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Building Model Bridges Following the Engineering Process

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"Building Model Bridges Following the Engineering Process" is a curriculum unit designed to be used with students in grades 5 through 8. I am a Magnet School Facilitator at East Rock Global Magnet School where I run an after school program called CPEP. The acronym CPEP stands for the Connecticut Pre-Engineering Program. CPEP is designed to introduce students to the field of engineering and to motivate them to pursue majors in math and science when they enter college. During the second weekend of May, the students participate in CPEP Day where they enter one or more engineering contest ranging from bridge building to designing the fastest solar cars and boats. Since bridge building is one of the major contests during CPEP Day, I decided to write this unit in order to prepare my students for the competition. In addition to introducing students to the principles of engineering and different types of bridges, this unit will also prepare teachers to sponsor a bridge building exercise in their classrooms or schools.

Upon completion of this unit, the students will be able to: (1) identify the engineering principles behind bridge building; (2) identify different types of bridges; (3) become aware of a process outlining how bridges are designed and built; (4) understand some of the physics important for designing, building and using bridges (5) understand some of the preliminary events that takes place before construction, and finally (6) draw and build a bridge according to specification using the principles of engineering.

The curriculum unit will be divided into three major sections. The first section will introduce students to the three major types of bridges- the beam bridge, the arch bridge and the suspension bridge. Even though most bridges combine attributes from more than one bridge design, all have as their most basic element one of these three bridge types.

The second section of the unit will discuss the engineering process in bridge design. The engineering process can be broken down into eight simple steps: (1) identifying the problem; (2) determining the constraints; (3) designing the bridge; (4) analyzing the design; (5) refining the design; (6) implementing the plan; (7) modifying the plan of implementation, and; (8) building the bridge based on modifications. The data that engineers need in order to design the bridge will also be covered in this section.

The third section of the unit will introduce teachers to one type of bridge building contests. The wooden coffee stirrer bridge contest presented in this unit can easily be adapted to using other materials such as popsicle sticks, straws, balsa wood or any other desired materials. I will cover the design constraints and specifications for each contest presented in this section. The materials that each group of students will use to complete the bridge, along with some helpful hints to complete the projects will be included in this section. Finally, an evaluation tool, or judging criteria will be presented to the instructor in order to determine if each group completed the assigned task and to assess their achievements in learning.

Introduction to the Different Types of Bridges

Even though bridges have different styles and designs, they all are constructed to support their own weight (dead weight) and the weight of the traffic that must go across them. Bridge designers or civil engineers must also consider other factors such as the weather, strong winds and earthquakes when designing bridges. There are several elements that all bridges have in common. All bridges consist of piers that hold up the center of the bridge and abutments that support the end of the bridge. The distance between the two supports is identified as the span. Each support is a foundation that transfers forces into the substrata of the earth. Civil engineers decide which type of bridge to build based on the weight or load that the bridge must support, the distance the bridge has to span, and the forces of nature that the bridge will have to endure. According to which source that you read, there are three or four different types of bridges, the beam bridge, suspension bridge, arch bridge and the truss bridge. Some sources categorize the truss bridge as a type of beam bridge. For the purposes of this paper, we classify the truss bridge as a type of beam bridge. Therefore, the major difference between the three types of bridges is the distance that they can cover in a single span. For example, a beam bridge can span up to 200 feet, if trusses are added it can span as far as 1200 feet. The arch bridge can span up to 1800 feet, whereas a suspension bridge can span up to 7,000 feet. Each of the different types of bridges holds weight in different ways.

Beam Bridges

A beam bridge is basically a rigid horizontal structure that rest on two piers, one located at each end of the bridge. A simple beam bridge is flat across and supported by two ends or abutments. The beam bridges can be made longer by placing piers or towers in the middle of the bridge to support the beam structure and extending the support into the solid substrata below the surface.

Another way engineers make the beam bridge longer or have more span and accommodate more weight is to allow the deck to set upon a truss system. A truss system is composed of triangles and can support heavy loads with its relatively small weight. The beam must be strong enough so that it doesn't bend under its own weight and the added weight of the traffic crossing it. When the load pushes down on the beam the top edge is pushed together or compressed, while the bottom of the beam is stretched or is under tension. The force of compression on the upper side of the beam causes it to shorten because of the load pushing the beam inward. The result of the compression on the on the topside of the beam causes tension in the lower part of the beam. Tension causes the lower part of the beam to lengthen. The middle of the beam bridge experiences very little tension and compression.

There are several different types of beam bridges. One type of beam bridge is the truss bridge. A truss bridge is a series of connected triangles that distribute the weight or load to each member of the truss. It consists of a top chord, bottom chord and web members. The truss bridge is lightweight, but very strong due to the open triangular members along its sides. Two special features about the truss bridge are that the members that make up the triangles or diagonals do not bend. Secondly, a truss bridge is more efficient because the individual members carry axial load and minimize any bending. Therefore it requires less material than a simple beam bridge. The members get pulled apart during tension and pushed together during compression. While the simple beam bridge consists of a solid web member to carry the load, the truss has a top chord that is in compression and the bottom chord typically in tension. The other members of the truss are in different stages of tension and compression. As heavy loads travel across the bridge it may deflect vertically in the middle due to the individual members of the truss reacting to the forces of compression and tension.

There are many different types of truss. The design, location and composition of the truss determine the type. For example, the Warren Truss, Pratt Truss and Howe Truss differ based on the arrangement of the triangles. Their identifying names are attributed to the engineers who invented each of these particular arrangements.

The cantilever bridge is another type of beam bridge. This kind of bridge is supported on two levers that are continuous over piers. A simple cantilever bridge consists of two cantilever sections with abutments on each side to act as counterweights. The downward force at the center of the cantilevered end of the bridge is counteracted by the weight of the continuous adjacent span anchored at the far end. The opposite ends called arms reaches out and meet in the center. There is also a pier that supports each cantilever arm. The cantilever bridge can be made even longer by adding an additional simply supported section to the middle of a cantilever bridge.

Arch Bridges

An arch bridge is composed of a curved structure with abutments on each end. Instead of the weight pushing straight downward like on the beam bridge, the weight is carried outward along the curve of the arch to the abutments at each end of the arch. The abutments also keep the end of the bridge from spreading outward. Therefore, the arch bridge is always under compression because the weight of the deck is pushed outward along the curve of the arch towards the abutments. The rise in the form of the curved arch causes the vertical load to have a horizontal thrust. The amount of tension placed on the arch is determined by the degree of curvature of the arch. The greater the degree of curvature of the arch, the greater the amount of tension on the bottom if the arch itself. There are three basic types of arches, the false arch, the ribbed arch and the true arch. A true arch is made up of wedged shaped bricks called voissoirs that are fitted together between vertical supports. True arches are built in from the end, towards the middle. The final wedge called the keystone is set in place at the top of the arch. Sidewalls called spandrels are built up between the arches and filled with rubble. Ribbed arches are actually several rows of arches built next to each other. Long, flat stones are laid across the ribs for support. This technique reduces the weight of the arch and cuts construction time and the amount of materials used. The false arch resembles the corbelling of bricks in order to span an opening. The composite form and behavior resembles the arch but it needs heavy vertical loads to secure its shape and structure.

Suspension Bridges

A suspension bridge is composed of a deck that is attached to or suspended from cables. Just like the name states, the suspended bridge literally suspends the roadbed from huge cables, which extend form one end of the bridge to the other. The cables are attached to two tall towers and are secured at each end by anchorages. The tower allows the cables to be draped over very long distances. The cable carries the weight on a suspended bridge to the anchorages that are imbedded in solid rock or massive concrete blocks. The cables are spread over a large area in order to evenly distribute the load inside the anchorages to prevent the cables from breaking free.

In the suspension bridge each cable supporting a segment of the roadbed is vertically suspended from the primary drapped cable spanning between main pylon towers. The forces from permanent and moving loads push down onto the roadbed placing it in compression. The cables through tension, then transfer the forces to the towers, which carries the forces, through compression, directly into the earth where they are firmly imbedded. The tension cables running between the two anchorages support the forces. The cables stretch from the weight of the bridge and the traffic that travels from anchor to anchor. In addition to the cables, the anchorages are also under the forces of tension. Because they are firmly imbedded into the earth like the towers, the amount of tension exerted on them is resisted by the counter forces of the dead load. Most suspension bridges also have a supporting truss system underneath the bridge deck to help stiffen the roadbed and to provide a lateral stabilization of the roadbed. This extra support system resists wind and lateral forces and reduces the tendency of the roadbed to ripple and sway.

Suspension bridges come in two different types of designs; the elongated "M" shape and the "A" shaped design called a cable-stayed bridge. The two designs support the load of the roadbed in very different ways. The differences lie in the way the cables are connected to the towers. The cable-stayed bridge attaches all cables that support the roadbed to the tower and they alone carry the weight of the roadbed and the traffic. The series of cables are attached to the roadbed in two basic ways, using a running parallel pattern or a radial pattern. In the parallel pattern, the cables are parallel to one another and attached at different heights along the tower. Each cable carries a segment of the roadbed. In the radial pattern, each cable carries its section of the roadbed and they are attached to the tower at a single point. In the cable stay bridge, all segments of the roadbed must carry a horizontal compressive force to counter balance the equal force from the other side.

Other Forces That Act on Bridges

During the discussion in the previous sections concerning the different types of bridges, I only mentioned compression and tension forces that acton bridges. However, there are other forces caused by dynamic movements, resonance and nature that must be considered in the design and construction of bridges. Torsional resistance is rotational or twisting forces that act on all bridges at times when lateral or unbalanced loads are applied some bridges. It is a major factor on the larger suspension bridges. However, the roadbed tends to be thinner in the section hanging from the cables. This section is very susceptible to torsion during high winds due to unequal wind pressure. Most suspension bridges have a supporting trusses system on the deck to eliminate the effects of torsion. But suspension bridges with extremely long spans need more than just the supporting truss to protect them form torsion. Some of the methods employed to mitigate the effects of torsion include; diagonal suspender cables, aerodynamic truss structures or an exaggerated ratio between the depth of the supporting truss to the length of the span.

If not considered when designing a bridge resonance can also have a detrimental effect on a bridge. Vibrations can travel through a bridge in the form of waves. In order to prevent a resonant magnification of the vibration, the potentially destructive resonance is controlled. Methods to dampen such vibrations must be built into the bridge design in order to avoid any resonance frequencies. Interrupting the waves prevents the harmonics from growing in length and becoming destructive. The dampening technique used to prevent resonance waves from growing usually involves variable inertias. For example, if a bridge roadbed is made up in different sections of overlapping plates the movement of one section is transferred to the next section via the slightly varied weights and sizes. This simple technique will create enough friction to counteract the frequency of the resonant wave. This change in frequency will prevent the wave from building and create two different waves, thus eliminating the chance of the resonant wave strength to become destructive. An excellent example of a resonance wave destroying a bridge occurred in 1940 when the Tacoma Narrows Bridge was destroyed by a forty miles per hour wind.

Factors in Bridge Construction and Design

Before an engineer or bridge designer can adequately begin working on the design for a bridge, a substantial amount of information is needed. (Leonhardt, Fritz)

(1) A plan of the site is needed in order for the engineer to see all of the obstacles that has to be bridged, such as rivers, streets, contour lines of valleys and the desired alignment of the new traffic route.
(2) The requirements of the bridge itself such as the width of the bridge, including the width of the lanes, safety rails, medians and walkways.
(3) Weather and environmental conditions such as length of flood periods, high and low tide levels, length of flood or drought periods.
(4) The topography of the environment.
(5) The soil and substrata conditions of the planned site based on the results from the data collected from borings and the soil mechanics data.
(6) Local conditions like the accessibility for the transport of equipment, materials and structural elements that must be used for construction.
(7) The environmental requirements regarding the aesthetic quality of the bridge which is about to be built.
(8) Health and safety requirements such as noise, vibrations and it compatibility with adjacent sites surrounding the bridge.

Once the bridge designer has taken all of these factors into consideration, the bridge then takes on the preliminary shape or design in the designer's imagination.

The Engineering Process

The engineering process is an extension of the scientific method. Teaching students to use this process when they begin to build their bridges will provide them with valuable skills to use when it comes to solving problems or creating a project. The engineering process includes basic procedures that engineers use to identify the problem and determine an adequate solution to the challenge they have undertaken. The engineering process can be broken down into the following eight simple steps: (Isidro-Cloudas and Cassis, Glenn)

(1) Identify the Problem
Before the engineer can begin work, the problem or task that is going to be undertaken must be known.
(2) Determine the Constraints
Constraints are the limitations that must be considered before you begin designing your bridge. Even though they are not limited to the materials, size, and money, you have to consider them the problem or task.
Preliminary Design
(A) Brainstorming- Once both the problem or task has been determined and the constraints have been identified the group needs to think of as many ways to possible to solve the problem. The ideas should be broad enough to allow for unique solutions to arise. The class, meeting in smaller groups, may find that rough sketches are extremely helpful to stimulate a lot of different ideas. Even though all of the ideas may not be good ones, but they may inspire another idea that may lead to a solution to the problem.
(B) Focus- Once all reasonable ideas are listed and the sketches are drawn, the group should choose the best two or three ideas for further development. The rough sketches should be converted to scaled or measured drawings.
(3) Analysis of Design
During this step, the designs are studied based on their merit in relationship to strength, cost, market appeal, and manufacturability. Models, drawings and calculations can be presented at this stage. A decision should be made at this point on which design to use or rather to begin a new design.
(4) Design Refinement
This step begins after a design has been analyzed. Any problems or unresolved considerations with the design should have been made apparent by now. Each design team should attempt to rectify the problems by making improvements in the design. After the corrections have been made, then each team should go back and analyze the design once again.
(5) Implementation Plan
Once the final design has been approved, it must be translated from an idea on paper to the real thing. Before the plan can be implemented, plans need to be made outlining the construction process. The methods of construction together with the strategy for scheduling involved a list of the tools; machinery and materials needed to complete the project. A listing of the parts and the

dimension of the project are drawn up. The order is which the bridge is to be built is also written down and the specifications are compiled.
(6) Modify for Implementation
Any obstacles that may arise during the building of the bridge must be analyzed in order to find out if it is a big enough problem to cause a change in the original plan.
(7) Implementation

The final step is to manufacture the individual parts as prescribed in the implementation plans. Even though the steps are listed in a specific order, in real life two or more of these steps maybe combined or done in a different order. In the field of engineering, sometimes one person may specialize in a certain step, but the method is always followed in one respect or the other.

Lesson Plans for Teaching This Unit

Introduction to Bridges (Day 1- 2)

Introduce your students to the different types of bridges by reviewing the information in "Introduction to the Different Types of bridges" presented in an earlier section of this paper. Show the students slide show presentations, pictures or a film about bridges. Have the students collect pictures of different types of bridges over a period of time. Instruct the students to make a poster and place each bridge under the heading of beam, arch or suspension bridge. If possible, show the students a film about the history and different types of bridges.

Virtual Bridge Fieldtrip (Day 3)

Have the student search several different websites and lists the different types of beam, arch and suspension bridges that they observed during the class period. Have them identify which bridge they especially liked, and why.

Town Meeting (Day 4-5)

Break the classroom down into four of five groups. Make up a scenario where they have to decide on what type of bridge they should build in a particular area. Review the requirements presented in "Factors in Bridge Building and Design" earlier in this paper with them before they do this assignment. Have each group find a picture of the bridge they intend to build (this will assist them in drawing the bridge that they will create) and explain how they came up with the decision.

Bridge Fieldtrip (Day 6)

Arrange for your class to take a fieldtrip to a bridge. The field trip will be extremely helpful and enlightening if the students can see a bridge of construction and a bridge already in place. Try to contact a bridge superintendent so that they can give the students pertinent information about the bridge and answer students' questions. Have the students write a reaction paper about their trip to the bridge. Have several of the students read their paper to the class and discuss them as a group.

Simple Bridge Experiments and Activities (Day 7-9)

Perform the experiment and activities in the "Hands-On Bridge Building Activities" section of this unit. This will help the students to better understand the principles behind bridge building and enable them to design and construct better bridges for the culminating activity where the students actually build a bridge.

Introduction to the Bridge Building Contest (Day 10-11)

Show the film "Build'em and Bust'em" to motivate the students for the actual bridge building contest. (See teacher's bibliography for a brief summary and explanation about the film). Let the students know about the bridge building activity that they are about to undertake. Explain the rubric (grading sheet and expectations) at the end of this unit so that the students will fully understand the assignment. Break the class down into small construction companies. Review the building specifications with the class before they before they begin designing their bridges. If possible show the students an example of how their sketches and a blue print of the building should look.

Meeting of the Companies (Day 12)

The students will meet in their individual groups and decide on a company name, and the type of bridge that they want to build. Instruct each member of the group to come up with a sketch or picture that they would like for the company to build. They can complete this part of the assignment for homework. During the next group meeting they will decide on which bridge that they will construct from their completed designs.

Blueprint of the Bridge (Day 13-14)

Each group will draw a picture of the bridge that they plan to build. They should include a side view, end view and a top view of the bridge. Each group will present their final plans to the class before building their bridge design. These designs should be drawn to building specifications made during the earlier class meeting. These designs will also serve as the template for the students to follow when they start to construct the bridge.

Bridge Building (Day 15-16)

Give the students five or more days to build their bridge models during class. The time allotment will vary to the type of bridge they are building.

Final Inspection (final class period)

Evaluate the model based on the rubric presented during day seven.

Hands-On Bridge Building Activities

Activity I: Strength Test of a Beam and Arched Bridge

Objectives

The students will build a beam and arch bridge. Then they will see which of the two bridges will hold the most weight.

Materials Needed

2-4 bricks per group, corrugated card board, weights

Procedures

(1) Place two bricks 20 cm apart.
(2) In order to make a higher structure, place the second set of bricks on top of the first layer of bricks.
(3) Place a piece of corrugated cardboard between the two bricks.
(4) Gradually place weights in the center of the cardboard until it begins to sag in the middle.
(5) Record the amount of weight the bridge held before it began to sag.
(6) Rebuild your bridge as stated in steps one and two above.

(7) Place an arch between the two bricks by carefully bending a piece of corrugated cardboard in the form of the arch. Make sure that it fits snugly between the bricks that are 20 cm apart.
(8) Place a piece of cardboard on top of the arch between the two bricks.
(9) Gradually place weights in the center of the cardboard until it begins to sag in the middle.
(10) Record the amount of weight the bridge held.

Observations

(1) What type of bridge did you build at the beginning of the activity?
(2) What was the second type of bridge you built called?
(3) What effect did adding the arch to the bridge have, if any?
(4) Which bridge would you rather cross, why?

Activity II: Building a Strong Support

Objective

The students will build a tower with wooden coffee stirrers. Each tower will be tested to see which one will hold the most amount of weight. Be sure to point out the characteristics that made a tower weaker or stronger.

Materials Needed

Wooden coffee stirrers, glue, weights

Procedures

(1) Break the class down into groups of three or four.
(2) Have each group draw a blueprint of the tower that they plan to build.

(3) Once the instructor approves the tower, have the students build the tower.
(4) Place the towers on display in front of the class.
(5) Place weights on the tower until it begins to buckle.
(6) Record the weight that the tower held before it began to buckle.
(7) Have each group discuss why their bridge buckled, and any improvements that they could make in order to make their tower stronger.

Lesson Extension

Have each group redesign their tower with the recommendations they made to improve their tower. Test each tower to see if it is stronger than the first one they made.

Culminating Activity: Bridge Building Contest

In order for your students to learn the steps involved in the Engineering Process listed above, you should design the Bridge Building Contests based on those principles. In this section of the paper, I will give you examples of how to use it as a basic guide when you plan your contest at your school. No matter what type of contest you sponsor you can apply any these steps to straw, cardboard, toothpick, wooden coffee stirrers bridge contests.

When the contest is first announced the problem or task the students are about to undergo must be presented to the student. This could be done in a variety of ways. You can present the information to the class by showing the class a film, placing the information on the board, or design a rubric such as the one at the end of this section. The materials used can be change, but the criteria presented not only serve as explicit directions for the student, but it also a performance based evaluation that really assess the students work.

A list of the parameters the students must use before designing their bridges should be done as you determine the type of bridge the students will make. If you wish to consider the economic behind bridge building, like buying materials, you can copy this activity by letting the students buy or keep a record of the amount of materials they use in completing their bridge. For example, if your students are building a straw bridge, you can place a price on the straws and have your students keep record of how many straws were used. They can also be charged for all materials used while constructing their bridge. Have the students figure out how much their bridge is costing on the daily basis. The dimensions of the bridge should also be stated. For example, you could have the students build a bridge of straw with a span of 30 cm and a width of 5 cm. As an additional criteria you can limit the amount of straws each kid should use, or the amount of weight (load) the bridge should hold. A list of specific materials should be presented to the students based on the parameters of your contest.

Once the students have a full understanding of their limitations. Let the students meet in groups and decide the type of bridge they will build. Have them make a rough design of their bridge on construction paper. This will serve as their preliminary design. The next step in this process will call for the students analyze their design by drawing a more detailed drawing on graph paper. The students should design the bridge according to parameters presented during the introduction. Each student in the group should design a bridge, make sure they include a side, end and front view of the bridge. As a group, have the students decide on a design, or utilizing ideas from each of the individual bridges design a final blueprint of the bridge the group will construct.

Have the students write down the steps involved in building their bridges. Keeping a daily journal is a wonderful way of ensuring that all students are actively involved in designing and constructing the bridge. Whenever there is a structural change in the bridge design, the group has to update or draw a new blueprint of the bridge. All of this work should be kept in a portfolio under the group or company name.

Once the students begin constructing the bridge, they will make modifications which should be recorded in their journals. Make sure you check the students logs on the daily basis. Give daily observational grades in order to promote good work, and group working skills. You could also have students do weekly reports to the class of their progress. Through the use of the previously stated ideas, this would be a wonderful integrated unit of study for any middle school classroom.

Task:

Your Civil Engineering Firm has been hired to design and build a model of a bridge to replace the old truss bridge across town. You have to design the bridge and build a model using coffee stirrers to present before the community leaders for approval. The model must meet the following specifications.

The bridge must have a span at least 30 cm long, a roadbed at least 5 cm wide and a clearance of at least 10-cm in height. The distance between the bridge supports should be at least 10 cm apart, unless the bridge has only one tower or support structure. Draw the side, top and end view of the bridge along with the support structure according to the specifications. This will serve as the template, or blueprint that the firm will use to construct their model. Once the design is approve by the president of the firm, you will be given materials (according to the type of bridge the firm choose) to build the model.

The following materials are available for your group to use in order to build the model: coffee stirrers, wire, glue, string and hooks. Make sure the materials that are needed to complete your model are clearly shown on the firms' drawing. You will receive these materials once your design is approved. Your design and model will be evaluated using the rubric below.

A rubric is an evaluation tool that lets the student know exactly what is expected of them in an assignment. Before the students begin the project, the instructor should go over each of the criteria listed below. The possible points for each item listed should be told to the students. To make grading easier, the points should total one hundred. Once the students fully understand their task and how they will be graded everyone will have a full understanding of what is expected of them.

Rubric for the Bridge Design

	Possible Points	Points Earned
The drawing is neat and legible..................	_____	_____
The three views are labled..........................	_____	_____
The bridge span is at least 30 cm long........	_____	_____
The roadbed is at least 5 cm wide..............	_____	_____
The clearance of at least 10 cm in tall.........	_____	_____
The distance between the bridge supports is at least 10 cm apart.................	_____	_____

Rubric for the Model

	Possible Points	Points Earned
The team adhered to the design..................	_____	_____
The model is neatly done..........................	_____	_____
The model is built with materials supplied...	_____	_____
The bridge span is at least 30 cm long........	_____	_____
The roadbed is at least 5 cm wide..............	_____	_____
The clearance of at least 10 cm in tall.........	_____	_____
The distance between the bridge supports is at least 10 cm apart.................	_____	_____

Notes

Isidro-Cloudas and Cassis, Glenn. *Instructors Guide to Connecticut Pre-Engineering Program Bridge Project* .
Leonhardt, Fritz. *Bridges: Aesthetic and Design* . MIT Press, Massachusetts (1984).

Additional Resources

Videos

"*Bridges*" - Video produced by Kaw Valley Films and Video. This video covers an array of subjects about bridges such as the history of bridges, the four basic types of bridges and also discusses the collapse of the Tacoma Narrows Bridge in 1940. "*Build 'Em and Bust 'Em* "- Video by Midwest Products Co., Educational Products Division. Prepares students for a balsa wood bridge contest. It also demonstrates different techniques to build the bridges discussed in this paper and important information to prepare for a bridge building contest.

Websites

The following websites can be extremely helpful to both students and teachers while teaching this unit. The websites listed introduce the different types of bridges, explain how bridges work, and also provide hands-on activities. "Building Big: Bridge Basics", http://www.pbs.org/wgbh/buildingbig/bridge/basics.html, 2000.

"Civil Engineering: Why Do Bridges Stand Up?", http://civilengineer.about.com/science/civilengineer/library/weekly/aa032501a.htm, 2000.

"Super Bridge: Beam Bridges", NOVA Online/Super Bridge/Build a Bridge, http://www.pbs.org/wgbh/nova/bridge/meetbeam.html, 2000.

"Super Bridge:Build a Bridge", NOVA Online/Super Bridge/Build a Bridge, http://www.pbs.org/wgbh/nova/bridge/build.html, 2000.

"Super Bridge:Cable-Stayed Bridge", NOVA Online/Super Bridge/Cable-Stayed Bridge, http://www.pbs.org/wgbh/nova/bridge/meetcable.html, 2000.

Teachers' Bibliography

Cordel, Betty, Courtney, Barry. *Hardhitting in a Geo-World* . AIMS Education Foundation, California (1996). This is a part of the AIMS (Activities Integrating Math and Science) series. In addition to teaching measurement and introducing geometry, metric system and patterns, the book contains a unit on building straw bridges. The unit includes excellent worksheets, and hands-on activities which promotes problems solving skills.

Isidro-Cloudas and Cassis, Glenn. *Instructors Guide to Connecticut Pre-Engineering Program Bridge Project* . A great resource for bridge design based on the engineering process and principles. Includes excellent math algebraic problems as they relate to civil engineers.

Leonhardt, Fritz. *Bridges: Aesthetic and Design* . MIT Press, Massachusetts (1984). Excellent source for background information concerning all aspects of bridge building. It discusses the importance of aesthetics, the different types of bridges that exist in the world today, how bridges stand up, etc…

Outerbridge, David. *Bridges* . Henry N. Abrams, Inc., (1989). This book includes excellent illustrations (close up shots) of the three types of bridges discussed in this paper. It is a great source for giving students ideas about the bridges they will create in this unit.

Pollard, Jeanne. *Building Toothpick Bridges* . Dale Seymour Publication, United States of America (1985). An excellent guide for teachers wishing to sponsor a toothpick bridge contest. The unit includes excellent worksheets, and hands-on activities which promotes problems solving skills.

Salvadori, Mario. *Why Buildings Stand Up: The Strength of Architecture* . W.W. Norton and Company, New York (1980). Contains two chapters on bridges which explains how the arch, truss and suspension bridges carry their load. It also gives several hands-on examples to further explain the concepts being presented in the book. The other chapter gives the history of the Brooklyn Bridge. (pages 145-178)

Students' Bibliography

Corbett, Scott. *Bridges* . Four Winds Press, New York (1978). Discusses the history of bridges from ancient times to the present. It also discussed how various types of bridges were built. An excellent source on the history of bridges.

Kingston, Jeremy. *How Bridges Are Made* . Facts on File Publications, New York (1985). Not only does this book illustrates and describes the different types of bridges, it goes into detail about the materials that are used to make bridges. An excellent source for middle school students.

Levy, Matthys and Panchy, Richard. *Engineering the City: How Infrastructure Works* . Chicago Review Press, Illinois. This book contains an excellent chapter on bridge building and other engineering marvels. It also gives several creative angles to building all of the bridges presented in this paper.

MacGregor, Scott and Ann. *Bridges: A Project Book* . Pepper Press, Great Britain (1980). Discusses the history, use and construction of the three types of bridges presented in this paper. It also has hands-on projects to demonstrate the how these bridges carry their loads.

Sandak, Cass R. *Bridges* . Franklin Watts, (1983). This book introduces all the various types of bridges and how they are constructed.

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