

# The Physics of Bridges

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**Subject:** Physics

**Grade Level:** 9-12

**Standards:** Next Generation Science Standards ([www.nextgenscience.org](http://www.nextgenscience.org))

**HS-PS2-4** Use mathematical representations of Newton's law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.

**Schedule:** 6-60 minute classes

**CCMR Lending Library Connected Activities:**



<p><b><u>Objectives:</u></b></p> <p>Use Newton's Laws in designing a bridge by using free body diagrams and Hooke's law to choose an appropriate bridge design and material for the project. To use engineering skills to build and test a bridge.</p>	<p><b><u>Vocabulary:</u></b></p> <p>Newton's Laws of Motion              Force              Equilibrium              Hooke's Law              Young's Modules              Efficiency</p>
<p><b><u>Students Will:</u></b></p> <ul style="list-style-type: none"> <li>· Learn about different kinds of bridges by doing research and experiments.</li> <li>· Draw free body diagrams of forces acting on the different kinds of bridges.</li> <li>· Test different materials to find an appropriate one to use for the construction of their bridge.</li> </ul> <p>Build an appropriate bridge for the parameters.</p>	<p><b><u>Materials:</u></b></p> <p><b>For Each Pair:</b>              Computer with internet access              Activity packet              Strip of cardboard              2 Blocks of wood              String/Rope              Sponge              20 Popsicle sticks with screws              Straws              Popsicle Sticks              Cardboard              Toothpicks              Masses              Ruler              Scale              Glue/tape</p>
<p><b>Safety</b></p>	<p>This activity does not contain any safety concerns.</p>

## **Science Content for the Teacher:**

### **Relating Newton's Laws to bridges**

Newton's First Law: An object in motion will stay in motion unless acted upon by an outside force. An object at rest will stay at rest unless acted upon by an outside force.



This law says that unless an external force is applied the bridge it will stay at rest. The wind applies forces to suspension bridges and they move.

Newton's Second Law:  $F_{\text{net}} = ma$

This law says that if a force is applied to the bridge it will accelerate in the direction of that force. If the forces all add up to zero the bridge is in equilibrium and does not move.

Newton's Third Law: For every action there is an equal and opposite reaction.

If a car is on a bridge it is exerting a force on the bridge, therefore the bridge must be exerting the same amount of force on the car. If the bridge is not moving it is in equilibrium and all the forces will add up to zero.

Law of Gravity: Any two bodies in the universe attract each other with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

$$F_g = G \frac{m_1 \times m_2}{r^2}$$

$F_g$  = Gravitational force

$M_1$  and  $M_2$  = Masses of the two objects

$r$  = Distance between two objects

$G$  = Universal gravitational constant

For more information on how forces are distributed on different types of bridges see the following website and PowerPoint:

**PBS "Bridge Basics":**

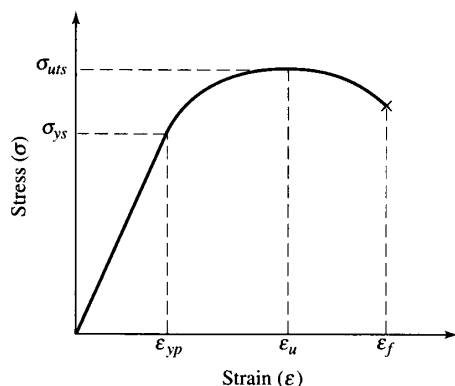
<http://www.pbs.org/wgbh/buildingbig/bridge/basics.html>

**Physics of Bridges by Norman Kwong, University of British Columbia:**

[https://docs.google.com/presentation/d/1VOD\\_xgWswRa32nR\\_SW4Diao35LKyhiSJtt0XUcF94dc/edit#slide=id.p19](https://docs.google.com/presentation/d/1VOD_xgWswRa32nR_SW4Diao35LKyhiSJtt0XUcF94dc/edit#slide=id.p19)



## Hooke's Law and Young's Modulus



Hooke's law states that  $F_s = kx$  (where  $F_s$  is the force of the spring,  $k$  is spring constant and  $x$  is the amount the spring is stretched or compressed). Materials follow Hooke's law to a certain extent. As materials follow this law they go back to the original shape when the force is done being applied. A graph of  $F$  vs.  $x$  would be a direct relationship. Each material will reach a certain yield position where it will no longer go back to the original shape. Shortly after this the material will break. This process is known as Young's Modulus and is shown is a graph of stress vs. strain seen on the left.

<http://www.benbest.com/cryonics/sscurve.gif>

### Preparation:

#### Day 1:

Pictures of bridges should be printed and posted around the room. Each student should get an activity booklet. Each group of students should have a strip of cardboard, sponge, 2 blocks of wood, string, and around 20 popsicle sticks with holes at each end and screws.

#### Day 2:

None

#### Day 3:

Teacher should have a plastic spoon, popsicle sticks, masses, and ruler to show demonstration. Each group should have the same set of materials as the teacher but also more materials to test like straws, toothpicks, paper, etc.

Have partners picked for each group. It can be picked at random in front of the students using an appropriate method.

#### Day 4:

Make sure there is glue, tape, staplers available to students along with material to build bridges.

#### Day 5:

Have an area and materials set up for testing. Have an order completed for the tests before students arrive.



## **Classroom Procedure:**

### **Day 1:**

#### ***Engage (Time: 5 min.)***

Pictures of bridges from around the world will be around the room. The teacher will ask the students to get up and walk around the room and make observations while looking at the pictures. Once they are back in their seats the teacher will tell the students they will be exploring different kinds of bridges in the next few days.

#### ***Explore (Time: 40 min.)***

Students will explore the different types of bridges through a website search/hand on activity at <http://www.pbs.org/wgbh/buildingbig/bridge/basics.html>. Students will investigate 4 types of bridges: arch, beam, suspension, and cable-stayed. As the students search through the website they will take notes on the activity sheet. Students will work individually or in groups of 2.

#### ***Explain (Time: 15 min.)***

Students will be placed in groups of 4. They will discuss their findings to see which bridge they feel is the best for certain situations. The teacher will walk around and facilitate discussions.

#### ***Expand (Time: 15 min.)***

We will have a discussion on how to make bridges stronger. Students will complete the trusses activity sheet and make observations. We will then have a class discussion on why trusses make a bridge stronger.

## **Assessment:**

The following rubric can be used to assess students during each part of the activity. The term “expectations” here refers to the content, process and attitudinal goals for this activity. Evidence for understanding may be in the form of oral as well as written communication, both with the teacher as well as observed communication with other students. Specifics are listed in the table below.

- 1= exceeds expectations
- 2= meets expectations consistently
- 3= meets expectations occasionally
- 4= not meeting expectations



	Engage	Explore	Explain	Expand/Synthesis
1	Student walked around the room investigating the picture taking notes or talking with other students. Student may raise questions on the bridges.	Student demonstrates interest in the search. Student takes careful notes in the activity booklet. Student seems very engaged in the activities to demonstrate bridges.	Student shows leadership in the discussion. Student allows for discussion in the group. Student shows an excellent understanding of bridge designs through a thoughtful analysis.	Student is actively involved in the activity. Student works well with partners where both are contributing. Student carefully does each activity and answers the questions.
2	Student walked around the room observing the pictures and was engaged in the activity.	Student shows interest in the search. Student takes some notes in the activity booklet. Student does the bridge demonstrations.	Student contributes to the discussion. Has a good understanding of the bridge designs through the web search.	Student is involved in the activity. Student may let partner do more work. Student does each activity and answers the questions.
3	Student walked around the room observing the pictures but was distracted and off topic.	Student demonstrates little interest in the search. Little notes are taken and they seem rushed. Student may do the bridge demonstrations but with little interest.	Student contributes little to the discussion. A clear understanding of bridge design cannot be seen through questioning the student.	Student is not very involved with the activity. Student may have the partner doing all the work. Student skips steps and does not fully answer questions.
4	Student did not look at the pictures and was not engaged in the activity.	Student shows no interest in the activity. Student takes little to no notes and does not do the bridge demonstrations.	Students make little to no contribution to the discussion. Student is unable to demonstrate an understanding of bridge design.	Student is not involved with the activity. Students let partner do all the work. Student does not answer questions or copies from other students.



## **Day 2:**

### ***Engage (Time: 15 min.)***

Teacher will facilitate discussion on different types of bridges the students learned the previous day. Teacher will bring up Newton's Laws and ask the students to describe how each of Newton's Laws relates to bridges. Students will draw free body diagrams for each of the bridges discussed the previous day.

### ***Explore (Time: 30 min. )***

Students will work alone or in a group of 2 to complete a web quest on the following website <http://www.pbs.org/wgbh/buildingbig/bridge/index.html>. As the students go through the site they will complete the activity sheet.

### ***Explain (Time: 15 min.)***

Students will work in groups of 4 to discuss how they thought forces were acting on the bridges and compare that to what they found. Teacher will walk around the room and assess their knowledge.

### ***Expand (Time: 20 min.)***

Students will be introduced to their bridge building project. They will learn the efficiency formula of a bridge and be placed into partners. Students can start discussing their plans for their bridges.

## **Assessment:**

The following rubric can be used to assess students during each part of the activity. The term "expectations" here refers to the content, process and attitudinal goals for this activity. Evidence for understanding may be in the form of oral as well as written communication, both with the teacher as well as observed communication with other students. Specifics are listed in the table below.

- 1= exceeds expectations
- 2= meets expectations consistently
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	Engage	Explore	Explain
1	Student talks with partner to determine the FBD of each bridge. Student is actively engaged in discussion. Student works with partner to draw the FDB.	Student demonstrates interest in the search. Student takes careful notes in the activity booklet.	Student shows leadership in the discussion. Student allows for discussion in the group. Student shows an excellent understanding of forces through a thoughtful analysis.
2	Student works with partner to determine the FBD. Student contributes to discussion of the forces. Student helps draw the FBD.	Student shows interest in the search. Student takes some notes in the activity booklet.	Student contributes to the discussion. Has a good understanding of the forces through the web search.
3	Student works little with partner and does not contribute much to discussion. Student helps draw FBD occasionally.	Student demonstrates little interest in the search. Little notes are taken and they seem rushed.	Student contributes little to the discussion. A clear understanding of forces cannot be seen through questioning the student.
4	Student does not work with partner. Student does not contribute to discussion and does not help draw FBD.	Student shows no interest in the activity. Student takes little to no notes.	Students make little to no contribution to the discussion. Student is unable to demonstrate an understanding of forces.





**Day 3:*****Engage (Time: 20 min. )***

Teacher will take a plastic spoon or fork and bend it to a point where it will go back to its original position. Now the teacher will apply a force great enough that the spoon no longer goes back to its original shape. The teacher will discuss Young's Modulus with the students. Students should have previous knowledge of Hooke's Law and if they do not this now needs to be discussed.

Teacher will show a student how to do a stress test by placing a popsicle stick between a gap. The teacher will place masses on the bridge formed by the stick. It should be noted that as more weight is added a displacement can be seen. At the point where the popsicle stick breaks the mass of the weights should be recorded.

***Explore (Time: 35 min.)***

Students will work in their partners to find the material to use for their bridge. They should weigh each material along with perform a stress test. As the students complete this section they will follow the activity sheet.

***Explain (Time: 5 min.)***

The partners will work together to determine the material that they would like to use for their bridge. They will fill out the sheet of the material that they want to use for their bridge and the reason why to their teacher.

***Expand (Time: 20 min.)***

Students will work in their partners to design their bridge. They should discuss materials that they will need to build their bridges. If it is not available in the classroom they will have to bring it the following day for building.

**Assessment:**

The following rubric can be used to assess students during each part of the activity. The term "expectations" here refers to the content, process and attitudinal goals for this activity. Evidence for understanding may be in the form of oral as well as written communication, both with the teacher as well as observed communication with other students. Specifics are listed in the table below.

- 1= exceeds expectations
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	Explore	Explain	Expand/Synthesis
1	Student works well with partner. Student shows leadership in activity. Students tests materials thoroughly. Student takes careful notes of each material.	Student takes leadership in discussion. Student contributes in the discussion and accepts other opinions. Student is able to determine a material for the bridge.	Student worked well with partner. Student took leadership. Student came up with a plan for the bridge. Student was planning and discussing the entire time.
2	Student works with partner. Student helps test material. Student takes notes of each material.	Student contributes to discussion. Student may not accept other opinions. Student is able to determine a material for the bridge.	Student worked well with partner. Student helped plan bridge design. Student was distracted during this time and did some off topic talking.
3	Student does not work well with partner. Student is not very involved with testing the materials. Student takes little notes on each material.	Student contributes little to the discussion. Student refuses to accept other opinions. Student may still be unsure which material to use.	Student sometimes worked well with partner. Student was easily distracted and often talked off topic. Student did not do much planning.
4	Student does not work with partner. Student does no testing of the materials. Student takes little to no notes.	Student does not contribute to the discussion. Student will not accept other opinions. Student does not have a material for the bridge.	Student did not work or work well with partner. Student was not involved with the planning of the bridge and did not do anything towards the bridge during this time.

#### **Day 4: (Time: 80 min.)**

This day is completely devoted to building the bridges. Students will be given this time and only this time to build their bridge. If more time is needed they must complete their bridge outside of class. The testing will occur during the next class.

#### **Day 5: (Time: 80 min.)**

The bridges will be tested today. The bridges will be place between a table top that is 20 cm apart. The order will be picked at random before the class begins. Each group will have 5 minutes to do any finishing touches to their bridge.

#### **Additional Resources:**



Eureka Video on Gravity: <https://www.youtube.com/watch?v=fI7TQwPcJyI>

### **Acknowledgments:**

- Kevin Dilley
- <http://www.phys.unt.edu/students/sps/Olympic%20Rules%20Web%20Ver.doc>
- <http://www.pbs.org/wgbh/buildingbig/bridge/basics.html>
- <http://www.pbs.org/wgbh/buildingbig/bridge/index.html>.
- <http://www.benbest.com/cryonics/sscurve.gif>

