms are finished ranking and discussing, have the firms reflect on the process by answering some of the following questions:

1. *What was it like defending your group's point of view? Was it difficult? Why?*
2. *What was the biggest obstacle to settling on a compromise within your firm? What obstacles do civil engineering firms in general face when they are trying to get things done?*
3. *What are other similar situations where there are different groups with competing interests?*

Meet again as a large group and discuss these same questions. Using a projector system and networked computer display the lists and discuss general themes that appear. Ask students to consider: *Is any factor consistently in the top of the ranking? At the bottom of the ranking? What about those factors relate to design decisions in building a model bridge?*

Ask students to reflect in their journals about the most and least important features to consider when building a bridge. Read the entries to assess for understanding before moving on to the design phase of the project.

Decide on Bridge Type, Design, and Create a Blueprint (1-2 days)
Have students draw the side, top, and end view of the bridge they have chosen along with the support structure according to specifications. Be sure to have them include measurements and scale factor on their drawing. Make sure they keep track of the number of noodles they will use, the length of the noodles needed, and the amount of taped joints. This will serve as their firm's blueprint to use in constructing the model. Review the blueprints and offer suggestions as needed.

Bridge Building (5-6 days)
Give students five or more days to build their bridge models during class. The time allotment will vary by the type of bridge they are building. As students build their bridges, circulate through the

teams asking questions and taking notes about group processes, conceptual understanding, and thinking skills such as problem solving and analysis.

Final Presentation to the Town Council (1-2 days)
Use the presentation scoring guide to assess the final presentation, blueprints, and portfolio. As a part of each firm's presentation, they will test the maximum weight the structure can support before collapsing. The students will test the strength of the bridge by placing a can on top of the bridge (in the middle) and adding weights until it starts to wobble.

Summarize the unit work by asking students to respond in writing to the Essential and Unit Questions, *How can math help me understand my world?*, *How can geometry help us build a better world?, and Why is geometry important to building structures?* Remind students to use this opportunity to showcase what they have learned about structures and strength as they answer the questions.

Credits
A teacher participated in the Intel® Teach to the Future program, which resulted in this idea for a classroom project. A team of teachers expanded the plan into the example you see here.

Prerequisite Skills
- Measuring
- Drawing scale models
- Familiarity with multimedia presentation software

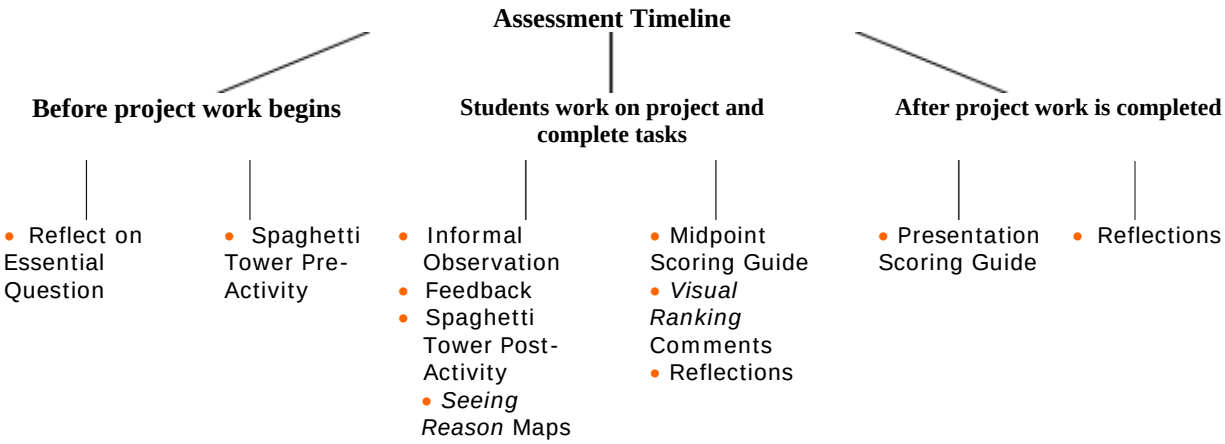
Differentiated Instruction
Resource Student
- Make modifications as dictated in the student's IEP
- Provide visual aids and examples (documents, photos, and examples from this Unit Plan can be helpful)
- Supply an outline of the tasks and timeline for the project (including milestones)
- Select group best suited to work with this student
- Provide extra time as needed to complete individual assignments

Gifted Student
- Have students keep a budget of the firm's bridge expenses, acting as the accountant for the firm; researching materials costs; deciding upon what lumber (noodles) cost per foot, what braces (masking taped joints) cost, how much material was used and the amount of waste; using a spreadsheet keep a running record of expenses incurred and an estimated beginning budget.

English Language Learner
- Provide visual aids and examples (documents, photos, and examples from this Unit Plan can be helpful)
- Use example structures from student's native culture in an effort to link the unit to student's prior knowledge and experiences
- Utilize the geometric shapes in creating tables (use images of triangles with side lengths labeled on charts to represent combinations that do and do not make triangles)

Things you Need Highlight Box

Assessment Plan



Use both informal and formal methods for checking student understanding. Informal: Monitor and listen carefully to student thinking, ask probing questions such as *How do you know that works?,* review drafts, and give students feedback as they work through project activities. Have students check work with their firm members. Formal: Assess students' understanding and readiness for the bridge building project by using the midpoint scoring guide and re-teach ideas if necessary. Provide the presentation scoring guide to students and explain the expectations before they start working. Assess students' final portfolio presentation, which includes the model bridge using the presentation scoring guide. Ask students to reflect on their learning by answering the Essential and Unit Questions.

Targeted Content Standards and Benchmarks

NCTM Content Standards:

Geometry Standard for Grades 6-8

In grades 6-8 all students should:

- Precisely describe, classify, and understand relationships among types of two- and three-dimensional objects using their defining properties
- Understand relationships among the angles, side lengths, perimeter, areas and volumes of similar objects
- Draw geometric objects with specified properties, such as side lengths or angle measures
- Use two-dimensional representations of three-dimensional objects to visualize and solve problems such as those involving surface area and volume
- Use geometric models to represent and explain numerical and algebraic relationships;
- Recognize and apply geometric ideas and relationships in areas outside the mathematics classroom, such as art, science, and everyday life

Problem-Solving Standard for Grades 6-8

In grades 6-8 instructional programs should enable all students to:

- Solve problems that arise in mathematics and in other contexts
- Build new mathematical knowledge through problem solving
- Apply and adapt a variety of appropriate strategies to solve problems

- Monitor and reflect on the process of mathematical problem solving

Connections Standard for Grades 6-8

In grades 6-8 instructional programs should enable all students to:

- Recognize and use connections among mathematical ideas
- Understand how mathematical ideas interconnect and build on one another to produce a coherent whole
- Recognize and apply mathematics in contexts outside of mathematics

Student Objectives

Students will be able to:

- Learn about triangulation
- Understand that side lengths determine the exact shape of a triangle (Side-Side-Side Congruence Theorem), as long as the sum of the lengths of any pair of sides is longer than the length of the third side (this is known as the triangle inequality: $a+b>c$ in order for it to make a triangle
- Understand that for quadrilaterals, side lengths can be arranged in a variety of shapes.
- Understand that the sum of the lengths of any three sides of a quadrilateral is greater than the length of the fourth side
- Understand that the triangle is a stable figure and keep their shape under stress, whereas quadrilaterals can wobble into many unstable shapes and become distorted under stress
- Examine the strengths and weaknesses of structures
- Create procedures for constructing and testing components of a structure
- Compare the strengths of different components of a structure
- Learn about bridge types and their structural design
- Provide arguments related to principles and to evidence for ideas and choices expressed
- Use measurement and scale factor to draw accurate scale models

Materials and Resources

Printed Materials

- Books or magazines on structures and bridges (optional)

Supplies

- Spaghetti noodles
- Masking tape
- Cans for each group (about 4” or 10 cm in diameter and 5” or 12 cm in height)
- Weights of some kind for each group such as: marbles, rocks, or fishing weights
- Straws
- String
- Rulers

Internet Resources

- Bridge from *Fact Monster*

http://www.factmonster.com/ce6/sci/A0808901.html*
This introductory site provides some basic information about bridges.

- Basic Bridge Types from *Matsuo Bridge*

http://www.matsuo-bridge.co.jp/english/bridges/index.shtm*
This site has lots of introductory information about different bridge types.

- Bridge Basics: A Spotter's Guide to Bridge Design

http://pghbridges.com/basics.htm*

- Bridge Building Information from Brantacan

www.brantacan.co.uk/bridges.htm*

- Geometry of Bridge Construction

www.faculty.fairfield.edu/jmac/rs/bridges.htm*

- Bridge Pros

http://bridgepros.com/*
This comprehensive bridge-site is dedicated to the engineering, history and construction of bridges. *Not-To-Be-Missed Section:* Bridge Projects from around the world past, current and future. http://bridgepros.com/projects/index.html*

- Super Bridge from *PBS NOVA Online*

www.pbs.org/wgbh/nova/bridge/*
Learn about the four major types of bridges and then test your knowledge by matching the right bridge to the right location.

- Building Big: All About Bridges from a *Related PBS Website:*
  www.pbs.org/wgbh/buildingbig/bridge/index.html*

This site includes a Forces Lab in which students can explore forces, loads, materials and shapes.

- Building A Virtual Bridge**.** Use your skill and judgment to decide which bridge best fits each location at

(1) *Bridge Building*
www.brad.ac.uk/acad/civeng/marketing/civeng/game2.htm*
Read the clues and follow the basic steps of a preliminary feasibility study to build the right bridge. Another virtual bridge building activity can be found at
(2) *Bridge Builder*
www.pbs.org/teachersource/mathline/concepts/architecture/activity3.shtm*
from *PBS's TeacherSource*.

- Design and Build a Virtual Bridge Truss

www.jhu.edu/~virtlab/bridge/truss.htm*
Use the program at ***Bridge Designer*** to design trusses. Once a truss is drawn in the program, a click on "Calculate" will check your design. Another click will generate a complete force diagram showing compression/tension forces in each of the members and reactive forces at the support nodes.

- Spaghetti Bridges: 11th Annual Spaghetti Bridge Contest

http://www.jhu.edu/news_info/news/audio-video/spaghetti.html*
Pictures of spaghetti bridges from John Hopkins University

Other Resources

- List kits
- Equipment
- Film
- Video
- CD-ROM or DVD resources
- Field trip sites
- Experts

Technology – Hardware

- Computer for creating presentations
- Printer for handouts
- Projector for presenting and *Visual Ranking* activity
- Internet connectivity for research and using the thinking tools

Technology – Software

- Presentation software for creating presentations
- Word processing software for writing reflections
- Internet Browser for research