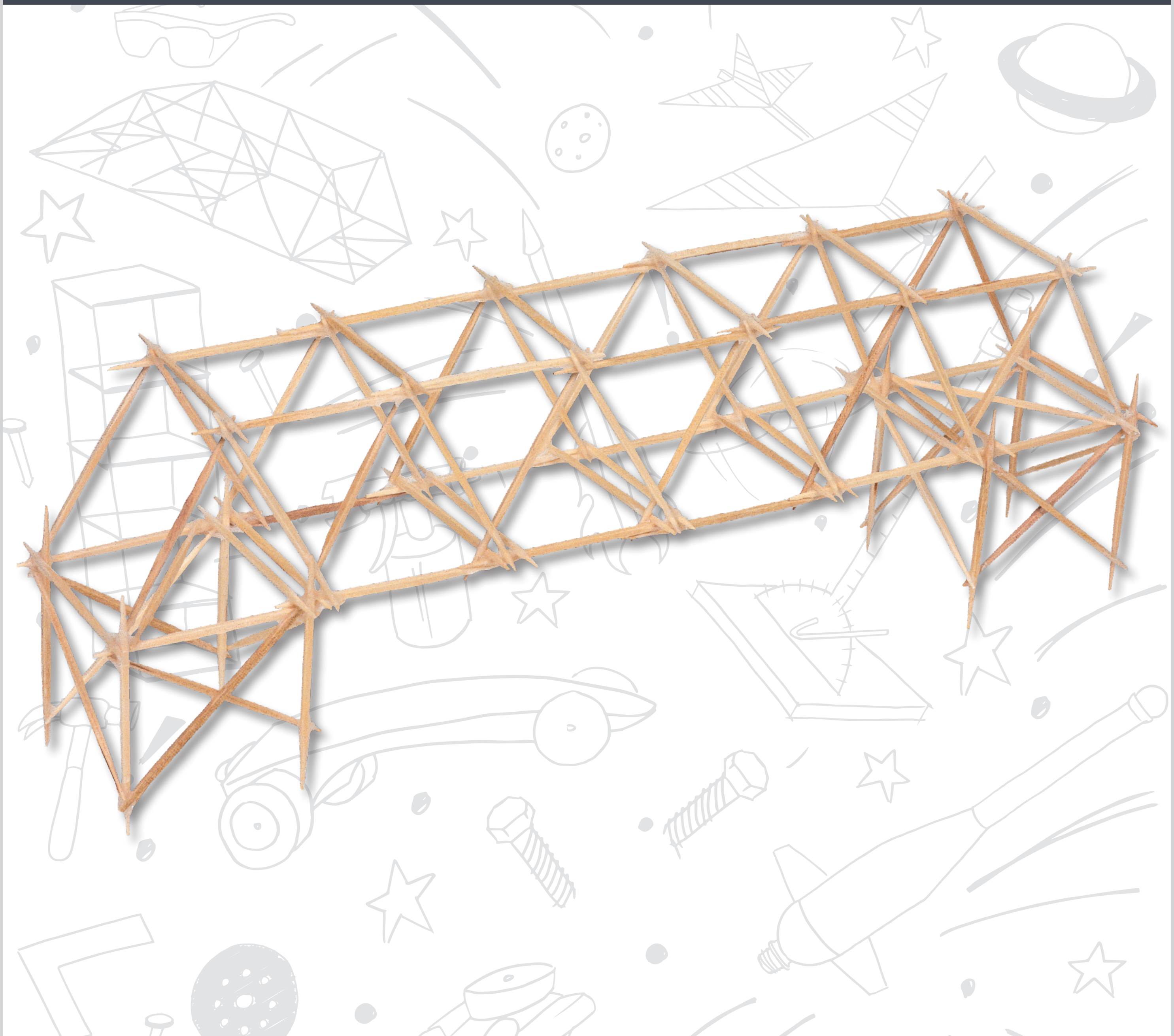
# TOOTHPICK BRIDGES

## Teacher's Guide



STEM Curriculum for Toothpick Bridges

PITSCO EDUCATION

45136

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*Creativity* *Critical Thinking* *Communication* *Collaboration* *Back to Last Page Viewed* *Table of Contents*

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## Activity Overview

Using the provided kit materials, students construct a toothpick bridge. After the bridge is built, it can be tested using Pitsco's Toothpick Bridge Tester or other Pitsco bridge-testing equipment.

The *Toothpick Bridges Teacher's Guide* contains both basic and advanced lesson plans. Basic lesson plans provide a more guided approach to instruction while advanced lesson plans are more open-ended. All lesson plans can be used to extend students' understanding of science, math, and technology concepts using toothpick bridges.

Resource materials are provided to supplement students' understanding of core content. Resources include vocabulary, assessments, and content fact sheets.

## Materials

This section lists required or optional materials and equipment for activities found in this guide. The first section lists materials and equipment needed for all activities. The second section lists optional materials and equipment, including class packs for replenishing consumables. If you are planning to complete only select activities, refer to the materials list located in each activity. Links are provided to Pitsco products for your convenience and offer at least one option. Other options might be available; to explore them, use the search box on Pitsco.com.

### All Materials and Equipment Needed for All Activities

- Toothpick Bridges – Getting Started Package: Pitsco.com/Toothpick-Bridges-Getting-Started-Package
    - Bridge tester or container: Pitsco.com/Toothpick-Bridge-Tester
    - *Dr. Zoon Toothpick Bridges Video*: Pitsco.com/Dr-Zoon-Toothpick-Bridges-Video
    - Empty glue bottles (2 oz): Pitsco.com/Empty-Glue-Bottle
    - Glue: Pitsco.com/Structures-Glue
    - Test block
    - Toothpicks: Pitsco.com/Toothpicks
    - Waxed paper: Pitsco.com/Waxed-Paper
- 2 solid surfaces to use as supports
- Calculator: Pitsco.com/Calculator-Sharp-EL-500
- Digital scale or balance: Pitsco.com/CJ300-Digital-Scale
- Graph paper: Pitsco.com/Grid-Paper
- Masses: Pitsco.com/Hooked-Weight-Set
- Paper
- Pencil
- Ruler: Pitsco.com/12-Flexible-Stainless-Steel-Ruler
- Sand, gravel, or other mass
- Scissors: Pitsco.com/Super-Sharp-Scissors-8
- Tape: Pitsco.com/Transparent-Tape

### Optional Materials and Equipment

- 5 mL graduated droppers or cylinders
- *Building Toothpick Bridges* book: Pitsco.com/Building-Toothpick-Bridges
- Hobby knife: Pitsco.com/Hobby-and-Craft-Knife
- Spring scale: Pitsco.com/Spring-Scale-2000-g
- Structure Testing Device: Pitsco.com/Structure-Testing-Device
- Structures Testing Instrument: Pitsco.com/Structures-Testing-Instrument-2

Activities with the following icons include opportunities for students to apply 21st-century skills in communication, collaboration, critical thinking, and creativity. If time is available, you might choose to focus on these skills in conjunction with the activities. These icons will appear in the Procedure sections of the Teacher Instruction. Additional icons might appear in the Note section that suggest how an additional skill can be addressed in the activity.

| | |
|---|---|
| **Communication** | Sharing thoughts, questions, ideas, and solutions.<br>Indicators:<br>• Articulate thoughts and ideas effectively using oral, written and nonverbal communication skills in a variety of forms and contexts<br>• Listen effectively to decipher meaning, including knowledge, values, attitudes and intentions<br>• Use communication for a range of purposes (e.g. to inform, instruct, motivate and persuade)<br>• Utilize multiple media and technologies, and know how to judge their effectiveness a priori as well as assess their impact<br>• Communicate effectively in diverse environments (including multi-lingual) |
| **Collaboration** | Working together to reach a goal – putting talent, expertise, and smarts to work.<br>Indicators:<br>• Demonstrate ability to work effectively and respectfully with diverse teams<br>• Exercise flexibility and willingness to be helpful in making necessary compromises to accomplish a common goal<br>• Assume shared responsibility for collaborative work, and value the individual contributions made by each team member |
| **Critical Thinking** | Looking at problems in a new way, linking learning across subjects and disciplines.<br>Indicators:<br>**Reason Effectively**<br>• Use various types of reasoning (inductive, deductive, etc.) as appropriate to the situation<br>**Use Systems Thinking**<br>• Analyze how parts of a whole interact with each other to produce overall outcomes in complex systems<br>**Make Judgments and Decisions**<br>• Effectively analyze and evaluate evidence, arguments, claims and beliefs<br>• Analyze and evaluate major alternative points of view<br>• Synthesize and make connections between information and arguments<br>• Interpret information and draw conclusions based on the best analysis<br>• Reflect critically on learning experiences and processes<br>**Solve Problems**<br>• Solve different kinds of non-familiar problems in both conventional and innovative ways<br>• Identify and ask significant questions that clarify various points of view and lead to better solutions |
| **Creativity** | Trying new approaches to get things done equals innovation and invention.<br>Indicators:<br>**Think Creatively**<br>• Use a wide range of idea creation techniques (such as brainstorming)<br>• Create new and worthwhile ideas (both incremental and radical concepts)<br>• Elaborate, refine, analyze and evaluate their own ideas in order to improve and maximize creative efforts<br>**Work Creatively with Others**<br>• Develop, implement and communicate new ideas to others effectively<br>• Be open and responsive to new and diverse perspectives; incorporate group input and feedback into the work<br>• Demonstrate originality and inventiveness in work and understand the real-world limits to adopting new ideas<br>• View failure as an opportunity to learn; understand that creativity and innovation is a long-term, cyclical process of small successes and frequent mistakes<br>**Implement Innovations**<br>• Act on creative ideas to make a tangible and useful contribution to the field in which the innovation will occur |

Source: Partnership for 21st Century Skills: Pitsco.com/c-4cs-research

## Standards Addressed

Standards were taken from the International Technology and Engineering Educators Association (ITEEA), the Next Generation Science Standards (NGSS), and the Common Core State Standards (CCSS).

### NGSS

NGSS.MS.FI Forces and Interactions

NGSS.MS-PS2-2
Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

NGSS.MS.ED Engineering Design

NGSS.MS.ETS1-1
Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

NGSS.MS.ETS1-2
Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

NGSS.MS.ETS1-3
Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

NGSS.MS.ETS1-4
Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

### CCSS.MATH

Grade 6

CCSS.MATH.CONTENT.6.RP.A
Understand ratio concepts and use ratio reasoning to solve problems.

CCSS.MATH.CONTENT.6.RP.A.1
Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities.

CCSS.MATH.CONTENT.6.RP.A.3
Use ratio and rate reasoning to solve real-world and mathematical problems, e.g., by reasoning about tables of equivalent ratios, tape diagrams, double number line diagrams, or equations.

CCSS.MATH.CONTENT.6.RP.A.3.B
Solve unit rate problems including those involving unit pricing and constant speed.

CCSS.MATH.CONTENT.6.RP.A.3.D
Use ratio reasoning to convert measurement units; manipulate and transform units appropriately when multiplying or dividing quantities.

CCSS.MATH.CONTENT.6.NS.B
Compute fluently with multi-digit numbers and find common factors and multiples.

CCSS.MATH.CONTENT.6.NS.B.2
Fluently divide multi-digit numbers using the standard algorithm.

CCSS.MATH.CONTENT.6.NS.B.3
Fluently add, subtract, multiply, and divide multi-digit decimals using the standard algorithm for each operation.

CCSS.MATH.CONTENT.6.G.A
Solve real-world and mathematical problems involving area, surface area, and volume.

CCSS.MATH.CONTENT.6.G.A.1
Find the area of right triangles, other triangles, special quadrilaterals, and polygons by composing into rectangles or decomposing into triangles and other shapes; apply these techniques in the context of solving real-world and mathematical problems.

CCSS.MATH.CONTENT.6.SP.B
Summarize and describe distributions.

CCSS.MATH.CONTENT.6.SP.B.5
Summarize numerical data sets in relation to their context, such as by:

CCSS.MATH.CONTENT.6.SP.B.5.A
Reporting the number of observations.

CCSS.MATH.CONTENT.6.SP.B.5.B
Describing the nature of the attribute under investigation, including how it was measured and its units of measurement.

Grade 7

CCSS.MATH.CONTENT.7.RP.A
Analyze proportional relationships and use them to solve real-world and mathematical problems.

CCSS.MATH.CONTENT.7.RP.A.1
Compute unit rates associated with ratios of fractions, including ratios of lengths, areas and other quantities measured in like or different units.

CCSS.MATH.CONTENT.7.RP.A.3
Use proportional relationships to solve multistep ratio and percent problems.

CCSS.MATH.CONTENT.7.NS.A
Apply and extend previous understandings of operations with fractions to add, subtract, multiply, and divide rational numbers.

CCSS.MATH.CONTENT.7.NS.A.1
Apply and extend previous understandings of addition and subtraction to add and subtract rational numbers; represent addition and subtraction on a horizontal or vertical number line diagram.

CCSS.MATH.CONTENT.7.NS.A.1.D
Apply properties of operations as strategies to add and subtract rational numbers.

CCSS.MATH.CONTENT.7.NS.A.2
Apply and extend previous understandings of multiplication and division and of fractions to multiply and divide rational numbers.

CCSS.MATH.CONTENT.7.NS.A.2.C
Apply properties of operations as strategies to multiply and divide rational numbers.

CCSS.MATH.CONTENT.7.NS.A.3
Solve real-world and mathematical problems involving the four operations with rational numbers.

CCSS.MATH.CONTENT.7.EE.B
Solve real-life and mathematical problems using numerical and algebraic expressions and equations.

CCSS.MATH.CONTENT.7.EE.B.3
Solve multi-step real-life and mathematical problems posed with positive and negative rational numbers in any form (whole numbers, fractions, and decimals), using tools strategically. Apply properties of operations to calculate with numbers in any form; convert between forms as appropriate; and assess the reasonableness of answers using mental computation and estimation strategies.

CCSS.MATH.CONTENT.7.G.A
Draw, construct, and describe geometrical figures and describe the relationships between them.

CCSS.MATH.CONTENT.7.G.A.1
Solve problems involving scale drawings of geometric figures, including computing actual lengths and areas from a scale drawing and reproducing a scale drawing at a different scale.

CCSS.MATH.CONTENT.7.G.A.2
Draw (freehand, with ruler and protractor, and with technology) geometric shapes with given conditions. Focus on constructing triangles from three measures of angles or sides, noticing when the conditions determine a unique triangle, more than one triangle, or no triangle.

## Standards Addressed

CCSS.MATH.CONTENT.7.G.B
Solve real-life and mathematical problems involving angle measure, area, surface area, and volume.

CCSS.MATH.CONTENT.7.G.B.6
Solve real-world and mathematical problems involving area, volume and surface area of two- and three-dimensional objects composed of triangles, quadrilaterals, polygons, cubes, and right prisms.

CCSS.MATH.CONTENT.7.SP.A
Use random sampling to draw inferences about a population.

CCSS.MATH.CONTENT.7.SP.A.1
Understand that statistics can be used to gain information about a population by examining a sample of the population; generalizations about a population from a sample are valid only if the sample is representative of that population. Understand that random sampling tends to produce representative samples and support valid inferences.

CCSS.MATH.CONTENT.7.SP.A.2
Use data from a random sample to draw inferences about a population with an unknown characteristic of interest. Generate multiple samples (or simulated samples) of the same size to gauge the variation in estimates or predictions.

### ITEEA

ITEEA.1.F
New products and systems can be developed to solve problems or to help do things that could not be done without the help of technology.

ITEEA.1.G
The development of technology is a human activity and is the result of individual and collective needs and the ability to be creative.

ITEEA.1.H
Technology is closely linked to creativity, which has resulted in innovation.

ITEEA.2.M
Technological systems include input, processes, output, and at times, feedback.

ITEEA.2.N
Systems thinking involves considering how every part relates to others.

ITEEA.2.Q
Malfunctions of any part of a system may affect the function and quality of the system.

ITEEA.2.R
Requirements are the parameters placed on the development of a product or system.

ITEEA.2.S
Trade-off is a decision process recognizing the need for careful compromises among competing factors.

ITEEA.5.D
The management of waste produced by technological systems is an important societal issue.

ITEEA.8.E
Design is a creative planning process that leads to useful products and systems.

ITEEA.8.F
There is no perfect design.

ITEEA.8.G
Requirements for design are made up of criteria and constraints.

ITEEA.9.F
Design involves a set of steps, which can be performed in different sequences and repeated as needed.

ITEEA.9.G
Brainstorming is a group problem-solving design process in which each person in the group presents his or her ideas in an open forum.

ITEEA.9.H
Modeling, testing, evaluating, and modifying are used to transform ideas into practical solutions.

ITEEA.10.F
Troubleshooting is a problem-solving method used to identify the cause of a malfunction in a technological system.

ITEEA.10.G
Invention is a process of turning ideas and imagination into devices and systems. Innovation is the process of modifying an existing product or system to improve it.

ITEEA.10.H
Some technological problems are best solved through experimentation.

ITEEA.11.H
Apply a design process to solve problems in and beyond the laboratory-classroom.

ITEEA.11.I
Specify criteria and constraints for the design.

ITEEA.11.J
Make two-dimensional and three-dimensional representations of the designed solution.

ITEEA.11.K
Test and evaluate the design in relation to pre-established requirements, such as criteria and constraints, and refine as needed.

ITEEA.11.L
Make a product or system and document the solution.

ITEEA.13.F
Design and use instruments to gather data.

# Construction Quick View

## Materials

- Graph paper
- Toothpicks
- Scissors or hobby knife
- Glue
- Tape
- Ruler
- Pencil
- Waxed paper
- 2 solid surfaces to use as supports
- Test block
- Bridge tester or container
- Sand, gravel, or other mass

## Construction

1. Use a ruler and pencil to draw on the graph paper a design for the roadbed, the bridge sides, and any other parts of the bridge. Draw the parts of the bridge full size.
2. Place a piece of waxed paper over the drawing. This will enable you to easily remove the bridge parts from the drawing.
3. Place the toothpicks on the designs. Cut any toothpicks to the proper length if necessary.
4. Use tape to hold the toothpicks in place.
5. Place drops of glue at each joint.
6. Allow the glue to dry.
7. After the glue has dried, remove the tape. Assemble the parts of the bridge into a complete bridge. Use tape to hold the bridge parts to one another.
8. Place glue at the bridge joints that connect the parts of the bridge together.
9. Allow the glue to dry.
10. After the glue is dry, remove the tape.

**Note: (3)** If students use hobby knives, you should closely supervise the knives and collect them as soon as students finish.

**Note: (4)** Students should use minimal tape.

**Note: (5)** Do not allow students to use excessive amounts of glue.

**Note: (6)** Glue should dry overnight if possible.

## Testing

1. Place the bridge across the space between two supports.

**Note: (1)** Two tables work well as supports.

2. Place a test block along the roadbed.

**Note: (2)** Make sure the test block does not overlap either support. Ideally, the test block should be two inches shorter than the span between supports.

3. Attach the bridge tester to the test block so that the container hangs straight down from the block.

**Note: (3)** If you use a commercial tester, consult the instructions that accompany it.

Pass/Fail Test:

Add the required mass to the container. If the bridge holds, it passes.

Destruction Test:

Gradually add sand, gravel, or another mass to the container until the bridge breaks. Measure the amount of mass the bridge supported.

# Teaching Tips

## Safety

- Make sure students carefully cut the toothpicks and do not break them. Broken toothpicks can result in minor injuries such as splinters.
- Be careful of fumes from glue.
- Monitor the use of hobby knives by the students. Review safety rules for knife use before letting students use the hobby knives.

## Construction Tips/Helpful Hints

- A commercial bridge tester such as the Pitsco Toothpick Bridge Tester works well for this activity. Other options include the Structure Testing Device and Structures Testing Instrument. You could also build your own tester.
- Toothpicks with pointed ends work well because their slanted parts form natural joints.
- Surfaces should be covered to protect them from glue. Waxed paper is provided for this purpose.
- Before students begin, consider where students will store their bridges during the construction phase. You could designate an area in the classroom for each class hour.
- You might wish to limit the amount of glue students are allowed to use. Excessive use of glue will artificially increase a bridge's strength.

## Troubleshooting

- Bridges must have a roadbed wider and longer than the test block, or the bridge tester will not work properly.


## Quick View

Students determine whether bridge superstructures are made stronger by using triangular or rectangular supports.

## Time Required

180-270 minutes (will vary with class size)

## Content Areas

Primary: Science

Secondary: Math, technology

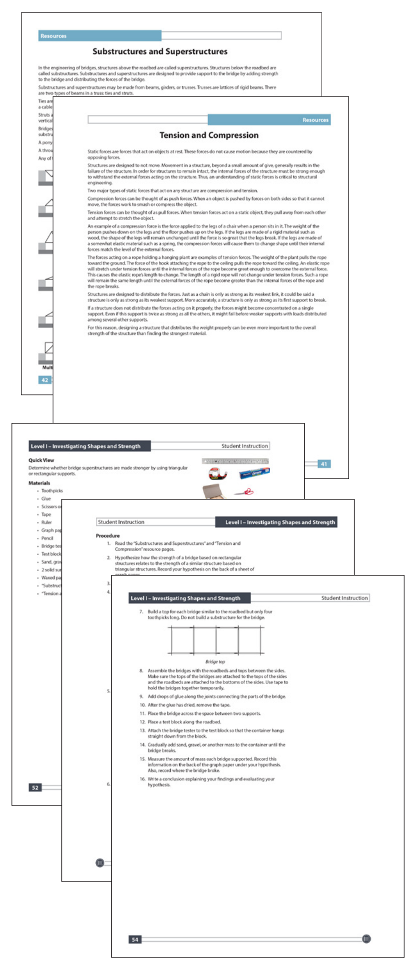
## Vocabulary

Glossary Resource: Pitsco.com/c/tb-glossary.pdf

- compression
- substructure
- superstructure
- tension

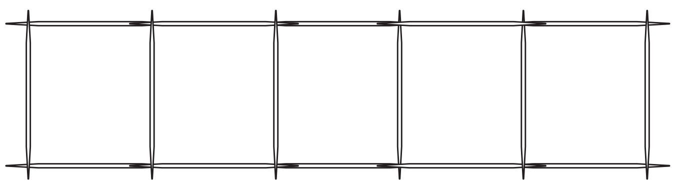
## Materials

- Toothpicks
- Glue
- Scissors or hobby knife
- Tape
- Ruler
- Graph paper
- Pencil
- Bridge tester or container
- Test block
- Sand, gravel, or other mass
- 2 solid surfaces to use as supports
- Waxed paper
- “Substructures and Superstructures” resource page: Pitsco.com/c/substructures-superstructures.pdf
- “Tension and Compression” resource page: Pitsco.com/c/tension-compression.pdf
- Investigating Shapes and Strength Student Instruction: Pitsco.com/c/tb-sp5.pdf



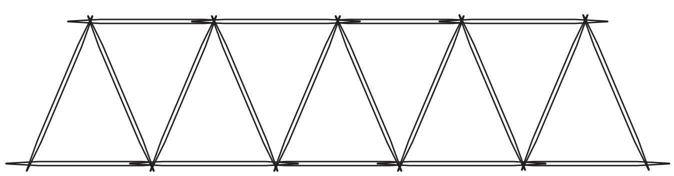
## Procedure

1. Read the "Substructures and Superstructures" and "Tension and Compression" resource pages.
2. Hypothesize how the strength of a bridge based on rectangular structures relates to the strength of a similar structure based on triangular structures. Record your hypothesis on the back of a sheet of graph paper.
3. Measure the length of the individual toothpicks.
4. Use a ruler and pencil to draw a design for the roadbeds on the front of the graph paper on which you recorded your hypothesis. Use straight lines to represent the toothpicks. The roadbeds for both types of bridge will be identical. The roadbeds will be five toothpicks long with adjacent toothpicks overlapping each other one-fourth inch. Place six toothpicks between each side of the roadbeds and perpendicular to the sides: one toothpick on each end and one toothpick at each intersection of two side toothpicks. Place a piece of waxed paper over your drawings and build the roadbeds.



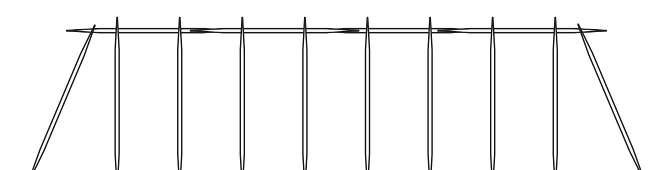
*Toothpick bridge roadbed*

5. Draw two copies of a triangular-based support superstructure side of the bridge. The top of the superstructure should be four toothpicks long, and the bottom should be five toothpicks long. The top should be centered above the bottom. Ten toothpicks should be placed so that each toothpick connects one end of a toothpick on top to the end of a toothpick on bottom. The distance between the sides needs to be equal to the height of the triangles formed by the angled supports rather than the length of the toothpicks on the ends. Build the sides.



*Triangular support bridge side*

6. Draw two copies of a rectangular-based support superstructure side of the bridge. The side should have an outside boundary identical to the triangular-based support superstructure. Inside the frame, eight evenly spaced toothpicks should be placed perpendicular to both sides so they connect the two sides. Build the sides.

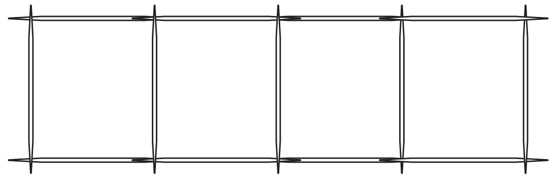


*Rectangular support bridge side*

**Note: (1)** You might wish to set a specific amount of time the students spend reading to ensure they do not skip this step.

**Note: (5)** The height of the superstructure will be less than the height of the toothpick because the slanted beams are each made from a single toothpick.

7. Build a top for each bridge similar to the roadbed but only four toothpicks long. Do not build a substructure for the bridge.



*Bridge top*

8. Assemble the bridges with the roadbeds and tops between the sides. Make sure the tops of the bridges are attached to the tops of the sides and the roadbeds are attached to the bottoms of the sides. Use tape to hold the bridges together temporarily.

   **Note: (8)** Students should use minimal tape.

9. Add drops of glue along the joints connecting the parts of the bridge.

   **Note: (9)** Do not allow students to use excessive amounts of glue.

10. After the glue has dried, remove the tape.

    **Note: (10)** Glue should dry overnight if possible.

11. Place the bridge across the space between two supports.

    **Note: (11)** Two tables work well as supports.

12. Place a test block along the roadbed.

    **Note: (12)** Make sure the test block does not overlap either support.

13. Attach the bridge tester to the test block so that the container hangs straight down from the block.

    **Note: (13)** If you use a commercial tester, consult the instructions that accompany it.

14. Gradually add sand, gravel, or another mass to the container until the bridge breaks.
15. Measure the amount of mass each bridge supported. Record this information on the back of the graph paper under your hypothesis. Also, record where the bridge broke.
16. Write a conclusion explaining your findings and evaluating your hypothesis.

    **Note: (16)** Students' conclusions should be at least one paragraph long.


## Quick View

Students calculate the efficiency of a bridge.

## Time Required

45 minutes (will vary with class size)

## Content Areas

Primary: Science

Secondary: Math, technology

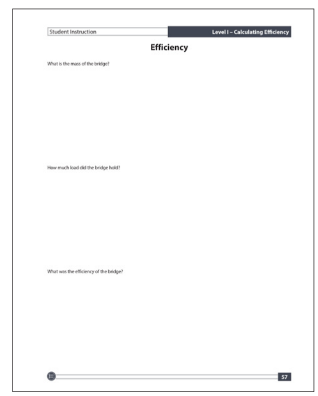
## Vocabulary

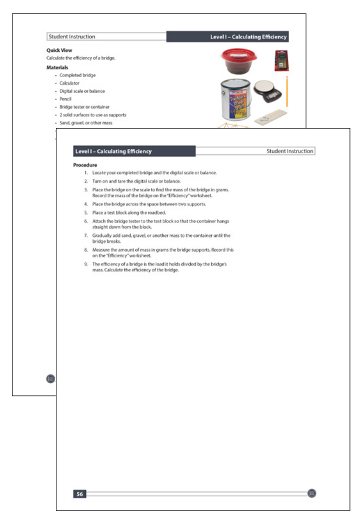
Glossary Resource: Pitsco.com/c/tb-glossary.pdf

- efficiency
- load
- mass

## Materials

- Completed bridge
- Calculator
- Digital scale or balance
- Pencil
- Bridge tester or container
- 2 solid surfaces to use as supports
- Sand, gravel, or other mass
- Test block
- “Efficiency” worksheet: Pitsco.com/c/tb-sp13.pdf
- Calculating Efficiency Student Instruction: Pitsco.com/c/tb-sp6.pdf



## Procedure

1. Locate your completed bridge and the digital scale or balance.
2. Turn on and tare the digital scale or balance.
3. Place the bridge on the scale to find the mass of the bridge in grams. Record the mass of the bridge on the "Efficiency" worksheet.
4. Place the bridge across the space between two supports.
5. Place a test block along the roadbed.
6. Attach the bridge tester to the test block so that the container hangs straight down from the block.
7. Gradually add sand, gravel, or another mass to the container until the bridge breaks.
8. Measure the amount of mass in grams the bridge supports. Record this on the "Efficiency" worksheet.
9. The efficiency of a bridge is the load it holds divided by the bridge's mass. Calculate the efficiency of the bridge.

**Note: (1)** Students can all use the same bridge or make their own bridge.

**Note: (3)** A digital scale or balance that measures to the nearest one-tenth of a gram is preferable.

**Note: (4)** Two tables work well as supports.

**Note: (5)** Make sure the test block does not overlap either support.

**Note: (7)** If you use a commercial tester, consult the instructions that accompany it.

**Note: (9)** Students will likely need to round the calculation. The nearest tenth is generally accurate enough.

## Quick View

Students use a set amount of resources to design and build the strongest possible bridge consisting of only a roadbed and substructure or superstructure.


## Time Required

180-270 minutes (will vary with class size)

## Content Areas

Primary: Math

Secondary: Science

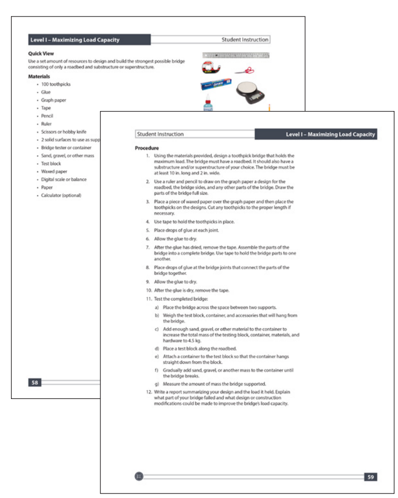
## Vocabulary

Glossary Resource: Pitsco.com/c/tb-glossary.pdf

- load
- substructure
- superstructure

## Materials

- 100 toothpicks
- Glue
- Graph paper
- Tape
- Pencil
- Ruler
- Scissors or hobby knife
- 2 solid surfaces to use as supports
- Bridge tester or container
- Sand, gravel, or other mass
- Test block
- Waxed paper
- Digital scale or balance
- Paper
- Maximizing Load Capacity Student Instruction: Pitsco.com/c/tb-sp7.pdf
- Calculator (optional)



## Procedure

1. Using the materials provided, design a toothpick bridge that holds the maximum load. The bridge must have a roadbed. It should also have a substructure and/or superstructure of your choice. The bridge must be at least 10 in. long and 2 in. wide.

**Note: (1)** If you have a bridge tester with a larger test block, you will need to modify the roadbed requirements to a size larger than the test block.

2. Use a ruler and pencil to draw on the graph paper a design for the roadbed, the bridge sides, and any other parts of the bridge. Draw the parts of the bridge full size.
3. Place a piece of waxed paper over the graph paper and then place the toothpicks on the designs. Cut any toothpicks to the proper length if necessary.

**Note: (3)** Closely supervise students using hobby knives and collect the knives as soon as students finish.

4. Use tape to hold the toothpicks in place.

**Note: (4)** Students should use minimal tape.

5. Place drops of glue at each joint.

**Note: (5)** Do not allow students to use excessive amounts of glue.

6. Allow the glue to dry.

**Note: (6)** Glue should dry overnight if possible.

7. After the glue has dried, remove the tape. Assemble the parts of the bridge into a complete bridge. Use tape to hold the bridge parts to one another.
8. Place drops of glue at the bridge joints that connect the parts of the bridge together.
9. Allow the glue to dry.
10. After the glue is dry, remove the tape.
11. Test the completed bridge:
    a) Place the bridge across the space between two supports.
    b) Weigh the test block, container, and accessories that will hang from the bridge.
    c) Add enough sand, gravel, or other material to the container to increase the total mass of the testing block, container, materials, and hardware to 4.5 kg.
    d) Place a test block along the roadbed.
    e) Attach a container to the test block so that the container hangs straight down from the block.
    f) Gradually add sand, gravel, or another mass to the container until the bridge breaks.
    g) Measure the amount of mass the bridge supported.

**Note: (11)** If you use a commercial tester, consult the instructions that accompany it.

12. Write a report summarizing your design and the load it held. Explain what part of your bridge failed and what design or construction modifications could be made to improve the bridge's load capacity.

**Note: (12)** Students' conclusions should be at least two paragraphs long. Students should justify any design modifications.

## Quick View

Students design and build a bridge to support a 4.5 kg load using the least possible amount of materials.

## Time Required

180-270 minutes (will vary with class size)

## Content Areas

Primary: Technology

Secondary: Math, science, language arts

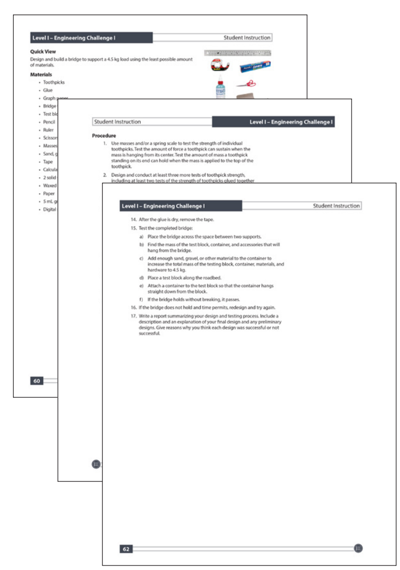
## Vocabulary

Glossary Resource: Pitsco.com/c/tb-glossary.pdf

- bridge
- load
- mass
- substructure
- superstructure

## Materials

- Toothpicks
- Glue
- Graph paper
- Bridge tester or container
- Test block
- Pencil
- Ruler
- Scissors or hobby knife
- Masses and/or spring scale
- Sand, gravel, or other mass
- Tape
- Calculator
- 2 solid surfaces to use as supports
- Waxed paper
- Paper
- Engineering Challenge I Student Instruction: Pitsco.com/c/tb-sp8.pdf
- 5 mL graduated droppers or cylinders (optional)
- Digital scale or balance (optional)

**Procedure**

1. Use masses and/or a spring scale to test the strength of individual toothpicks. Test the amount of force a toothpick can sustain when the mass is hanging from its center. Test the amount of mass a toothpick standing on its end can hold when the mass is applied to the top of the toothpick.
2. Design and conduct at least three more tests of toothpick strength, including at least two tests of the strength of toothpicks glued together at some kind of joint.

   **Note: (2)** Students must design the tests and explain how they will be conducted.
3. On the back of a piece of graph paper, write a paragraph explaining the tests you conducted and the results of these tests.

   **Note: (3)** Students should explain each test and summarize their conclusions based on their tests.
4. Based on the information from your tests and your knowledge of toothpick bridges, design a toothpick bridge that uses the minimum amount of material and will hold at least 4.5 kg of load. Material used is defined as the number of toothpicks and amount of glue used. Each toothpick or piece of toothpick used counts as a whole toothpick, so try to minimize waste. Each milliliter of glue is worth five toothpicks in material costs.
5. Use a ruler and pencil to draw on the graph paper a design for the roadbed, the bridge sides, and any other parts of the bridge. Draw the parts of the bridge full size.

   **Note: (5)** You might wish to have the students explain and justify their design before they begin the building process.
6. Place a piece of waxed paper over the graph paper and then place the toothpicks on the designs. Cut any toothpicks to the proper length if necessary.

   **Note: (6)** Closely supervise students using hobby knives and collect the knives as soon as students finish.
7. Use tape to hold the toothpicks in place.

   **Note: (7)** Students should use minimal tape.
8. Place drops of glue at each joint.

   **Note: (8)** Do not allow students to use excessive amounts of glue.
9. Allow the glue to dry.

   **Note: (9)** Glue should dry overnight if possible.
10. After the glue has dried, remove the tape. Assemble the parts of the bridge into a complete bridge. Use tape to hold the bridge parts to one another.
11. Place glue at the bridge joints that connect the parts of the bridge together.
12. Allow the glue to dry.
13. Calculate the total material used. Each toothpick equals one unit, and each milliliter of glue equals five units.

    **Note: (13)** Students' glue should be measured before and after their bridge construction to determine the amount of glue used. Measurement can be done using a small graduated cylinder or by weighing the glue bottle before and after students build their bridge.

14. After the glue is dry, remove the tape.
15. Test the completed bridge:
    a) Place the bridge across the space between two supports.
    b) Find the mass of the test block, container, and accessories that will hang from the bridge.
    c) Add enough sand, gravel, or other material to the container to increase the total mass of the testing block, container, materials, and hardware to 4.5 kg.
    d) Place a test block along the roadbed.
    e) Attach a container to the test block so that the container hangs straight down from the block.
    f) If the bridge holds without breaking, it passes.

**Note: (15)** If you use a commercial tester, consult the instructions that accompany it.

16. If the bridge does not hold and time permits, redesign and try again.

**Note: (16)** Testing and retesting are important engineering concepts. If possible, allocate time for testing and design modifications.

17. Write a report summarizing your design and testing process. Include a description and an explanation of your final design and any preliminary designs. Give reasons why you think each design was successful or not successful.

**Note: (17)** Students' conclusions should be at least two paragraphs long.

## Quick View

Students examine static forces acting on a toothpick bridge, test the strength of toothpicks, predict how much load a bridge will hold, and predict the failure point of a bridge.


## Time Required

180-270 minutes (will vary with class size)

## Content Areas

Primary: Science

Secondary: Math, technology

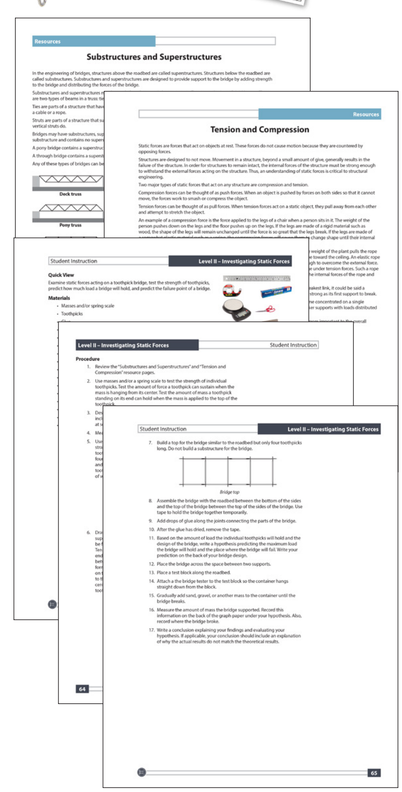
## Vocabulary

Glossary Resource: Pitsco.com/c/tb-glossary.pdf

- compression
- force
- load
- substructure
- superstructure
- tension

## Materials

- Masses and/or spring scale
- Toothpicks
- Glue
- Scissors or hobby knife
- Tape
- Ruler
- Graph paper
- Pencil
- Bridge tester or container
- Test block
- Sand, gravel, or other mass
- 2 solid surfaces to use as supports
- Waxed paper
- Digital scale or balance
- “Substructures and Superstructures” resource page: Pitsco.com/c/substructures-superstructures.pdf
- “Tension and Compression” resource page: Pitsco.com/c/tension-compression.pdf
- Investigating Static Forces Student Instruction: Pitsco.com/c/tb-sp9.pdf



## Procedure

1. Review the "Substructures and Superstructures" and "Tension and Compression" resource pages.

**Note: (1)** You might wish to set a specific amount of time the students spend reading to ensure they do not skip this step.

2. Use masses and/or a spring scale to test the strength of individual toothpicks. Test the amount of force a toothpick can sustain when the mass is hanging from its center. Test the amount of mass a toothpick standing on its end can hold when the mass is applied to the top of the toothpick.

**Note: (2)** Students must design their own method for supporting the mass on the toothpick.

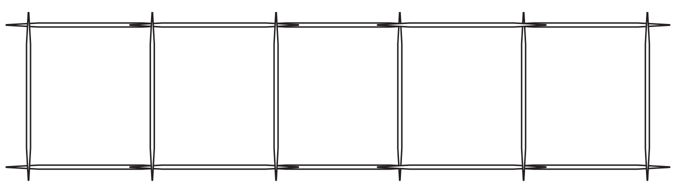
3. Design and conduct at least three more tests of toothpick strength, including at least two tests of the strength of toothpicks glued together at some kind of joint.

**Note: (3)** Make sure the students' tests each measure truly different scenarios.

4. Measure the length of the individual toothpicks.

5. Use the ruler to draw a design for the roadbed on graph paper. Use straight lines to represent the toothpicks. The roadbed will be five toothpicks long with adjacent toothpicks overlapping each other one-fourth inch. Place six toothpicks between each side of the roadbed and perpendicular to the sides: one toothpick on each end and one toothpick at every point where the side toothpicks overlap. Place a piece of waxed paper over your drawings and build the roadbed.

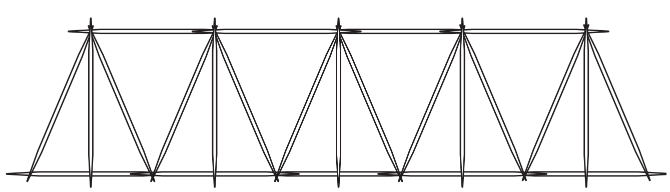
**Note: (5)** Make sure the students' toothpicks are evenly spaced along the roadbed.



*Toothpick bridge roadbed*

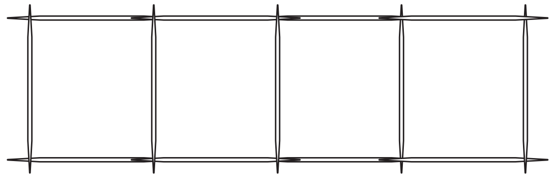
6. Draw two copies of the superstructure side of the bridge. The top of the superstructure should be four toothpicks long, and the bottom should be five toothpicks long. The top should be centered above the bottom. Ten toothpicks should be placed so that each toothpick connects one end of a toothpick on top and the other end on bottom. The distance between the sides needs to be equal to the height of the triangles formed by the angled supports rather than the length of the toothpicks on the ends. Five vertical toothpicks should be placed perpendicular to the top and bottom. The vertical toothpicks should run from the center of the bottom toothpicks to the end of the corresponding top toothpicks. Build the sides.

**Note: (6)** The height of the superstructure will be less than the height of a toothpick because the slanted beams are each made from a single toothpick.



*Superstructure bridge side*

7. Build a top for the bridge similar to the roadbed but only four toothpicks long. Do not build a substructure for the bridge.



*Bridge top*

8. Assemble the bridge with the roadbed between the bottom of the sides and the top of the bridge between the top of the sides of the bridge. Use tape to hold the bridge together temporarily.

**Note: (8)** Students should use minimal tape.

9. Add drops of glue along the joints connecting the parts of the bridge.

10. After the glue has dried, remove the tape.

**Note: (10)** Glue should dry overnight if possible.

11. Based on the amount of load the individual toothpicks will hold and the design of the bridge, write a hypothesis predicting the maximum load the bridge will hold and the place where the bridge will fail. Write your prediction on the back of your bridge design.

**Note: (11)** Make sure students' descriptions of where the bridge will fail are clear enough that the location can be identified before the test.

12. Place the bridge across the space between two supports.

13. Place a test block along the roadbed.

**Note: (13)** Make sure the test block does not overlap either support.

14. Attach the bridge tester to the test block so the container hangs straight down from the block.

15. Gradually add sand, gravel, or another mass to the container until the bridge breaks.

**Note: (15)** If you use a commercial tester, consult the instructions that accompany it.

16. Measure the amount of mass the bridge supported. Record this information on the back of the graph paper under your hypothesis. Also, record where the bridge broke.

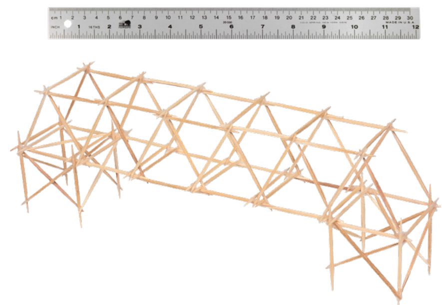
**Note: (16)** The students should write a clear description of the location of the bridge failure without referencing their original hypothesis.

17. Write a conclusion explaining your findings and evaluating your hypothesis. If applicable, your conclusion should include an explanation of why the actual results do not match the theoretical results.

**Note: (17)** Students' conclusions should be at least one paragraph long.

## Quick View

Students calculate the cost of building a bridge based on a toothpick scale model.



## Time Required

90-180 minutes (will vary with class size)

## Content Areas

Primary: Math

Secondary: Science, technology

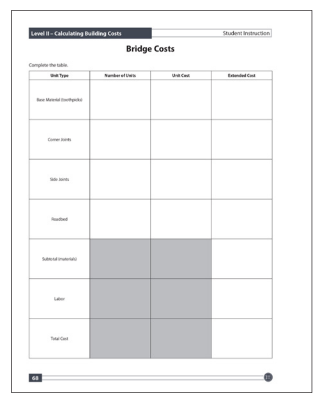

## Vocabulary

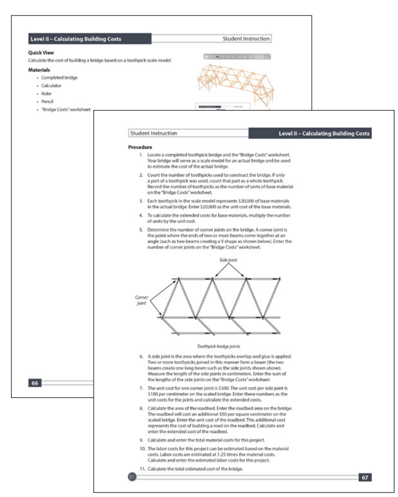
Glossary Resource: Pitsco.com/c/tb-glossary.pdf

- estimate
- labor cost
- materials
- scale model
- unit cost

## Materials

- Completed bridge
- Calculator
- Ruler
- Pencil
- "Bridge Costs" worksheet: Pitsco.com/c/tb-sp14.pdf
- Calculating Building Costs Student Instruction: Pitsco.com/c/tb-sp10.pdf



## Procedure

1. Locate a completed toothpick bridge and the "Bridge Costs" worksheet. Your bridge will serve as a scale model for an actual bridge and be used to estimate the cost of the actual bridge.

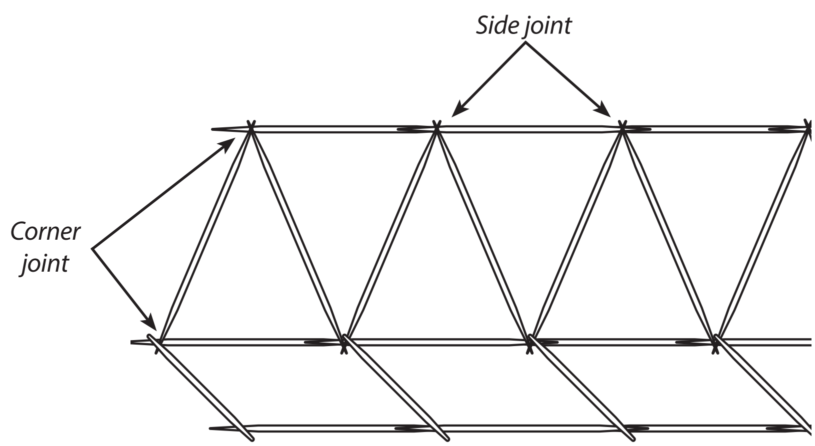
**Note: (1)** You may have all students use identical bridges or let them calculate the costs for a bridge they designed and built themselves.

2. Count the number of toothpicks used to construct the bridge. If only a part of a toothpick was used, count that part as a whole toothpick. Record the number of toothpicks as the number of units of base material on the "Bridge Costs" worksheet.
3. Each toothpick in the scale model represents $20,000 of base materials in the actual bridge. Enter $20,000 as the unit cost of the base materials.
4. To calculate the extended costs for base materials, multiply the number of units by the unit cost.

**Note: (2)** Make sure all students account for all full and partial toothpicks. You may modify the activity by allowing the students to count half toothpicks rather than counting all partial toothpicks as full toothpicks.

5. Determine the number of corner joints on the bridge. A corner joint is the point where the ends of two or more beams come together at an angle (such as two beams creating a V shape as shown below). Enter the number of corner joints on the "Bridge Costs" worksheet.

**Note: (5)** Make sure students count points at which more than two beams come together as a single joint.




*Toothpick bridge joints*

6. A side joint is the area where the toothpicks overlap and glue is applied. Two or more toothpicks joined in this manner form a beam (the two beams create one long beam such as the side joints shown above). Measure the length of the side joints in centimeters. Enter the sum of the lengths of the side joints on the "Bridge Costs" worksheet.
7. The unit cost for one corner joint is $500. The unit cost per side joint is $100 per centimeter on the scaled bridge. Enter these numbers as the unit costs for the joints and calculate the extended costs.
8. Calculate the area of the roadbed. Enter the roadbed area on the bridge. The roadbed will cost an additional $50 per square centimeter on the scaled bridge. Enter the unit cost of the roadbed. This additional cost represents the cost of building a road on the roadbed. Calculate and enter the extended cost of the roadbed.

**Note: (8)** The roadbed is rectangular, so students will calculate the area by finding the product of the length and the width of the roadbed. Make sure students enter units.

9. Calculate and enter the total material costs for this project.

10. The labor costs for this project can be estimated based on the material costs. Labor costs are estimated at 1.25 times the material costs. Calculate and enter the estimated labor costs for this project.

11. Calculate the total estimated cost of the bridge.

**Note: (9)** Students find the sum of the extended costs for the materials.

**Note: (10)** Students should not round this figure.

**Note: (11)** Students find the sum of the material and labor costs.

## Quick View

Students design and construct a bridge with the maximum possible efficiency.

## Time Required

90-180 minutes (will vary with class size)

## Content Areas

Primary: Technology

Secondary: Math, science, language arts

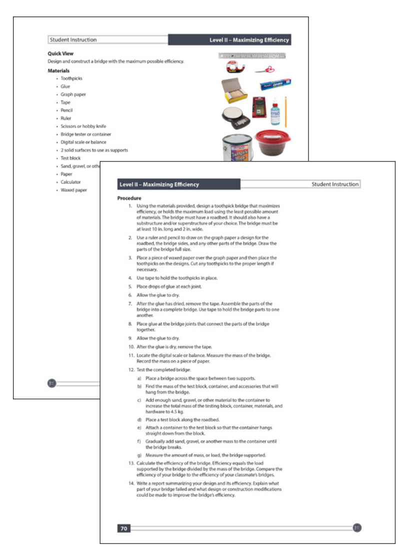
## Vocabulary

Glossary Resource: Pitsco.com/c/tb-glossary.pdf

- load
- substructure
- superstructure

## Materials

- Toothpicks
- Glue
- Graph paper
- Tape
- Pencil
- Ruler
- Scissors or hobby knife
- Bridge tester or container
- Digital scale or balance
- 2 solid surfaces to use as supports
- Test block
- Sand, gravel, or other mass
- Paper
- Calculator
- Waxed paper
- Maximizing Efficiency Student Instruction: Pitsco.com/c/tb-sp11.pdf

## Procedure

1. Using the materials provided, design a toothpick bridge that maximizes efficiency, or holds the maximum load using the least possible amount of materials. The bridge must have a roadbed. It should also have a substructure and/or superstructure of your choice. The bridge must be at least 10 in. long and 2 in. wide.
2. Use a ruler and pencil to draw on the graph paper a design for the roadbed, the bridge sides, and any other parts of the bridge. Draw the parts of the bridge full size.

   **Note: (2)** Approve students' designs before they build their bridge. If the bridge is not legal because it cannot be tested, calls for too much glue, or for any other reason, have them modify their designs before building the bridge.
3. Place a piece of waxed paper over the graph paper and then place the toothpicks on the designs. Cut any toothpicks to the proper length if necessary.

   **Note: (3)** Closely supervise students using hobby knives and collect the knives as soon as students finish.
4. Use tape to hold the toothpicks in place.

   **Note: (4)** Students should use minimal tape.
5. Place drops of glue at each joint.

   **Note: (5)** Do not allow students to use excessive amounts of glue.
6. Allow the glue to dry.

   **Note: (6)** Glue should dry overnight if possible.
7. After the glue has dried, remove the tape. Assemble the parts of the bridge into a complete bridge. Use tape to hold the bridge parts to one another.
8. Place glue at the bridge joints that connect the parts of the bridge together.
9. Allow the glue to dry.
10. After the glue is dry, remove the tape.
11. Locate the digital scale or balance. Measure the mass of the bridge. Record the mass on a piece of paper.

    **Note: (11)** A digital scale or balance that measures to the nearest one-tenth of a gram is best for this activity.
12. Test the completed bridge:

    **Note: (12)** If you use a commercial tester, consult the instructions that accompany it.

    a) Place a bridge across the space between two supports.
    b) Find the mass of the test block, container, and accessories that will hang from the bridge.
    c) Add enough sand, gravel, or other material to the container to increase the total mass of the testing block, container, materials, and hardware to 4.5 kg.
    d) Place a test block along the roadbed.
    e) Attach a container to the test block so that the container hangs straight down from the block.
    f) Gradually add sand, gravel, or another mass to the container until the bridge breaks.
    g) Measure the amount of mass, or load, the bridge supported.

13. Calculate the efficiency of the bridge. Efficiency equals the load supported by the bridge divided by the mass of the bridge. Compare the efficiency of your bridge to the efficiency of your classmate's bridges.

**Note: (13)** While students can usually round to the nearest tenth, it might be necessary to calculate to hundredths or thousandths to break ties if students are competing against each other.

14. Write a report summarizing your design and its efficiency. Explain what part of your bridge failed and what design or construction modifications could be made to improve the bridge's efficiency.

**Note: (14)** Students' conclusions should be at least two paragraphs long.

## Quick View

Students design and build two bridges with the same efficiency with one bridge weighing half as much as the other.

**Note:** Students might have more success with this activity if they have completed the Calculating Efficiency activity and/or Maximizing Efficiency activity.

## Time Required

180-260 minutes (will vary with class size)

## Content Areas

Primary: Technology

Secondary: Math, science, language arts

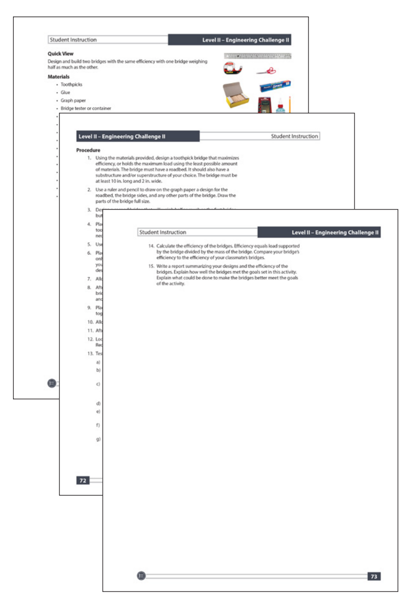
## Vocabulary

Glossary Resource: Pitsco.com/c/tb-glossary.pdf

- efficiency
- load

## Materials

- Toothpicks
- Glue
- Graph paper
- Bridge tester or container
- Test block
- Pencil
- Ruler
- Scissors or hobby knife
- Digital scale or balance
- Sand, gravel, or other mass
- Tape
- 2 solid surfaces to use as supports
- Paper
- Calculator
- Waxed paper
- Engineering Challenge II Student Instruction: Pitsco.com/c/tb-sp12.pdf

## Procedure

1. Using the materials provided, design a toothpick bridge that maximizes efficiency, or holds the maximum load using the least possible amount of materials. The bridge must have a roadbed. It should also have a substructure and/or superstructure of your choice. The bridge must be at least 10 in. long and 2 in. wide.

**Note: (1)** You could set limits on the amount of material or the maximum mass of the bridges if the students begin creating designs that use so much material the project costs become excessive. Teams of two students can build a bridge so that collaboration can be practiced.

2. Use a ruler and pencil to draw on the graph paper a design for the roadbed, the bridge sides, and any other parts of the bridge. Draw the parts of the bridge full size.

**Note: (2)** Approve students' designs before they build their bridge. If the bridge is not legal because it cannot be tested, calls for too much glue, or for any other reason, have them modify their designs before building the bridge.

3. Design a second bridge that will weigh half as much as the first bridge but will have the same efficiency.

**Note: (3)** Students should make a drawing of their second bridge using the same process as their first. You may ask students to justify why their bridge design will meet the requirements before you allow them to build it.

4. Place a piece of waxed paper over the graph paper and then place the toothpicks on the designs. Cut any toothpicks to the proper length if necessary.

**Note: (4)** Closely supervise students using hobby knives and collect the knives as soon as students finish.

5. Use tape to hold the toothpicks in place.

**Note: (5)** Students should use minimal tape.

6. Place drops of glue at each joint. Follow your design plan. Apply glue only to places indicated in your design. If you apply glue to places not on your design, you must get approval and note the modification on your design.
7. Allow the glue to dry.

**Note: (7)** Glue should dry overnight if possible.

8. After the glue has dried, remove the tape. Assemble the parts of the bridge into a complete bridge. Use tape to hold the bridge parts to one another.
9. Place glue at the bridge joints that connect the parts of the bridge together.
10. Allow the glue to dry.
11. After the glue is dry, remove the tape.
12. Locate the digital scale or balance. Measure the mass of the bridge. Record the mass.

**Note: (12)** A digital scale or balance that measures to the nearest one-tenth of a gram is best for this activity.

13. Test the completed bridge:
    a) Place a bridge across the space between two supports.
    b) Find the mass of the test block, container, and accessories that will hang from the bridge.
    c) Add enough sand, gravel, or other material to the container to increase the total mass of the testing block, container, materials, and hardware to 4.5 kg.
    d) Place a test block along the roadbed.
    e) Attach a container to the test block so that the container hangs straight down from the block.
    f) Gradually add sand, gravel, or another mass to the container until the bridge breaks.
    g) Measure the amount of mass, or load, the bridge supported.

**Note: (13)** If you use a commercial tester, consult the instructions that accompany it.

14. Calculate the efficiency of the bridges. Efficiency equals load supported by the bridge divided by the mass of the bridge. Compare your bridge's efficiency to the efficiency of your classmate's bridges.

**Note: (14)** While students can usually round to the nearest tenth, it might be necessary to calculate to hundredths or thousandth to break ties if students are competing against each other.

15. Write a report summarizing your designs and the efficiency of the bridges. Explain how well the bridges met the goals set in this activity. Explain what could be done to make the bridges better meet the goals of the activity.

**Note: (15)** Students' conclusions should be at least two paragraphs long.

## Supplemental Lessons

Listed below are ideas for other lessons that can be developed to engage and challenge students with materials and equipment used in this teacher guide. Suggestions can be combined by you or the students to create a larger scope of study.

- Determine the strength of a single toothpick, two toothpicks, and four toothpicks.
- Build toothpick towers.
- Build a bridge. Then, build a larger version with all dimensions doubled. Compare the load capacities and efficiencies of the two bridges.
- Determine the mass and load of all bridges from the class. Graph mass versus load of each bridge.
- Determine the mass, load, and efficiency of all bridges from the class. Graph mass versus efficiency of each bridge.
- Research the history of bridges and various bridge designs.

# Vocabulary

bridge

compression

efficiency

estimate

force

labor cost

load

mass

materials

scale model

substructure

superstructure

tension

unit cost

# Glossary

**bridge:** a pathway spanning a stream, valley, or road; anything that spans a gap

**compression:** the tendency to push, squash, or squeeze a material

**efficiency:** the strength-to-mass ratio

**estimate:** to approximate the value, amount, worth, or significance of something

**force:** the capacity to do work or cause physical change; energy, strength, or active power

**labor cost:** the cost of paying workers to do a specific job

**load:** the overall force to which a structure is subjected in supporting a mass or in resisting externally applied forces

**mass:** the amount of matter within an object

**materials:** substances that are used in the making of other things

**scale model:** generally, a smaller representation of an object created so that all parts remain in proportion with each other and with the original

**substructure:** the structure of a bridge that extends below the roadbed

**superstructure:** the structure of a bridge that extends above the roadbed

**tension:** the force pulling a material apart

**unit cost:** the cost of an individual item

## Careers Related to Structural Engineering

The activities in this unit are a small part a larger field called structural engineering. Careers in or concerning structures can be fun, challenging, and rewarding. Use the following links to see videos concerning structure-related careers. Then, explore the websites to learn more about other careers related to structural engineering.

- Civil Engineers: Pitsco.com/c-cv17-2051-01
- Structural Iron and Steel Workers: Pitsco.com/c-cv47-2221-00
- Construction and Building Inspectors: Pitsco.com/c-cv47-4011-00
- Bridge and Lock Tenders: Pitsco.com/c-cv53-6011-00
- Rough Carpenters: Pitsco.com/c-cv47-2031-02

### Military Careers

Students may search the following sites for potential careers within the military related to structural engineering:

- Air Force: Pitsco.com/c-cv-mc-air-force
- Army: Pitsco.com/c-cv-mc-army
- Coast Guard: Pitsco.com/c-cv-mc-coast-guard
- Marine Corps: Pitsco.com/c-cv-mc-marine-corps
- National Guard: Pitsco.com/c-cv-mc-national-guard
- Navy: Pitsco.com/c-cv-mc-navy

Additional information about each career can be found by exploring the following websites:

- *Occupational Outlook Handbook:* Pitsco.com/c-ooh
- O*NET – Occupational Information Network: Pitsco.com/c-onet

### Activity Suggestion

Have students create a "Structural and Civil Careers" pamphlet detailing career information such as skills required, nature of work, and level of education needed. Students should include information about at least two careers.

### Careers

Pitsco.com/c/career.pdf

Students can use the "Careers" worksheet to help them gather information about a career by using the *OOH* and O*NET websites. They might find other related careers of interest they would like to explore. Print extra "Careers" worksheet if needed.

# Careers

## *Occupational Outlook Handbook* Research

Career Title: ______________________________

| Career Summary | | | |
|---|---|---|---|
| **Median Pay** | **$** | **Current Number of Jobs** | |
| **Lowest 10% Pay** | **$** | **Projected Job Growth %** | |
| **Highest 10% Pay** | **$** | | |
| **What do people in this career do?** | | | |

What are the pros and cons of a career in this field? Justify your answer using information from the *OOH*.

Would you consider a career in this field? State the reasons for your decision. Cite evidence from the *OOH* that supports your decision. (For example: *I would not consider a career in this field. One of the reasons is that I do not like cold weather and the* OOH *states that these jobs exist only in regions close to the Arctic Circle.*)

# Lab Report Template

**Title**

## Abstract

The abstract is a short paragraph that summarizes your experiment. Include applicable information about your experimental subjects, materials and methods, results, and conclusions. The abstract is the part of the report that others will read to see if they are interested in the topic.

## Introduction

The introduction should give background information on the experiment. It should include an explanation of the general problem or area being investigated. The introduction should outline what information is already known about the problem. In building this part of your report, you might want to consult references or, at the very least, reread the text. Be sure to keep track of the information and list all references used.

The introduction should also present the question you are trying to answer or the hypothesis you are testing. Include what outcome you expect and how it would support or disprove your hypothesis or answer your question. Distinguish between the hypothesis and the experiment you will do to test the hypothesis.

## Materials and Methods

This section should include a concise, step-by-step numbered description of the materials, procedures, and equipment you used. Clearly describe the experimental situation, the control situation, and the type of observations you made. This should be detailed so that someone else could repeat your work. Do not include the rationale for your work in this section. Be sure to write this report as a past event, not as a set of instructions for the reader.

## Results

This section should describe what happened. Include your raw data sheets or refer to the reference section of the report where they can be found. Present your findings in a logical order, not a chronological order. Give the results that you found, not what you think you should have found. Do not explain your results in this section. Results can be reported in the form of graphs, tables, or drawings. Be sure that the data recorded are single readings or averages.

## Conclusion/Discussion

Give your interpretations of the data and relate them to the questions posed in the introduction. Avoid making this section a repetition of the introduction. If you have data to explain or a new hypothesis of why the results were unexpected, list them here.

Draw some conclusions, supporting them with your data. Did the results answer your question? Did they support or disprove your hypothesis? What is the significance of your results? Should further experiments be performed to clear up discrepancies or ambiguities in your results?

## References

In this section, list the data that was concluded during the experiment. This could include graphs, charts, drawings, or data tables. In the Results section, you explained what happened; in this section, provide quantitative proof that your results are accurate.

# History of Bridges

It is easy to see why people need bridges. Can you imagine trying to cross the Mississippi River without one? That is what pioneers faced centuries ago.

Cross-country journeys often required travelers to go miles out of their way to cross a river or creek at a narrow, shallow point or wait weeks for a swollen river to go down enough to cross. Even under the best of circumstances, the crossings were very dangerous.

One of the first ways in which people tried to remedy this situation was by laying logs across supporting timbers. Bridges built in this fashion were not very stable or strong. Wood deteriorates when left out in the elements, leading to even less stability. For this reason, some bridge builders in the 19th century, most notably in the US, began placing roofs over the bridges to protect them from all forms of precipitation. Many of these covered bridges still exist.

A more weather-resistant material for building bridges is stone. Simple bridges primarily for pedestrian crossings were constructed of large stone slabs supported by dry-stone pillars. They are thought to have been constructed mainly during medieval times. This type of bridge is called a clapper bridge, and a few of them can still be found in England today.

The Romans also used stone to build arch bridges. The Romans were probably the most-skilled bridge builders in ancient times. They created road and bridge networks throughout the Roman Empire, often using concrete to bond stones together in their bridgework.

However, the first known Roman bridge was made of wooden beams. The Pons Sublicius was constructed across the Tiber River. Experts differ on when the Pons Sublicius was built, but all seem to agree that it was before the first century A.D.

After the fall of the Roman Empire, bridge-building technology was on hold until the 18th or 19th century. The Industrial Revolution occurred around that time as well. Around 1825, Scottish engineer Thomas Telford used iron to build the first large suspension bridge.

Iron was also used to build long beam bridges. But the development of steel allowed for even better bridges to be built in the 20th century. Steel began replacing iron in suspension bridges and was also used to create reinforced concrete.

The Golden Gate Bridge in San Francisco, California, designed by Joseph Strauss in the 1930s, is one of many bridges built using a combination of steel and reinforced concrete.

There are many different types of bridges. Each type has pros and cons, strengths and weaknesses. The span and load capacity needed and the materials and funds available are some of the factors used to determine what style of bridge will be built in a specific location.

The world will have to wait and see what innovations the engineers of tomorrow will come up with to build the bridges of the future.

# Biography

## Horace King

Horace King, born into slavery in 1807 in South Carolina, was of African, Native American, and European descent.

In 1829, King came under the ownership of John Godwin, a man who would have a significant impact on King's life. Godwin was a contractor, and King became his partner as well as his servant. Godwin and King together built the first bridge, a covered bridge, across the Chattahoochee River around 1832. It connected Columbus, Georgia, with Girard, Alabama. (Girard was later renamed Phenix City.)

The pair continued building covered bridges in Georgia, Alabama, and a few neighboring states. King's skill at bridge-building began to eclipse his master's, and during the 1840s he became the superintendent and architect of bridges built in Alabama and Mississippi without Godwin's supervision.

The style of bridges that King built was similar to the Town lattice truss bridges invented by Ithiel Town. King is credited with building approximately 100 such bridges throughout the Deep South.

In 1846, Godwin granted King his freedom, which was not a simple procedure and required the authorization of the Alabama State Legislature. The two men were apparently close; and upon Godwin's death in 1859, King purchased a very expensive headstone for Godwin's grave on which he proclaimed his "love and gratitude" for his friend and former master.

Ironically, Godwin died penniless and his family was unable to purchase a headstone themselves.

During the Civil War, King, like other contractors in the South, was kept busy building things for the Confederacy. After the Civil War, he was elected to the Alabama State Legislature as a Republican for two terms. He and his family later moved to LeGrange, Georgia, where he continued to build things. By this time, he had expanded his construction business to include commercial buildings, public buildings, and houses.

King died in LeGrange in the mid- to late 1880s (sources differ as to the exact date) and left his business, King Brothers Bridge Company, to his children.

His memory is kept alive in the South by a monument erected to him in Phenix City, Alabama, and a street named after him in LeGrange, Georgia. Tourists may also travel across an authentic King bridge in Meriwether County, Georgia, near Atlanta.

Horace King is remembered not only as a master bridge builder but also as a man who overcame the unfortunate circumstances of his birth to succeed at a level to which few can rise.

# Tension and Compression

Static forces are forces that act on objects at rest. These forces do not cause motion because they are countered by opposing forces.

Structures are designed to not move. Movement in a structure, beyond a small amount of give, generally results in the failure of the structure. In order for structures to remain intact, the internal forces of the structure must be strong enough to withstand the external forces acting on the structure. Thus, an understanding of static forces is critical to structural engineering.

Two major types of static forces that act on any structure are compression and tension.

Compression forces can be thought of as push forces. When an object is pushed by forces on both sides so that it cannot move, the forces work to smash or compress the object.

Tension forces can be thought of as pull forces. When tension forces act on a static object, they pull away from each other and attempt to stretch the object.

An example of a compression force is the force applied to the legs of a chair when a person sits in it. The weight of the person pushes down on the legs and the floor pushes up on the legs. If the legs are made of a rigid material such as wood, the shape of the legs will remain unchanged until the force is so great that the legs break. If the legs are made of a somewhat elastic material such as a spring, the compression forces will cause them to change shape until their internal forces match the level of the external forces.

The forces acting on a rope holding a hanging plant are examples of tension forces. The weight of the plant pulls the rope toward the ground. The force of the hook attaching the rope to the ceiling pulls the rope toward the ceiling. An elastic rope will stretch under tension forces until the internal forces of the rope become great enough to overcome the external force. This causes the elastic rope's length to change. The length of a rigid rope will not change under tension forces. Such a rope will remain the same length until the external forces of the rope become greater than the internal forces of the rope and the rope breaks.

Structures are designed to distribute the forces. Just as a chain is only as strong as its weakest link, it could be said a structure is only as strong as its weakest support. More accurately, a structure is only as strong as its first support to break.

If a structure does not distribute the forces acting on it properly, the forces might become concentrated on a single support. Even if this support is twice as strong as all the others, it might fail before weaker supports with loads distributed among several other supports.

For this reason, designing a structure that distributes the weight properly can be even more important to the overall strength of the structure than finding the strongest material.

# Substructures and Superstructures

In the engineering of bridges, structures above the roadbed are called superstructures. Structures below the roadbed are called substructures. Substructures and superstructures are designed to provide support to the bridge by adding strength to the bridge and distributing the forces of the bridge.

Substructures and superstructures may be made from beams, girders, or trusses. Trusses are lattices of rigid beams. There are two types of beams in a truss: ties and struts.

Ties are parts of a structure that have tension forces acting upon them. A tie may be a beam such as in a truss, or it may be a cable or a rope.

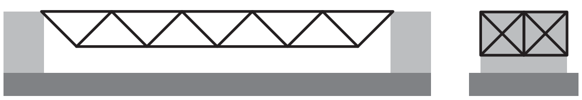
Struts are parts of a structure that support compression forces. Struts built at an angle distribute the force better than vertical struts do.

Bridges may have substructures, superstructures, or both. A deck configuration bridge has a roadbed that sits on top of a substructure and contains no superstructure.

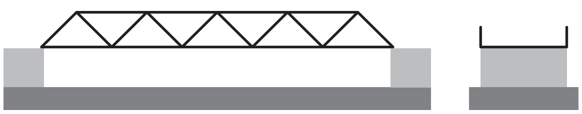
A pony bridge contains a superstructure of two sides with no cross bracing connecting the sides.

A through bridge contains a superstructure consisting of two sides and a top brace connecting the sides.

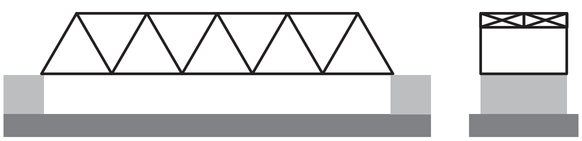
Any of these types of bridges can be designed and built using any truss design.



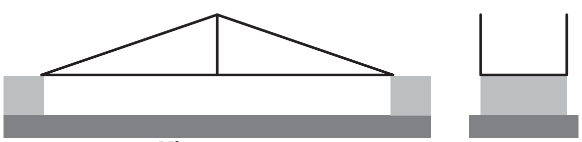
**Deck truss**



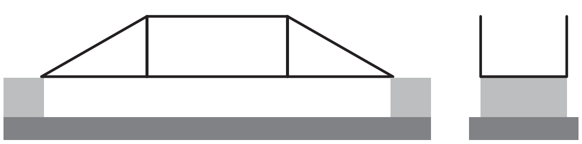
**Pony truss**



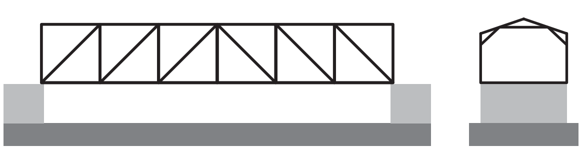
**Through truss**



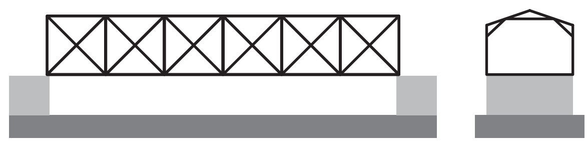
**King post**



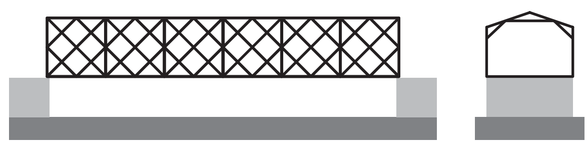
**Queen post**



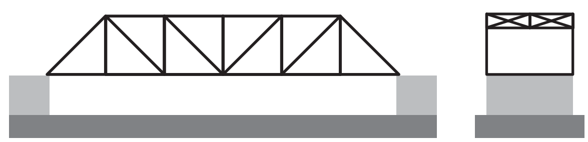
**Multiple king post truss (covered)**



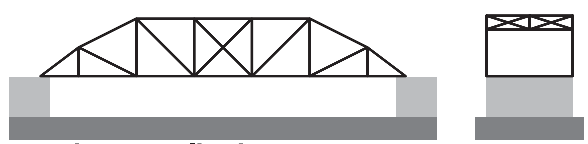
**Long "X" truss (covered)**



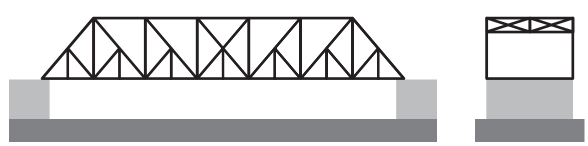
**Town lattice truss (covered)**



**Pratt truss**



**Parker "camelback" (Pratt) truss**



**Baltimore (Pratt) truss**

## Additional Resources

To find these resources, please refer to Pitsco's *Big Book* catalog or visit Pitsco.com. To order a free copy of this catalog, call 800-358-4983.

### Book

*Building Toothpick Bridges* by Jeanne Pollard: Pitsco.com/Building-Toothpick-Bridges

### Videos

*Dr. Zoon Toothpick Bridges*: Pitsco.com/Dr-Zoon-Toothpick-Bridges-Video

*Understanding Bridges*: Pitsco.com/Understanding-Bridges-Video

### Websites

Pghbridges.com/basics.htm

Howstuffworks.com/bridge.htm

### Digital Resources

Toothpick Bridges Video – Overview: Pitsco.com/c/v-toothpick-bridges.mp4

Toothpick Bridges Video – Design: Pitsco.com/c/v-toothpick-bridges-design.mp4

Toothpick Bridges Video – Layout: Pitsco.com/c/v-toothpick-bridges-layout.mp4

Toothpick Bridges Video – Gluing: Pitsco.com/c/v-toothpick-bridges-glueing.mp4

Toothpick Bridges Video – Removal: Pitsco.com/c/v-toothpick-bridges-removal.mp4

Toothpick Bridges Video – 2 Sides: Pitsco.com/c/v-toothpick-bridges-2sides.mp4

Toothpick Bridges Video – Testing: Pitsco.com/c/v-toothpick-bridges-testing.mp4

### Printable Resources

"History of Bridges" resource page: Pitsco.com/c/history-bridges.pdf

"Biography: Horace King" resource page: Pitsco.com/c/bio-hking.pdf

"Tension and Compression" resource page: Pitsco.com/c/tension-compression.pdf

"Substructures and Superstructures" resource page: Pitsco.com/c/substructures-superstructures.pdf

"4Cs" resource page: Pitsco.com/c/4cs.pdf

Career Video Links: Pitsco.com/c/tb-career.pdf

Vocabulary List: Pitsco.com/c/tb-vocab.pdf

Pretest I: Pitsco.com/c/tb-pre1.pdf

Pretest I Answer Key: Pitsco.com/c/13517.pdf

Pretest II: Pitsco.com/c/tb-pre2.pdf

Pretest II Answer Key: Pitsco.com/c/66950.pdf

Posttest I: Pitsco.com/c/tb-post1.pdf

Posttest I Answer Key: Pitsco.com/c/42000.pdf

Posttest II: Pitsco.com/c/tb-post2.pdf

Posttest II Answer Key: Pitsco.com/c/47606.pdf

1. What is the part of the bridge above the roadbed called?

2. What is the part of the bridge below the roadbed called?

3. What is the efficiency of an 8 g bridge that holds a 244 g ounce load?

4. The Golden Gate Bridge is an example of what type of bridge?

A. suspension bridge

B. hanging bridge

C. arch bridge

D. covered bridge

5. What bridge engineer of African, Native American, and European descent designed and built more than 100 bridges across the South during his life?

A. John Goodwin

B. Horace King

C. George Washington Carver

D. Joseph Strauss

6. What type of force pushes both sides of a beam?

A. tension

B. compression

C. static

D. dynamic

7. What type of force does a tie support?

8. What type of force acts on a strut?

9. A lattice of beams that is used as a superstructure or substructure of a bridge is called a ________.

A. strut

B. tie

C. truss

D. girder

10. Which type of beam distributes the load on a bridge best?

A. vertical

B. horizontal

C. diagonal

1. Where is the substructure of a bridge located in relation to the roadbed?

2. Where is the superstructure of a bridge located in relation to the roadbed?

3. What is the efficiency of a 6 g bridge that holds a 228 g load?

4. The Golden Gate Bridge is an example of what type of bridge?

   A. suspension bridge
   B. hanging bridge
   C. arch bridge
   D. covered bridge

5. What bridge engineer of African, Native American, and European descent designed and built more than 100 bridges across the South during his life?

   A. John Goodwin
   B. Horace King
   C. George Washington Carver
   D. Joseph Strauss

6. What type of force pulls both sides of a beam?

   A. tension
   B. compression
   C. static
   D. dynamic

7. What type of force does a strut support?

8. What type of force acts on a tie?

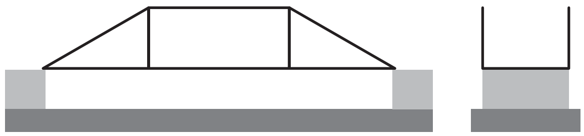
9. A lattice of beams that is used as a superstructure or substructure of a bridge is called a ________.

   A. strut
   B. tie
   C. truss
   D. girder

10. Which type of beam distributes the load on a bridge best?

    A. vertical
    B. horizontal
    C. diagonal

1. What is the part of the bridge above the roadbed called?



2. What type of truss is shown here?

A. king post
B. queen post
C. Howe
D. Pratt

3. What is the efficiency of an 8 g bridge that holds a 228 g load?

4. The Golden Gate Bridge is an example of what type of bridge?

A. suspension bridge
B. hanging bridge
C. arch bridge
D. covered bridge

5. What bridge engineer of African, Native American, and European descent designed and built more than 100 bridges across the South during his life?

A. John Goodwin
B. Horace King
C. George Washington Carver
D. Joseph Strauss

6. What type of force pulls both sides of a beam?

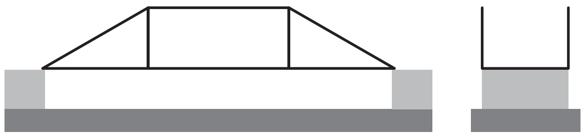
7. What type of force does a strut support?

8. What type of force acts on a tie?

9. A lattice of beams that is used as a superstructure or substructure of a bridge is called a ________.

10. Which type of beam distributes the load on a bridge best?

1. Where is the substructure of a bridge located in relation to the roadbed?



2. What type of truss is shown here?

A. king post
B. queen post
C. Howe
D. Pratt

3. What is the efficiency of a 6 g bridge that holds a 221 g load?

4. The Golden Gate Bridge is an example of what type of bridge?

A. suspension bridge
B. hanging bridge
C. arch bridge
D. covered bridge

5. What bridge engineer of African, Native American, and European descent designed and built more than 100 bridges across the South during his life?

A. John Goodwin
B. Horace King
C. George Washington Carver
D. Joseph Strauss

6. What type of force pushes on both sides of a beam?

7. What type of force does a tie support?

8. What type of force acts on a strut?

9. A lattice of beams that is used as a superstructure or substructure of a bridge is called a ________.

10. Which type of beam distributes the load on a bridge best?

1. What is the part of the bridge above the roadbed called?

   ***superstructure***

2. What is the part of the bridge below the roadbed called?

   ***substructure***

3. What is the efficiency of an 8 g bridge that holds a 244 g load?

   ***30.5***

4. The Golden Gate Bridge is an example of what type of bridge?

   ***A. suspension bridge***   C. arch bridge

   B. hanging bridge   D. covered bridge

5. What bridge engineer of African, Native American, and European descent designed and built more than 100 bridges across the South during his life?

   A. John Goodwin   C. George Washington Carver

   ***B. Horace King***   D. Joseph Strauss

6. What type of force pushes both sides of a beam?

   A. tension   C. static

   ***B. compression***   D. dynamic

7. What type of force does a tie support?

   ***tension***

8. What type of force acts on a strut?

   ***compression***

9. A lattice of beams that is used as a superstructure or substructure of a bridge is called a ________.

   A.strut   ***C. truss***

   B. tie   D. girder

10. Which type of beam distributes the load on a bridge best?

   A. vertical   ***C. diagonal***

   B. horizontal

1. Where is the substructure of a bridge located in relation to the roadbed?

   ***below it***

2. Where is the superstructure of a bridge located in relation to the roadbed?

   ***above it***

3. What is the efficiency of a 6 g bridge that holds a 228 g load?

   ***38***

4. The Golden Gate Bridge is an example of what type of bridge?

   ***A. suspension bridge***
   B. hanging bridge
   C. arch bridge
   D. covered bridge

5. What bridge engineer of African, Native American, and European descent designed and built more than 100 bridges across the South during his life?

   A. John Goodwin
   ***B. Horace King***
   C. George Washington Carver
   D. Joseph Strauss

6. What type of force pulls both sides of a beam?

   ***A. tension***
   B. compression
   C. static
   D. dynamic

7. What type of force does a strut support?

   ***compression***

8. What type of force acts on a tie?

   ***tension***

9. A lattice of beams that is used as a superstructure or substructure of a bridge is called a ________.

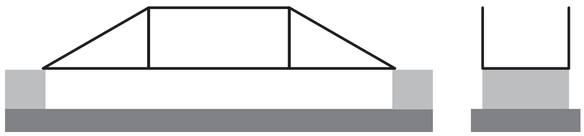
   A. strut
   B. tie
   ***C. truss***
   D. girder

10. Which type of beam distributes the load on a bridge best?

    A. vertical
    B. horizontal
    ***C. diagonal***

1. What is the part of the bridge above the roadbed called?

   ***superstructure***



2. What type of truss is shown here?

   A. king post
   ***B. queen post***
   C. Howe
   D. Pratt

3. What is the efficiency of an 8 g bridge that holds a 228 g load?

   ***28.5***

4. The Golden Gate Bridge is an example of what type of bridge?

   ***A. suspension bridge***
   B. hanging bridge
   C. arch bridge
   D. covered bridge

5. What bridge engineer of African, Native American, and European descent designed and built more than 100 bridges across the South during his life?

   A. John Goodwin
   ***B. Horace King***
   C. George Washington Carver
   D. Joseph Strauss

6. What type of force pulls both sides of a beam?

   ***tension***

7. What type of force does a strut support?

   ***compression***

8. What type of force acts on a tie?

   ***tension***

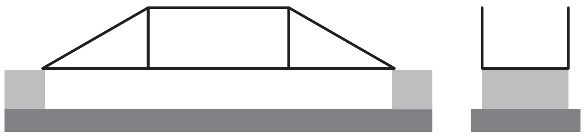
9. A lattice of beams that is used as a superstructure or substructure of a bridge is called a ***truss***.

10. Which type of beam distributes the load on a bridge best?

    ***diagonal***

1. Where is the substructure of a bridge located in relation to the roadbed?

   ***below it***



2. What type of truss is shown here?

   A. king post
   ***B. queen post***
   C. Howe
   D. Pratt

3. What is the efficiency of a 6 g bridge that holds a 221 g load?

   ***36.8***

4. The Golden Gate Bridge is an example of what type of bridge?

   ***A. suspension bridge***
   B. hanging bridge
   C. arch bridge
   D. covered bridge

5. What bridge engineer of African, Native American, and European descent designed and built more than 100 bridges across the South during his life?

   A. John Goodwin
   ***B. Horace King***
   C. George Washington Carver
   D. Joseph Strauss

6. What type of force pushes on both sides of a beam?

   ***compression***

7. What type of force does a tie support?

   ***tension***

8. What type of force acts on a strut?

   ***compression***

9. A lattice of beams that is used as a superstructure or substructure of a bridge is called a ***truss***.

10. Which type of beam distributes the load on a bridge best?

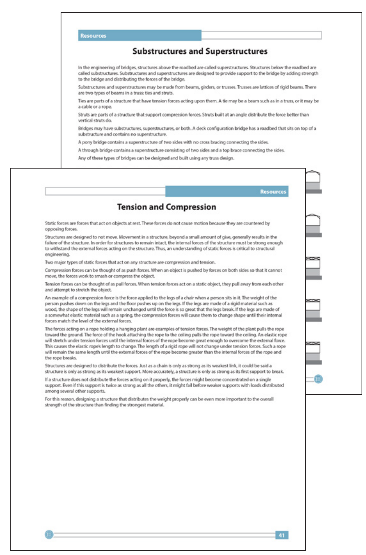
    ***diagonal***

## Quick View

Determine whether bridge superstructures are made stronger by using triangular or rectangular supports.

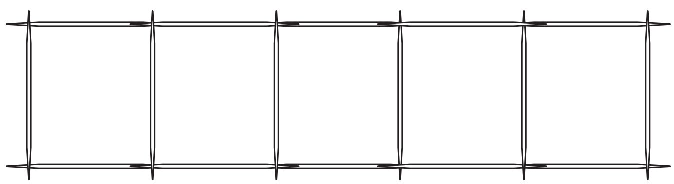
## Materials

- Toothpicks
- Glue
- Scissors or hobby knife
- Tape
- Ruler
- Graph paper
- Pencil
- Bridge tester or container
- Test block
- Sand, gravel, or other mass
- 2 solid surfaces to use as supports
- Waxed paper
- "Substructures and Superstructures" resource page
- "Tension and Compression" resource page

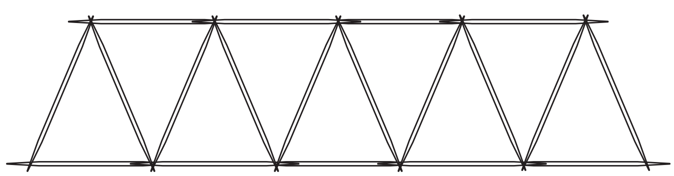
**Procedure**

1. Read the "Substructures and Superstructures" and "Tension and Compression" resource pages.
2. Hypothesize how the strength of a bridge based on rectangular structures relates to the strength of a similar structure based on triangular structures. Record your hypothesis on the back of a sheet of graph paper.
3. Measure the length of the individual toothpicks.
4. Use a ruler and pencil to draw a design for the roadbeds on the front of the graph paper on which you recorded your hypothesis. Use straight lines to represent the toothpicks. The roadbeds for both types of bridge will be identical. The roadbeds will be five toothpicks long with adjacent toothpicks overlapping each other one-fourth inch. Place six toothpicks between each side of the roadbeds and perpendicular to the sides: one toothpick on each end and one toothpick at each intersection of two side toothpicks. Place a piece of waxed paper over your drawings and build the roadbeds.



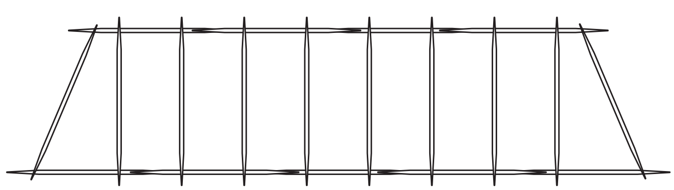
*Toothpick bridge roadbed*

5. Draw two copies of a triangular-based support superstructure side of the bridge. The top of the superstructure should be four toothpicks long, and the bottom should be five toothpicks long. The top should be centered above the bottom. Ten toothpicks should be placed so that each toothpick connects one end of a toothpick on top to the end of a toothpick on bottom. The distance between the sides needs to be equal to the height of the triangles formed by the angled supports rather than the length of the toothpicks on the ends. Build the sides.



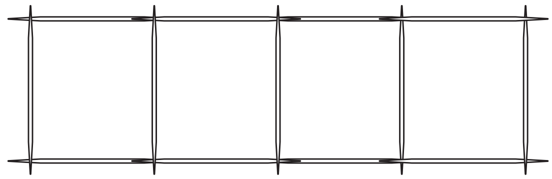
*Triangular support bridge side*

6. Draw two copies of a rectangular-based support superstructure side of the bridge. The side should have an outside boundary identical to the triangular-based support superstructure. Inside the frame, eight evenly spaced toothpicks should be placed perpendicular to both sides so they connect the two sides. Build the sides.



*Rectangular support bridge side*

7. Build a top for each bridge similar to the roadbed but only four toothpicks long. Do not build a substructure for the bridge.



*Bridge top*

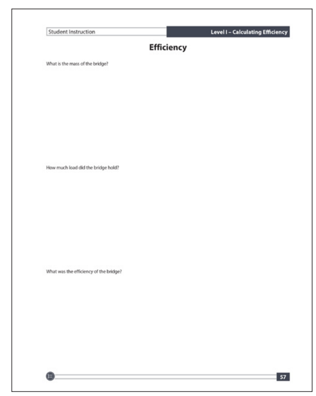
8. Assemble the bridges with the roadbeds and tops between the sides. Make sure the tops of the bridges are attached to the tops of the sides and the roadbeds are attached to the bottoms of the sides. Use tape to hold the bridges together temporarily.
9. Add drops of glue along the joints connecting the parts of the bridge.
10. After the glue has dried, remove the tape.
11. Place the bridge across the space between two supports.
12. Place a test block along the roadbed.
13. Attach the bridge tester to the test block so that the container hangs straight down from the block.
14. Gradually add sand, gravel, or another mass to the container until the bridge breaks.
15. Measure the amount of mass each bridge supported. Record this information on the back of the graph paper under your hypothesis. Also, record where the bridge broke.
16. Write a conclusion explaining your findings and evaluating your hypothesis.

## Quick View

Calculate the efficiency of a bridge.

## Materials

- Completed bridge
- Calculator
- Digital scale or balance
- Pencil
- Bridge tester or container
- 2 solid surfaces to use as supports
- Sand, gravel, or other mass
- Test block
- “Efficiency” worksheet

**Procedure**

1. Locate your completed bridge and the digital scale or balance.
2. Turn on and tare the digital scale or balance.
3. Place the bridge on the scale to find the mass of the bridge in grams. Record the mass of the bridge on the "Efficiency" worksheet.
4. Place the bridge across the space between two supports.
5. Place a test block along the roadbed.
6. Attach the bridge tester to the test block so that the container hangs straight down from the block.
7. Gradually add sand, gravel, or another mass to the container until the bridge breaks.
8. Measure the amount of mass in grams the bridge supports. Record this on the "Efficiency" worksheet.
9. The efficiency of a bridge is the load it holds divided by the bridge's mass. Calculate the efficiency of the bridge.

# Efficiency

What is the mass of the bridge?

How much load did the bridge hold?

What was the efficiency of the bridge?

## Quick View

Use a set amount of resources to design and build the strongest possible bridge consisting of only a roadbed and substructure or superstructure.

## Materials

- 100 toothpicks
- Glue
- Graph paper
- Tape
- Pencil
- Ruler
- Scissors or hobby knife
- 2 solid surfaces to use as supports
- Bridge tester or container
- Sand, gravel, or other mass
- Test block
- Waxed paper
- Digital scale or balance
- Paper
- Calculator (optional)

**Procedure**

1. Using the materials provided, design a toothpick bridge that holds the maximum load. The bridge must have a roadbed. It should also have a substructure and/or superstructure of your choice. The bridge must be at least 10 in. long and 2 in. wide.
2. Use a ruler and pencil to draw on the graph paper a design for the roadbed, the bridge sides, and any other parts of the bridge. Draw the parts of the bridge full size.
3. Place a piece of waxed paper over the graph paper and then place the toothpicks on the designs. Cut any toothpicks to the proper length if necessary.
4. Use tape to hold the toothpicks in place.
5. Place drops of glue at each joint.
6. Allow the glue to dry.
7. After the glue has dried, remove the tape. Assemble the parts of the bridge into a complete bridge. Use tape to hold the bridge parts to one another.
8. Place drops of glue at the bridge joints that connect the parts of the bridge together.
9. Allow the glue to dry.
10. After the glue is dry, remove the tape.
11. Test the completed bridge:
    a) Place the bridge across the space between two supports.
    b) Weigh the test block, container, and accessories that will hang from the bridge.
    c) Add enough sand, gravel, or other material to the container to increase the total mass of the testing block, container, materials, and hardware to 4.5 kg.
    d) Place a test block along the roadbed.
    e) Attach a container to the test block so that the container hangs straight down from the block.
    f) Gradually add sand, gravel, or another mass to the container until the bridge breaks.
    g) Measure the amount of mass the bridge supported.
12. Write a report summarizing your design and the load it held. Explain what part of your bridge failed and what design or construction modifications could be made to improve the bridge's load capacity.

## Quick View

Design and build a bridge to support a 4.5 kg load using the least possible amount of materials.

## Materials

- Toothpicks
- Glue
- Graph paper
- Bridge tester or container
- Test block
- Pencil
- Ruler
- Scissors or hobby knife
- Masses and/or spring scale
- Sand, gravel, or other mass
- Tape
- Calculator
- 2 solid surfaces to use as supports
- Waxed paper
- Paper
- 5 mL graduated droppers or cylinders (optional)
- Digital scale or balance (optional)

**Procedure**

1. Use masses and/or a spring scale to test the strength of individual toothpicks. Test the amount of force a toothpick can sustain when the mass is hanging from its center. Test the amount of mass a toothpick standing on its end can hold when the mass is applied to the top of the toothpick.
2. Design and conduct at least three more tests of toothpick strength, including at least two tests of the strength of toothpicks glued together at some kind of joint.
3. On the back of a piece of graph paper, write a paragraph explaining the tests you conducted and the results of these tests.
4. Based on the information from your tests and your knowledge of toothpick bridges, design a toothpick bridge that uses the minimum amount of material and will hold at least 4.5 kg of load. Material used is defined as the number of toothpicks and amount of glue used. Each toothpick or piece of toothpick used counts as a whole toothpick, so try to minimize waste. Each milliliter of glue is worth five toothpicks in material costs.
5. Use a ruler and pencil to draw on the graph paper a design for the roadbed, the bridge sides, and any other parts of the bridge. Draw the parts of the bridge full size.
6. Place a piece of waxed paper over the graph paper and then place the toothpicks on the designs. Cut any toothpicks to the proper length if necessary.
7. Use tape to hold the toothpicks in place.
8. Place drops of glue at each joint.
9. Allow the glue to dry.
10. After the glue has dried, remove the tape. Assemble the parts of the bridge into a complete bridge. Use tape to hold the bridge parts to one another.
11. Place glue at the bridge joints that connect the parts of the bridge together.
12. Allow the glue to dry.
13. Calculate the total material used. Each toothpick equals one unit, and each milliliter of glue equals five units.

14. After the glue is dry, remove the tape.
15. Test the completed bridge:
    a) Place the bridge across the space between two supports.
    b) Find the mass of the test block, container, and accessories that will hang from the bridge.
    c) Add enough sand, gravel, or other material to the container to increase the total mass of the testing block, container, materials, and hardware to 4.5 kg.
    d) Place a test block along the roadbed.
    e) Attach a container to the test block so that the container hangs straight down from the block.
    f) If the bridge holds without breaking, it passes.
16. If the bridge does not hold and time permits, redesign and try again.
17. Write a report summarizing your design and testing process. Include a description and an explanation of your final design and any preliminary designs. Give reasons why you think each design was successful or not successful.

## Quick View

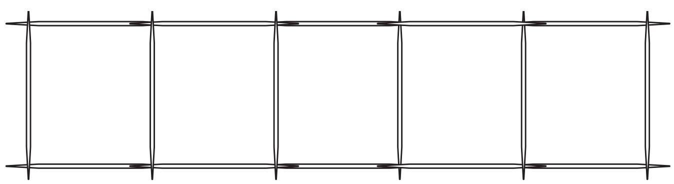
Examine static forces acting on a toothpick bridge, test the strength of toothpicks, predict how much load a bridge will hold, and predict the failure point of a bridge.

## Materials

- Masses and/or spring scale
- Toothpicks
- Glue
- Scissors or hobby knife
- Tape
- Ruler
- Graph paper
- Pencil
- Bridge tester or container
- Test block
- Sand, gravel, or other mass
- 2 solid surfaces to use as supports
- Waxed paper
- Digital scale or balance
- “Substructures and Superstructures” resource page
- “Tension and Compression” resource page

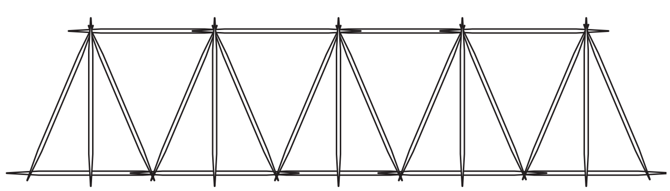
**Procedure**

1. Review the "Substructures and Superstructures" and "Tension and Compression" resource pages.
2. Use masses and/or a spring scale to test the strength of individual toothpicks. Test the amount of force a toothpick can sustain when the mass is hanging from its center. Test the amount of mass a toothpick standing on its end can hold when the mass is applied to the top of the toothpick.
3. Design and conduct at least three more tests of toothpick strength, including at least two tests of the strength of toothpicks glued together at some kind of joint.
4. Measure the length of the individual toothpicks.
5. Use the ruler to draw a design for the roadbed on graph paper. Use straight lines to represent the toothpicks. The roadbed will be five toothpicks long with adjacent toothpicks overlapping each other one-fourth inch. Place six toothpicks between each side of the roadbed and perpendicular to the sides: one toothpick on each end and one toothpick at every point where the side toothpicks overlap. Place a piece of waxed paper over your drawings and build the roadbed.



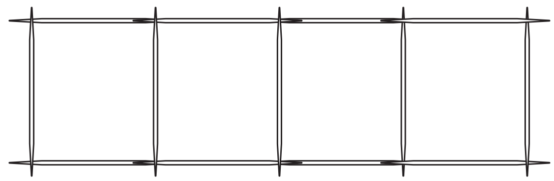
*Toothpick bridge roadbed*

6. Draw two copies of the superstructure side of the bridge. The top of the superstructure should be four toothpicks long, and the bottom should be five toothpicks long. The top should be centered above the bottom. Ten toothpicks should be placed so that each toothpick connects one end of a toothpick on top and the other end on bottom. The distance between the sides needs to be equal to the height of the triangles formed by the angled supports rather than the length of the toothpicks on the ends. Five vertical toothpicks should be placed perpendicular to the top and bottom. The vertical toothpicks should run from the center of the bottom toothpicks to the end of the corresponding top toothpicks. Build the sides.



*Superstructure bridge side*

7. Build a top for the bridge similar to the roadbed but only four toothpicks long. Do not build a substructure for the bridge.

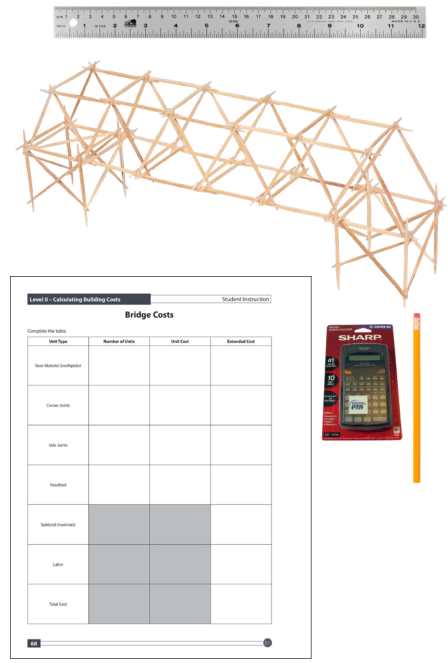


*Bridge top*

8. Assemble the bridge with the roadbed between the bottom of the sides and the top of the bridge between the top of the sides of the bridge. Use tape to hold the bridge together temporarily.
9. Add drops of glue along the joints connecting the parts of the bridge.
10. After the glue has dried, remove the tape.
11. Based on the amount of load the individual toothpicks will hold and the design of the bridge, write a hypothesis predicting the maximum load the bridge will hold and the place where the bridge will fail. Write your prediction on the back of your bridge design.
12. Place the bridge across the space between two supports.
13. Place a test block along the roadbed.
14. Attach a the bridge tester to the test block so the container hangs straight down from the block.
15. Gradually add sand, gravel, or another mass to the container until the bridge breaks.
16. Measure the amount of mass the bridge supported. Record this information on the back of the graph paper under your hypothesis. Also, record where the bridge broke.
17. Write a conclusion explaining your findings and evaluating your hypothesis. If applicable, your conclusion should include an explanation of why the actual results do not match the theoretical results.

## Quick View

Calculate the cost of building a bridge based on a toothpick scale model.

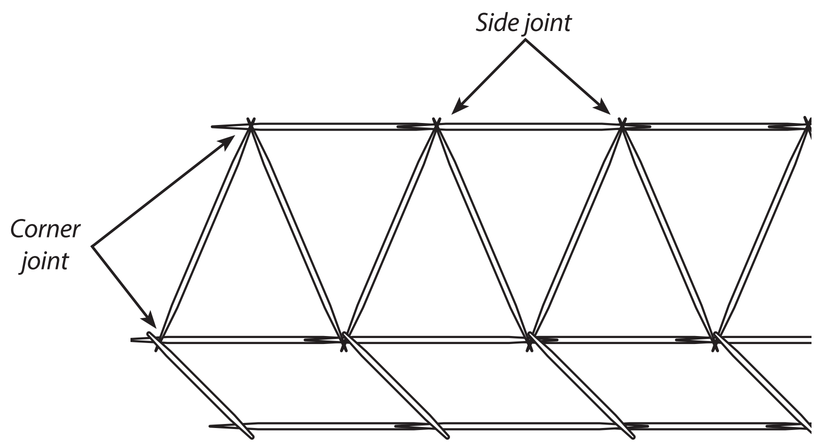



## Materials

- Completed bridge
- Calculator
- Ruler
- Pencil
- "Bridge Costs" worksheet

**Procedure**

1. Locate a completed toothpick bridge and the "Bridge Costs" worksheet. Your bridge will serve as a scale model for an actual bridge and be used to estimate the cost of the actual bridge.
2. Count the number of toothpicks used to construct the bridge. If only a part of a toothpick was used, count that part as a whole toothpick. Record the number of toothpicks as the number of units of base material on the "Bridge Costs" worksheet.
3. Each toothpick in the scale model represents $20,000 of base materials in the actual bridge. Enter $20,000 as the unit cost of the base materials.
4. To calculate the extended costs for base materials, multiply the number of units by the unit cost.
5. Determine the number of corner joints on the bridge. A corner joint is the point where the ends of two or more beams come together at an angle (such as two beams creating a V shape as shown below). Enter the number of corner joints on the "Bridge Costs" worksheet.




*Toothpick bridge joints*

6. A side joint is the area where the toothpicks overlap and glue is applied. Two or more toothpicks joined in this manner form a beam (the two beams create one long beam such as the side joints shown above). Measure the length of the side joints in centimeters. Enter the sum of the lengths of the side joints on the "Bridge Costs" worksheet.
7. The unit cost for one corner joint is $500. The unit cost per side joint is $100 per centimeter on the scaled bridge. Enter these numbers as the unit costs for the joints and calculate the extended costs.
8. Calculate the area of the roadbed. Enter the roadbed area on the bridge. The roadbed will cost an additional $50 per square centimeter on the scaled bridge. Enter the unit cost of the roadbed. This additional cost represents the cost of building a road on the roadbed. Calculate and enter the extended cost of the roadbed.
9. Calculate and enter the total material costs for this project.
10. The labor costs for this project can be estimated based on the material costs. Labor costs are estimated at 1.25 times the material costs. Calculate and enter the estimated labor costs for this project.
11. Calculate the total estimated cost of the bridge.

# Bridge Costs

Complete the table.

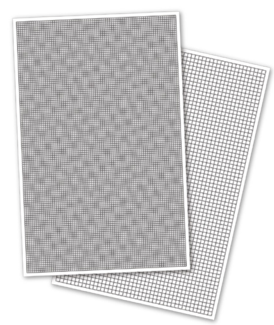
| Unit Type | Number of Units | Unit Cost | Extended Cost |
|---|---|---|---|
| Base Material (toothpicks) | | | |
| Corner Joints | | | |
| Side Joints | | | |
| Roadbed | | | |
| Subtotal (materials) | | | |
| Labor | | | |
| Total Cost | | | |

## Quick View

Design and construct a bridge with the maximum possible efficiency.

## Materials

- Toothpicks
- Glue
- Graph paper
- Tape
- Pencil
- Ruler
- Scissors or hobby knife
- Bridge tester or container
- Digital scale or balance
- 2 solid surfaces to use as supports
- Test block
- Sand, gravel, or other mass
- Paper
- Calculator
- Waxed paper

**Procedure**

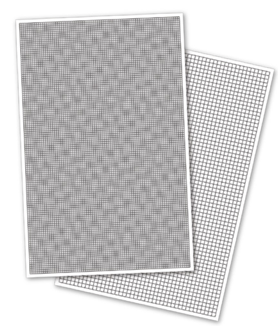
1. Using the materials provided, design a toothpick bridge that maximizes efficiency, or holds the maximum load using the least possible amount of materials. The bridge must have a roadbed. It should also have a substructure and/or superstructure of your choice. The bridge must be at least 10 in. long and 2 in. wide.
2. Use a ruler and pencil to draw on the graph paper a design for the roadbed, the bridge sides, and any other parts of the bridge. Draw the parts of the bridge full size.
3. Place a piece of waxed paper over the graph paper and then place the toothpicks on the designs. Cut any toothpicks to the proper length if necessary.
4. Use tape to hold the toothpicks in place.
5. Place drops of glue at each joint.
6. Allow the glue to dry.
7. After the glue has dried, remove the tape. Assemble the parts of the bridge into a complete bridge. Use tape to hold the bridge parts to one another.
8. Place glue at the bridge joints that connect the parts of the bridge together.
9. Allow the glue to dry.
10. After the glue is dry, remove the tape.
11. Locate the digital scale or balance. Measure the mass of the bridge. Record the mass on a piece of paper.
12. Test the completed bridge:
    a) Place a bridge across the space between two supports.
    b) Find the mass of the test block, container, and accessories that will hang from the bridge.
    c) Add enough sand, gravel, or other material to the container to increase the total mass of the testing block, container, materials, and hardware to 4.5 kg.
    d) Place a test block along the roadbed.
    e) Attach a container to the test block so that the container hangs straight down from the block.
    f) Gradually add sand, gravel, or another mass to the container until the bridge breaks.
    g) Measure the amount of mass, or load, the bridge supported.
13. Calculate the efficiency of the bridge. Efficiency equals the load supported by the bridge divided by the mass of the bridge. Compare the efficiency of your bridge to the efficiency of your classmate's bridges.
14. Write a report summarizing your design and its efficiency. Explain what part of your bridge failed and what design or construction modifications could be made to improve the bridge's efficiency.

## Quick View

Design and build two bridges with the same efficiency with one bridge weighing half as much as the other.

## Materials

- Toothpicks
- Glue
- Graph paper
- Bridge tester or container
- Test block
- Pencil
- Ruler
- Scissors or hobby knife
- Digital scale or balance
- Sand, gravel, or other mass
- Tape
- 2 solid surfaces to use as supports
- Paper
- Calculator
- Waxed paper

**Procedure**

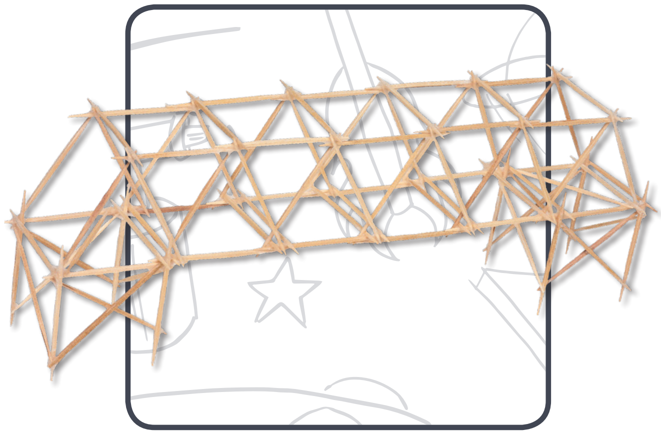
1. Using the materials provided, design a toothpick bridge that maximizes efficiency, or holds the maximum load using the least possible amount of materials. The bridge must have a roadbed. It should also have a substructure and/or superstructure of your choice. The bridge must be at least 10 in. long and 2 in. wide.
2. Use a ruler and pencil to draw on the graph paper a design for the roadbed, the bridge sides, and any other parts of the bridge. Draw the parts of the bridge full size.
3. Design a second bridge that will weigh half as much as the first bridge but will have the same efficiency.
4. Place a piece of waxed paper over the graph paper and then place the toothpicks on the designs. Cut any toothpicks to the proper length if necessary.
5. Use tape to hold the toothpicks in place.
6. Place drops of glue at each joint. Follow your design plan. Apply glue only to places indicated in your design. If you apply glue to places not on your design, you must get approval and note the modification on your design.
7. Allow the glue to dry.
8. After the glue has dried, remove the tape. Assemble the parts of the bridge into a complete bridge. Use tape to hold the bridge parts to one another.
9. Place glue at the bridge joints that connect the parts of the bridge together.
10. Allow the glue to dry.
11. After the glue is dry, remove the tape.
12. Locate the digital scale or balance. Measure the mass of the bridge. Record the mass.
13. Test the completed bridge:
    a) Place a bridge across the space between two supports.
    b) Find the mass of the test block, container, and accessories that will hang from the bridge.
    c) Add enough sand, gravel, or other material to the container to increase the total mass of the testing block, container, materials, and hardware to 4.5 kg.
    d) Place a test block along the roadbed.
    e) Attach a container to the test block so that the container hangs straight down from the block.
    f) Gradually add sand, gravel, or another mass to the container until the bridge breaks.
    g) Measure the amount of mass, or load, the bridge supported.

14. Calculate the efficiency of the bridges. Efficiency equals load supported by the bridge divided by the mass of the bridge. Compare your bridge's efficiency to the efficiency of your classmate's bridges.
15. Write a report summarizing your designs and the efficiency of the bridges. Explain how well the bridges met the goals set in this activity. Explain what could be done to make the bridges better meet the goals of the activity.

# TOOTHPICK BRIDGES

## Teacher's Guide

STEM Curriculum for Toothpick Bridges



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**Email** us at orders@pitsco.com.
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