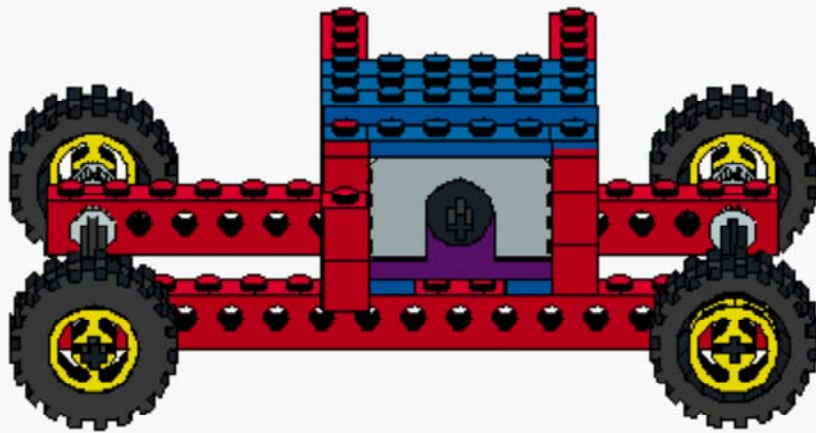


Structures by Design

Lego based building lessons
for
Grade Four

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Summer/ 2002



Structures by Design:

Lego based building lessons for Grade Four students

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Resources

Connections to Massachusetts Frameworks:

From: www.doe.mass.edu/frameworks/current.html

The Relationship Among Science, Engineering, and Technology

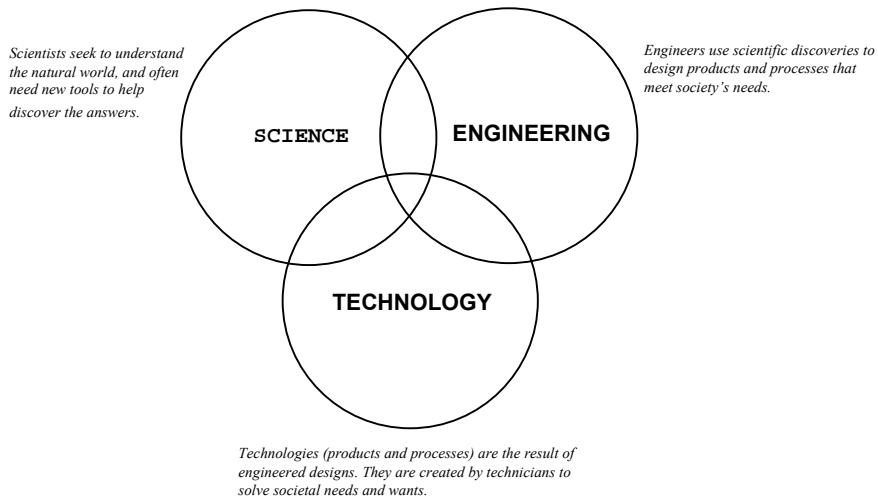
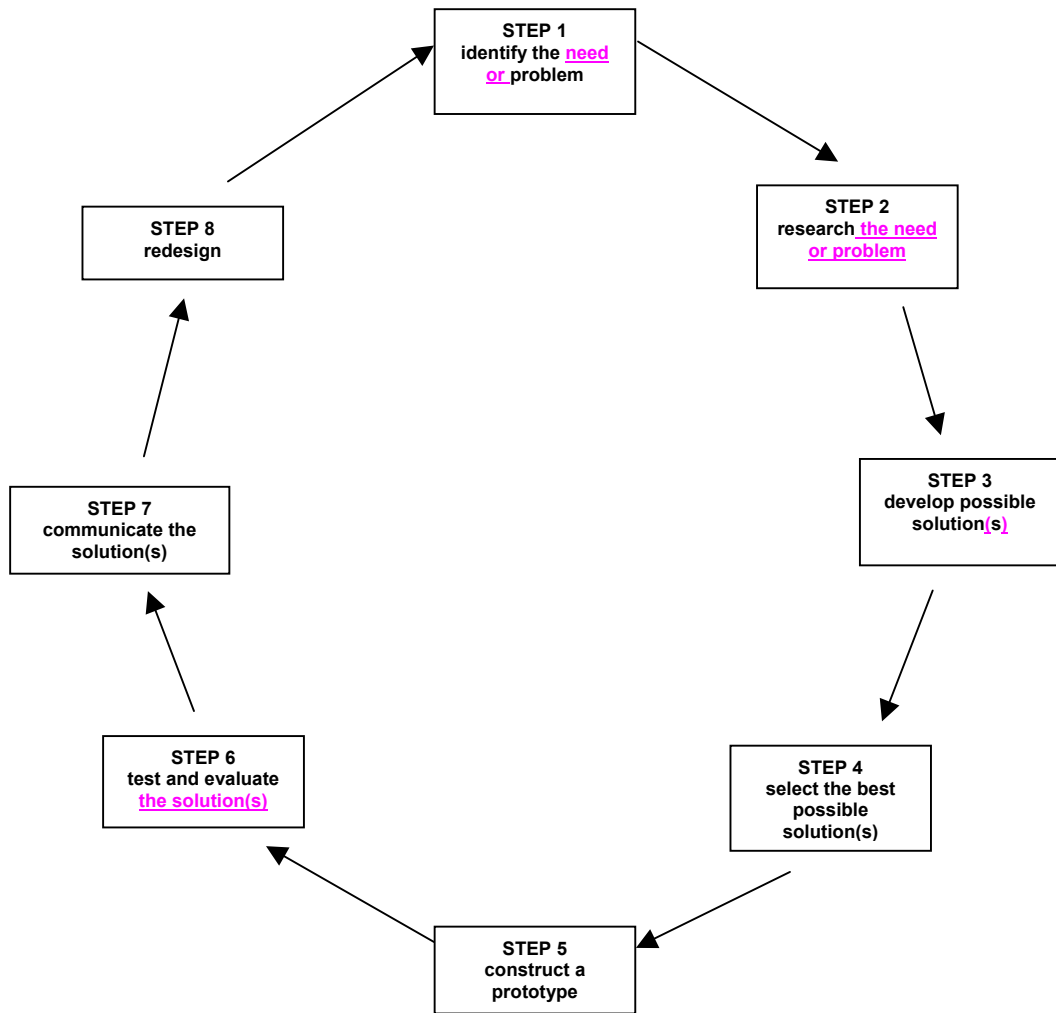


Figure 1
Steps of the Engineering Design Process



1. Identify the need or problem
2. Research the need or problem
 - Examine current state of the issue and current solutions
 - Explore other options via the internet, library, interviews, etc.
3. Develop possible solution(s)
 - Brainstorm possible solutions
 - Draw on mathematics and science
 - Articulate the possible solutions in two and three dimensions
 - Refine the possible solutions
4. Select the best possible solution(s)

- Determine which solution(s) best meet(s) the original requirements
- 5. Construct a prototype
 - Model the selected solution(s) in two and three dimensions
- 6. Test and evaluate the solution(s)
 - Does it work?
 - Does it meet the original design constraints?
- 7. Communicate the solution(s)
 - Make an engineering presentation that includes a discussion of how the solution(s) best meet(s) the needs of the initial problem, opportunity, or need
 - Discuss societal impact and tradeoffs of the solution(s)
- 8. Redesign
Overhaul the solution(s) based on information gathered during the tests and presentation

Grades 3-5

1. Materials and Tools

Broad Concept: Appropriate materials, tools, and machines extend our ability to solve problems and invent.

- 1.1 Identify materials used to accomplish a design task based on a specific property, i.e., weight, strength, hardness, and flexibility.
- 1.2 Identify and explain the appropriate materials and tools (e.g., hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) to construct a given prototype safely.
- 1.3 Identify and explain the difference between simple and complex machines, e.g., hand can opener that includes multiple gears, wheel, wedge gear, and lever.

2. Engineering Design

Broad Concept: Engineering design requires creative thinking and strategies to solve practical problems generated by needs and wants.

- 2.1 Identify a problem that reflects the need for shelter, storage, or convenience.
- 2.2 Describe different ways in which a problem can be represented, e.g., sketches, diagrams, graphic organizers, and lists.
- 2.3 Identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem.
- 2.4 Compare natural systems with mechanical systems that are designed to serve similar purposes, e.g., a bird's wings as compared to an airplane's wings.

Grade 4: Structures By Design

Lesson 1: Stable Shapes

Lesson Objective: To familiarized the students with triangulation

Learning Objective:

- To learn the names of different polygons.

Time: one 45-50 minute period

The Challenge: What polygons can be used to make a stable structure?

Materials:

Lego Simple Machine kits or other Lego building pieces

Exploring Polygons Worksheet

Vocabulary

- beams
- gray connector pegs
- stability: ability of an object to resist movement or bending
- triangulation: the use of triangles to make a structure rigid
- vertex: one of the points or corners of a triangle
- polygon

Sides	Name
• 3	Triangle
• 4	Quadrilateral
• 5	Pentagon
• 6	Hexagon
• 7	Heptagon
• 8	Octagon

Procedure:

The lesson begins with a teacher lead discussion about shapes and names for different polygons. The teacher may ask questions such as:

- Can anyone define a polygon?
- Can you name some polygons?
- Where have you seen some of these polygons?
- What polygons have you seen in different structures?

Next introduce the word *stability*. Use different things around the room (such as a table, chair, pencil, piece of rope, crayon) to talk about the concept. Push down on the different things to see if they hold their shape. Have the class come up with a working definition of stability that they all agree on.

Then, the students are presented with their first Lego challenge, Stable Shapes. Each student receives an *Exploring Polygon Worksheet*. Using the pieces from the Simple Machines Lego kits, they will build different polygons, testing the stability of each one. They should plan on testing a triangle and at least 3 other shapes. The groups should judge their structure's stability based on the class definition of what it looks like. The students are instructed to record their findings on the worksheet. Allow 20-25 minutes for the partners to explore.

Following the activity time, the teacher leads the students in a wrap up discussion about what was the most stable shape. The students are encouraged to share their findings. The word *triangulation* is introduced at this time. Also introduce the *vertex* of a triangle.

Students will be instructed on how to properly care for, put away, and store Lego materials.

Extensions:

- Students can build more polygon shapes to test.

Assessment:

- teacher observations and interviews

Trouble Shooting:

- some students will be very familiar with vocabulary and building while for others this will be a new experience

Resources:

Lego/Tufts website- www.ceeo.tufts.edu/curriculum

Lego Dacta "Simple and Motorized Machines" Teacher Guide
Lego Dacta "Bridges, Towers and Other Structures" Teacher Guide
AIMS Brick Layer II: Creative Engineering with LEGO Construction

Sample Work

QuickTime™ and a
Photo - JPEG decompressc
are needed to see this pi

QuickTime™ and a
Photo - JPEG decompressor
are needed to see this pic

Engineer: _____

Date: _____

Partner: _____

Exploring Polygons Worksheet

1. Using **3** beams and connector pegs, build a triangle.

Draw a Picture	
Stable or Unstable?	

2. Now build **3 more** polygons of your choice, testing the stability of each.
Record your results.

Draw Polygon			
Name of Polygon			
Stable or Unstable			
What I could do to make it stable			

Grade 4: Structures By Design

Lesson 2: Angle Fixer

Lesson Objective: To practice triangulation of a polygon.

Learning Objective:

- To learn how to modify a polygon with support braces to stabilize it.

Time: one 45-50 minute period

Background information:

The triangle is the most stable shape. Polygons can be divided into triangular spaces using support beams at the vertices or points of the triangles. The least number of connecting beams needed to triangulate a polygon is always **three less** than the **number of sides** of the polygon. For example, a quadrilateral, or 4-sided polygon, needs one support beam to triangulate its space. While a pentagon, or 5-sided polygon, needs two support beams to triangulate its space. In addition, the **number of spaces** or regions a polygon is divided into when triangulated is **two less** than the number of sides of the polygon. For example, a quadrilateral, or 4-sided polygon is divided into 2 spaces . While a pentagon, or 5-sided polygon, is divided into 3 spaces. By experimenting with different shapes, triangulating the space, students can discover this pattern.

The Challenge:

- How can you modify a polygon with support braces to stabilize it?

Materials:

Lego Simple Machine kits or other Lego building pieces

Angle Fixer Worksheet

Angle Fixer Connections Response Sheet

Vocabulary

- Axles, many different sizes (or stud length)
- piston rods

Procedure:

The lesson begins with a review of concepts learned in the previous lesson on what shape makes a stable structure. The teacher may ask questions such as:

- What polygon was the most stable?
- What did you think you could do to the other polygons to make them more stable?
- Who remembers what triangulation means?

Next, the students are presented with the second Lego challenge, *Angle Fixer*. Each student receives an *Angle Fixer Worksheet*. Using the pieces from the Simple Machines Lego kits, they will build two of the polygons from the previous lesson. They are then instructed to experiment with different shapes and techniques adding support beams to the structure, trying to make it as stable as possible. The students are instructed to record their findings on the worksheet. Allow 20-25 minutes for the partners to explore. Have the students bring their polygon to the discussion table to share during the whole class discussion time.

Following the activity time, the teacher leads the students in a wrap up discussion about what worked and what continued to be a problem. Explain that builders build rectangular (quadrilateral) shapes and then triangulate the space when building homes. Have students share their polygons and their building experiences. Wrap up the lesson with a further discussion of triangulation and patterns they observed in their building. Go over the *Angle Fixer Worksheet*.

If time permits, distribute *the Angle Fixer Connections Response Sheet*. Have the children complete the sheet based on the discussion and their investigation. Have building materials available for students to test their responses. You might want to save this sheet as a class starter for your next class.

Reminded students how to properly care for, put away, and store their Lego materials.

Extensions:

- *Angle Fixer Connections Response Sheet*

Assessment:

- teacher observations and interviews

- Angle Fixer Connections Response Sheet

Trouble Shooting:

- some students will be very familiar with vocabulary and building while for others this will be a new experience
- Angle Fixer Connections Response Sheet may be difficult for many students to work on independently

Resources:

Lego/Tufts website- www.ceeo.tufts.edu/curriculum

Lego Dacta "Simple and Motorized Machines" Teacher Guide

Lego Dacta "Bridges, Towers and Other Structures" Teacher Guide

AIMS Brick Layer II: Creative Engineering with LEGO Construction

Engineer: _____

Date: _____

Partner: _____

Angle Fixer Worksheet

Polygon	Quadrilateral (or square)	Pentagon
Number of sides		
Draw a Picture of how you stabilized it		
Least Number of Axles Used		
Number of regions original space was divided into		

Engineer: _____

Date: _____

Partner: _____

Angle Fixer Connections

Using your Angle Fixer Worksheet, answer these questions:

1. Complete the chart

Number of sides of polygon	Least Number of support beams used	Number of regions space was divided into
4		
5		

2. Now, looking at the chart, what patterns do you see with the numbers in the chart?

3. Now try sketching a hexagon, or six sided polygon. What are some possible ways of triangulating that space? Draw two.

--	--

4. Try building one of your solutions.

Engineer: _____

Date: _____

Partner: _____

Teacher Page: Angle Fixer Worksheet Answers

Polygon	Quadrilateral (or square)	Pentagon
Number of sides	4	5
Draw a Picture of how you stabilized it	Pictures will vary	Pictures will vary
Least Number of Axles Used	1	2
Number of regions original space was divided into	2	3

Engineer: _____
Partner: _____

Date: _____

Teacher Page: Angle Fixer Connections Answers

Using your Angle Fixer Worksheet, answer these questions:

1. Complete the chart

Number of sides of polygon	Least Number of support beams used	Number of regions space was divided into
4	1	2
5	2	3

2. Now, looking at the chart, what patterns do you see with the numbers in the chart?

Support beams are 3 less than the number of sides of the polygon; number of regions is 2 less than the number of sides

3. Now try sketching a hexagon, or six-sided polygon. What are some possible ways of triangulating that space? Draw two.

--	--

4. Try building one of your solutions.

Grade 4: Structures By Design

Lesson 3: Test My Stress

Lesson Objective: To build a bridge and test forces, tension and compression, acting on it.

Learning Objective:

To learn how to recognize tension, or a pulling force, and compression, or a pushing force, on a structure and to understand how they work in tandem to support a structure.

Time: two 45-50 minute periods

Background information:

All structures are affected by forces acting on them. Two of these forces, tension and compression, can affect whether a structure stands up or not.

Tension is a *pulling* force. It stretches the material to lengthen it. Try putting your hands together holding on at the finger tips. If you gently pull away with each hand, you can feel the tension created in your fingertips. You can also feel the force all the way through your arms & shoulder area. All structures are affected by tension or pulling forces on them.

Compression is a *pushing* force. It compresses the material to shorten it. My try putting your hands together at the palms. Push gently on your palms. You can feel the compressing force on your hands & all the way up your arms & shoulder area. All structures are affected by compression or pushing forces on them.

Different materials can withstand tension and compression better than others and are used for different purposes.. Steel, glass and plastic cables can support a great deal of hanging weight. We can say they have tensile strength. Since they are flexible, they have less compressive strength. Steel beams, concrete and rock all have good compressive strength but tend to be a heavy building material.

The Challenge:

- To build a bridge from pieces that are connected in a flexible way, testing tension & compression of the pieces.

Materials:

Lego Simple Machine kits or other Lego building pieces

Test My Stress Worksheet

Test My Stress Again Worksheet

Stress on a String" Building Card #1

Stress on a String" Building Card #2

Vocabulary

- Force
- Truss
- Tension
- Compression
- Tensile strength
- Compressive strength

Procedure:

The first class period

The lesson begins a discussion of the word force. The teacher should write the word on an easel. The teacher might ask the students:

- Has anyone heard of this word before?
- What are some examples of forces?
- Where might you feel forces?
- Can anyone define force? (a push or a pull)

Write the definition on the easel. Next instruct the students that they will be exploring two forces all structures, including themselves, experience all the time, **tension** and **compression**. The teacher should write these two words on the easel and ask the students for a definition of each. Accept all responses. The teacher then tells the students they will experience both forces with simple examples. Have the students grip their fingertips & gently pull away. Ask what it feels like. Ask where they are feeling forces. Explain that they are now experiencing tension or a **pulling force**. When things are

under tension, they are stretched. Write the definition next to the word on the easel. Now instruct the students to put their palms together and push. Ask what it feels like. Ask where they are feeling forces. . Explain that they are now experiencing compression or a **pushing force**. When things are under compression, they are squeezed. Write the definition next to the word on the easel.

Explain that they students will now be building a bridge. They will be testing the bridge to see where it is under tension and where it is under compression. They will be using Lego building blocks and string to build with. Ask how they will know if a string is under tension (it is taut). How will they know if it is under compression (it is sagging). Give each pair of partners the building card:

Stress on a String Building Card #1

Go over the bridge, answering any questions about how to build it. Distribute the *Test My Stress Worksheet*. Explain that the students should answer the questions on the worksheet after they have built the bridge.

Allow 20-25 minutes for the partners to explore and answer question. Save 10 minutes at the end of class to share the bridges & their observations. Go over the Test My Stress Worksheet the next period.

Students should clean up their materials at the end of the period.

The second class period:

The teacher begins the class with a discussion about the bridge building for the class period before. Review the vocabulary: tension and compression.

Go over the *Test My Stress Worksheet*.

The students are then introduced to the second bridge to be built for this lesson:

Stress on a String" Building Card #2

Go over the bridge, answering any questions about how to build it. Distribute the *Test My Stress Again Worksheet*. Explain that the students should answer the questions on the worksheet after they have built the bridge.

Allow the students to build and explore for 20-25 minutes.

Go over the worksheet at the end of the period, comparing the 2 bridges. Use the words tension and compression when talking about the forces.

Extensions:

- Have students build a hexagon frame out of Lego beams. Challenge them to make the frame support a weighted brick (on top) by only adding string and connector pegs the polygon

Assessment:

- teacher observations and interviews
- *Test My Stress Worksheet*
- *Test My Stress Again Worksheet*

Trouble Shooting:

- some students will be very familiar with vocabulary and building while for others this will be a new experience

Resources:

Lego/Tufts website- www.ceeo.tufts.edu/curriculum

Lego Dacta "Simple and Motorized Machines" Teacher Guide

Lego Dacta "Bridges, Towers and Other Structures" Teacher Guide

AIMS Brick Layer II: Creative Engineering with LEGO Construction

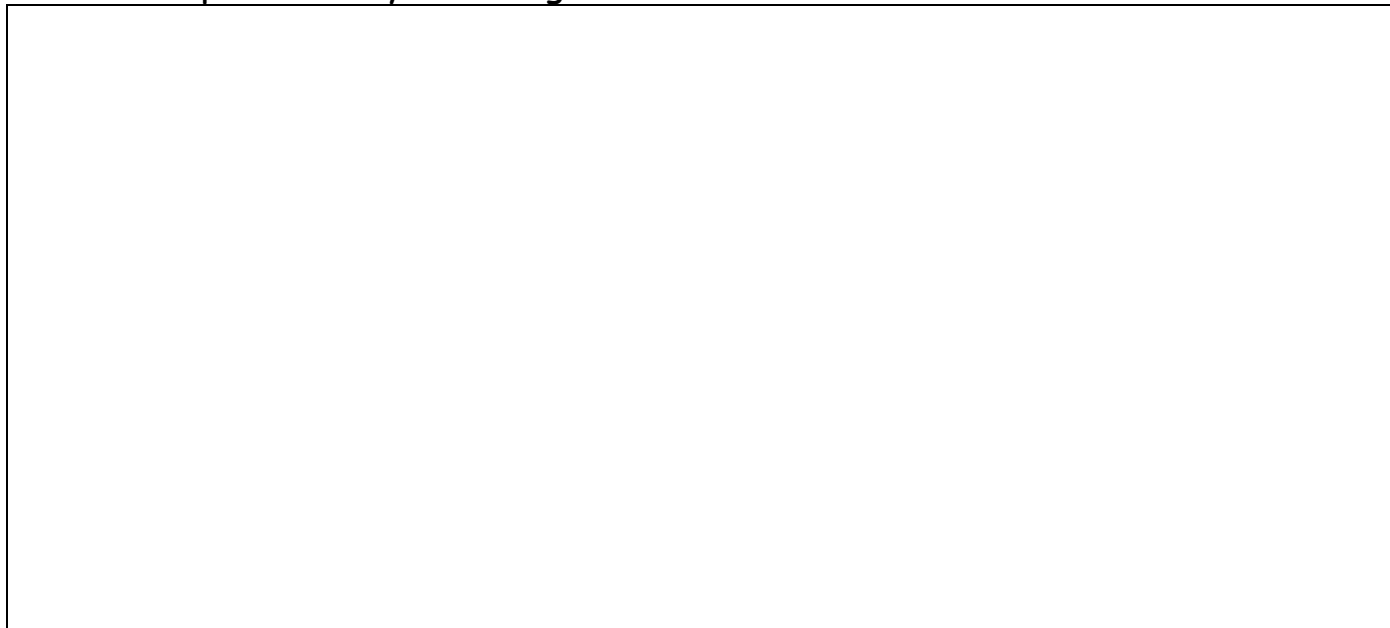
Engineer: _____

Date: _____

Partner: _____

Test My Stress Worksheet

1. Draw a picture of your bridge.



2. Place your bridge between 2 chairs so it spans a small gap.

3. *Gently* push down on the joint at the top of your bridge (so it doesn't break but is under compression). Is the bridge stable as you push? _____

4. Feel the string as you gently push. What happens to the string?

5. What force do you feel on the string? _____

6. On your drawing above, write label where **tension** is happening.

7. On your drawing above, label where **compression** is happening.

8. What makes your bridge stable as it sits on the chairs?

9. Now turn your bridge upside down, tell what happens. Why do you think it did that?

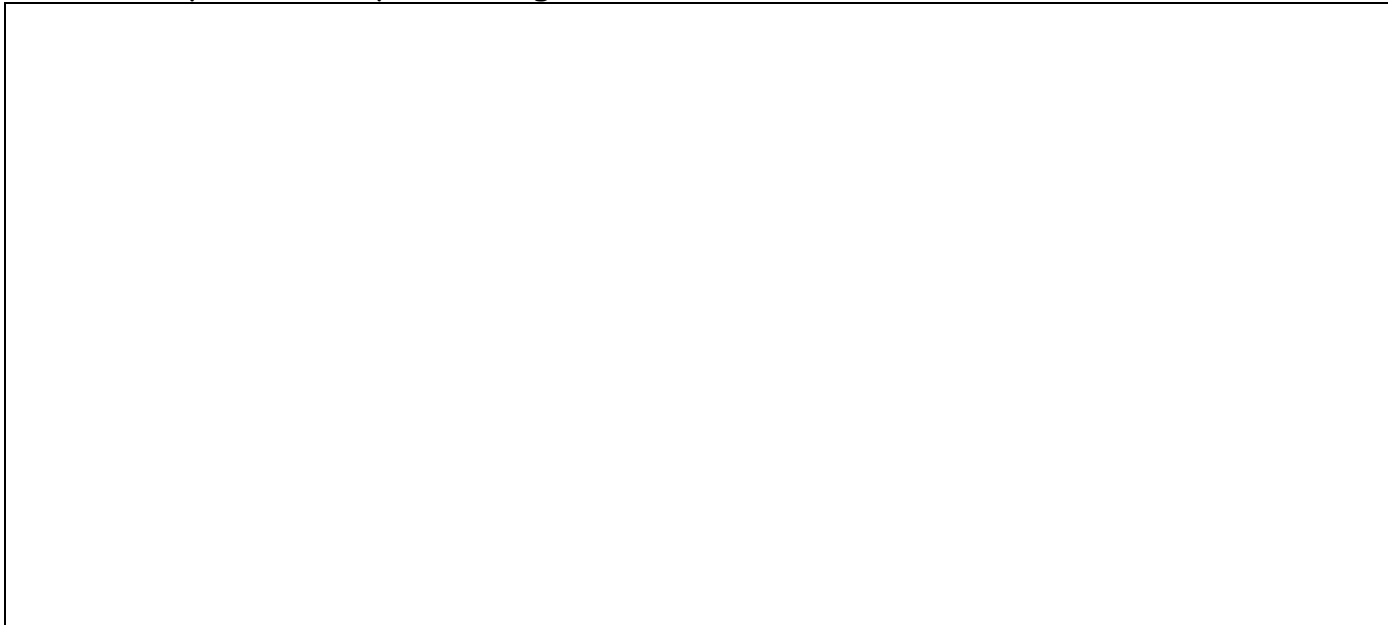
Engineer: _____

Date: _____

Partner: _____

Test My Stress Again Worksheet

1. Draw a picture of your bridge.



1. Place your bridge between 2 chairs so the strings and axle (or strut) are suspended underneath the two beams. The bridge should span a small gap.
2. *Gently* push down on the joint at the top of your bridge (so it doesn't break but is under compression). Is the bridge stable as you push? _____
3. Feel the strings as you gently push. What happens to the strings?

4. What force do you feel on the strings? _____
5. On your drawing above, write label where **tension** is happening.
6. On your drawing above, label where **compression** is happening.
7. What makes your bridge stable as it sits on the chairs?

9, Now turn your bridge upside down, tell what happens. Why do you think it did that?

Grade 4: Structures By Design

Lesson 4: Truss

Lesson Objective: To build a truss and test the forces, tension and compression, acting on it.

Learning Objective:

To learn how to build a truss and investigate how the pieces making up the truss interact to create a stable structure.

Time: two 45-50 minute periods

Background information:

Trusses are structures made up of a special framework or skeleton of pieces used to support the whole thing. The building pieces in a truss are triangulated to make the structure very strong. In a truss some of the building pieces are under tension while others are under compression. Together they support each other and are able to hold large loads. When building trusses, the pieces under tension are built out of materials that have high tensile strength, such as steel, glass or plastic. Some truss design replace steel beams with rods or cables, reducing the weight and cost of the structure but does not reducing its strength.

The Challenge:

- To build a truss bridge from a variety of building materials, predicting and testing areas of tension & compression on the bridge.

Materials:

Truss Testing Worksheet

Lego Dacta Structures II kit # 9618

Lego Dacta Structures II: Bridge, Towers & Other Structures Teacher's Guide

Lego Dacta Structures II Building card #3

Template of paper side beams (from Teacher's Guide page 33)

Vocabulary

- Truss

Procedure:

The first class period

The lesson begins a discussion of the word **truss**. The teacher should write the word on an easel and show some pictures as examples. The teacher might ask the students:

- Has anyone heard of this word before?
- Where might you see this kind of structure?
- Can anyone define truss? (a rigid framework of beams designed to support a structure such as a bridge)

Write the definition on the easel. Next instruct the students that they will be building a truss out of Lego building blocks and pieces of wood (tongue depressors). They will then explore the two forces **tension** and **compression** on the truss. The teacher should review the meaning of these 2 forces.

Explain that they students will now be building a truss described on building card #3, #3.7 (p.6-11). Distribute the booklets & have the students review the steps. Answer any questions about the building. Explain after the truss is build they will be answering questions about the structure on the *Truss Testing Worksheet*. The rest of this class period will be needed for the building phase of this activity.

Students should store their materials at the end of the period.

The second class period:

Most of this class period is used to investigate the truss and completing the *Truss Testing Worksheet*. Allow the last 10 minutes of class to go over the worksheet & reinforce the concepts learned.

The truss bridges should be saved for the next activity.

Extensions:

- Turn the truss over & modify it so it is supported on top rather than on the bottom. Test in a similar way & see if the forces acting on it occur in the same places.
- Replace some of the wooden side-pieces with different materials, such as cardboard, string, tissue paper & test the results.
- Experiment with spring scales to measure the force acting on the bridge. The bridge will need to be placed between 2 chairs to do this.

Assessment:

- teacher observations and interviews
- *Truss Testing Worksheet*

Trouble Shooting:

- Some students will have difficulty following the building steps, especially reading the axle length and putting them in the correct position on the bridge.

Resources:

Lego/Tufts website- www.ceeo.tufts.edu/curriculum

Lego Dacta "Simple and Motorized Machines" Teacher Guide

Lego Dacta "Bridges, Towers and Other Structures" Teacher Guide

Lego Dacta "Bridges, Towers and Other Structures" building booklet #3

AIMS Brick Layer II: Creative Engineering with LEGO Construction

Engineer: _____

Date: _____

Partner: _____

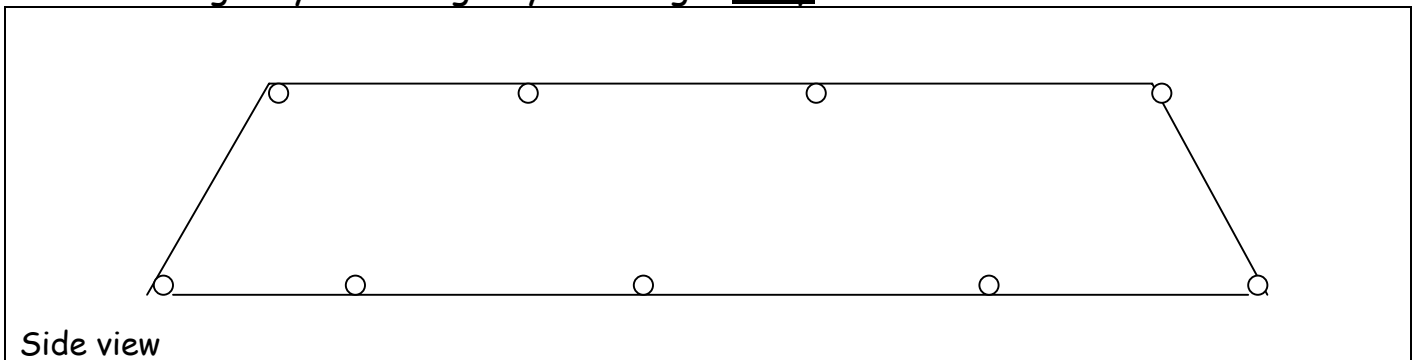
Truss Testing Worksheet

1. Build the truss bridge shown in picture #3.7 on building card #3, p.6-11.

2. Press down on the bottom axles one at a time. What happens?

3. Does one of the axles produce a greater bending in the bridge? ____ If yes, which one? _____

4. On the sketch below, predict where you think **tension** is occurring on your bridge by drawing a straight line. Predict where you think **compression** is occurring on your bridge by drawing a wavy line.



5. To test your prediction, on one side of your truss **replace** the middle 6 wooden sticks with *paper* pieces. (Be sure to keep to 1 wooden stick on each end and all the sticks on the other side of the bridge in place for support).

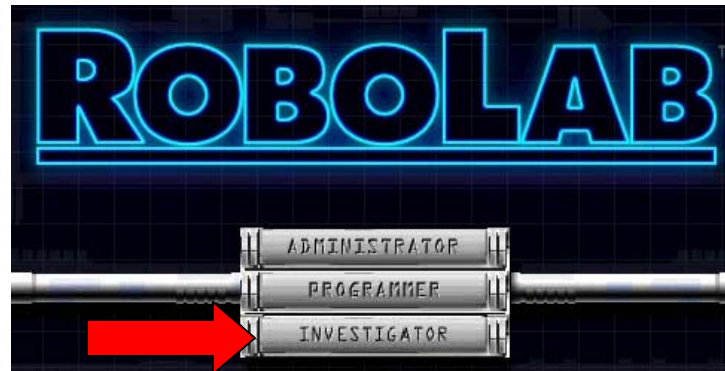
6. Now test your truss by pressing on the middle axle of the truss and sketch what you found out.



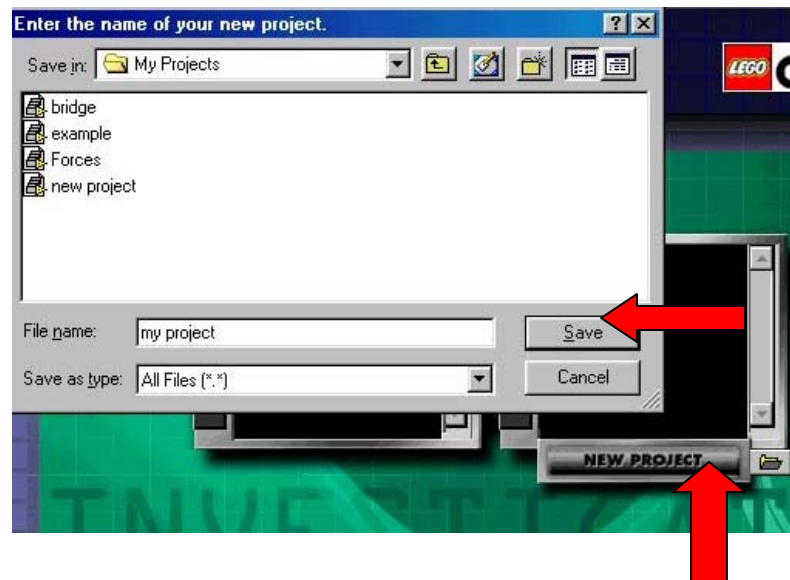
7. Push other axles & draw the bridge's response on the back side.

Force Meters

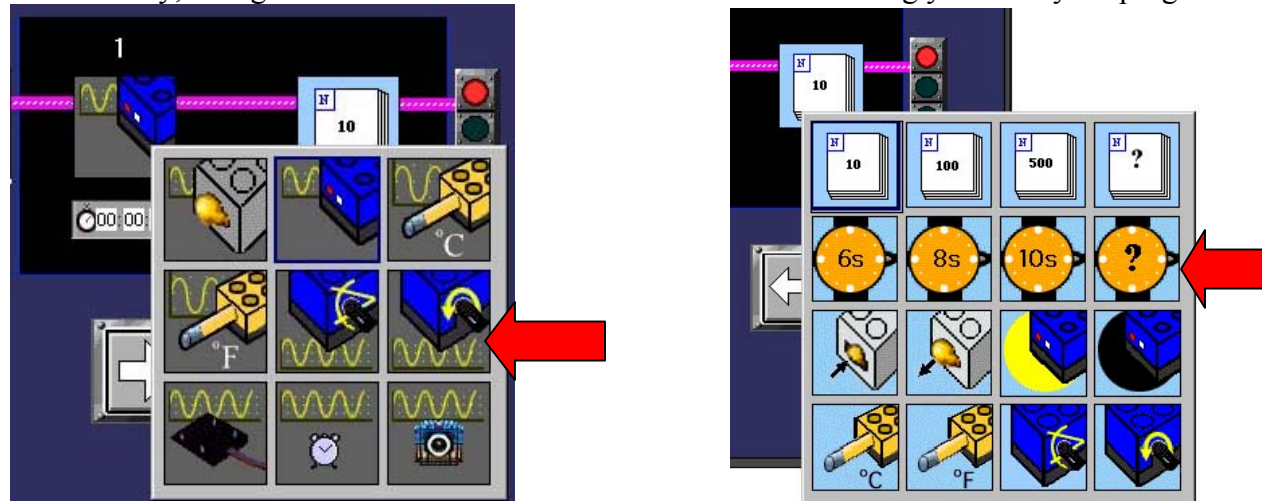
STEP 1: Open Investigator.



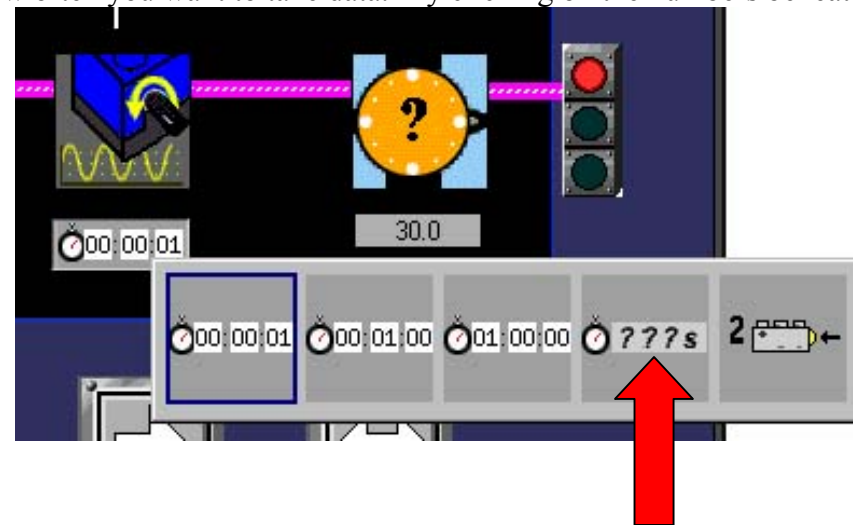
STEP 2: Start a new project by clicking the “New Project” button. Choose a name and save your project.



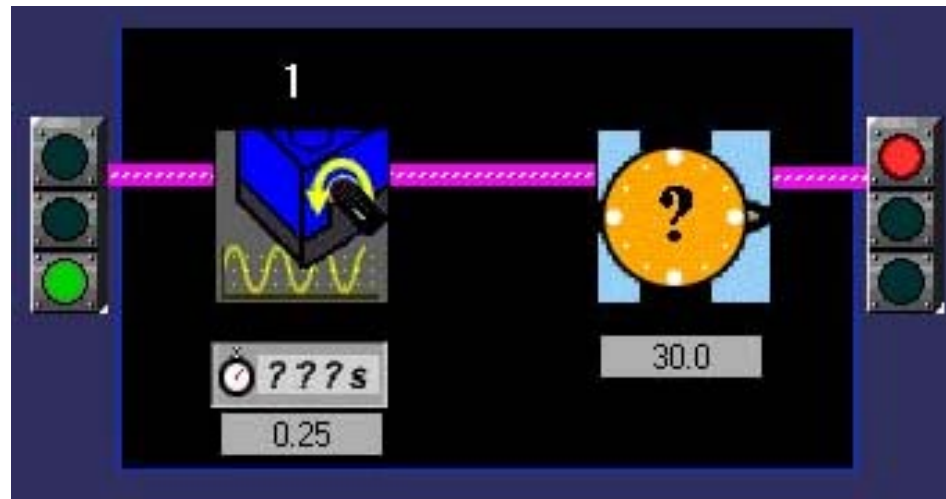
STEP 3: Investigator opens in the Programming Section. Change the program to read information from a rotation sensor by clicking on the light sensor icon. Similarly, change the Wait For Icon to a watch and select how long you want your program to run.



STEP 4: You can also choose how often you want to take data. By clicking on the numbers beneath the sensor icon.



In this example, the program takes rotation data every 0.25 seconds for 30 seconds.



STEP 5: Download your program to the RCX by pressing the white arrow:



STEP 6: Run your program. Move the weight to different axles. How do you think this will affect the force meter readings?

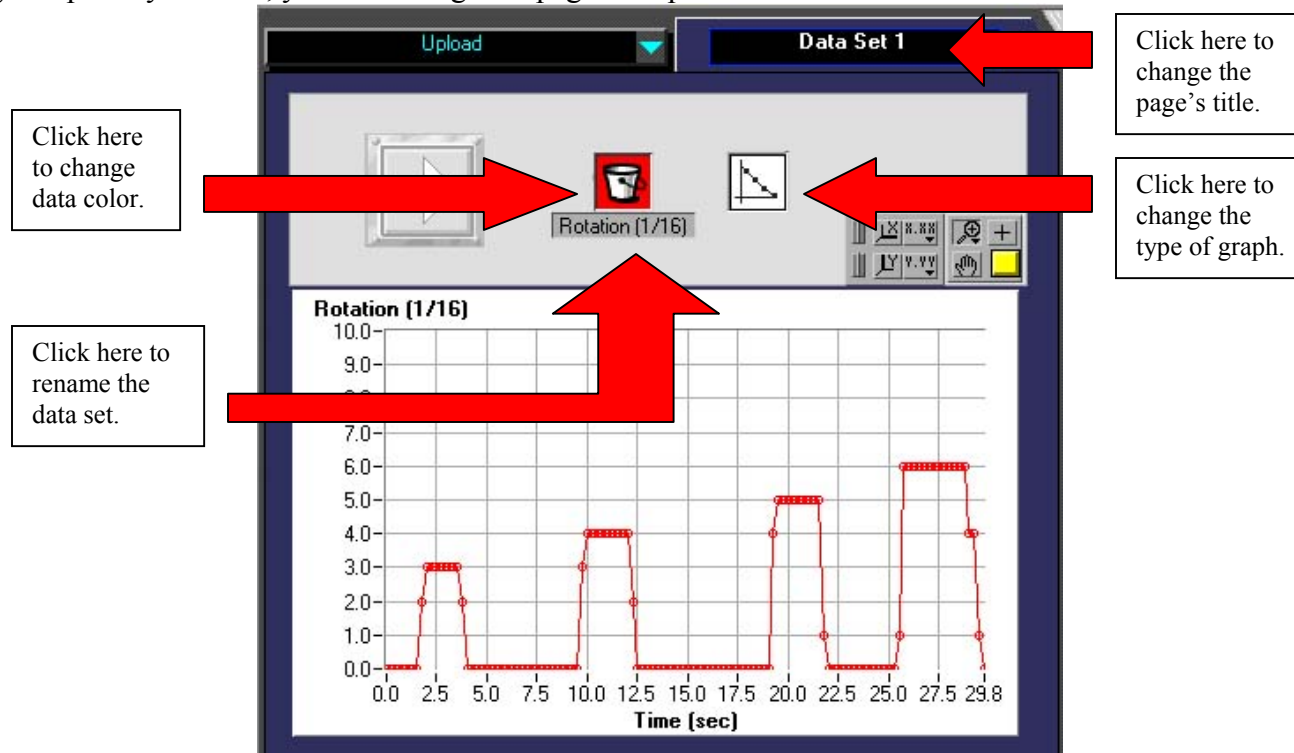


STEP 7: Open the Upload area by clicking on this icon:


STEP 8: To upload your data, place the RCX near the tower and click on the white arrow:

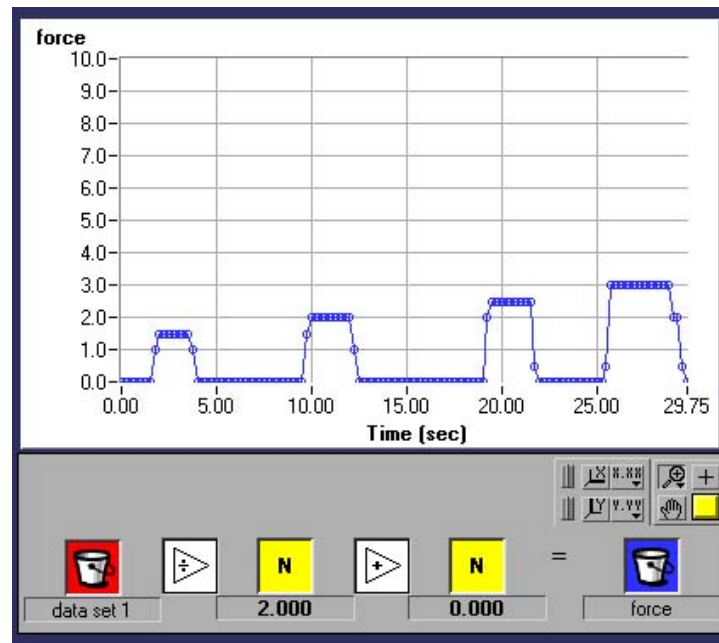


STEP 9: Once you upload your data, you can change the page to explain the data set.



STEP 10: The rotation sensor does not measure in units of force, so we need to convert our data to Newtons. Go to the Compute

section by clicking on this icon: .



By dividing our data by 2, we can read the force in Newtons experienced by the force meters on our bridge.

Final Assessment Ideas

The final assessment is an opportunity for the students to share all the various engineering, programming, and building skills they have learned throughout the Structures Unit. During the final project, students should be encouraged to integrate the concepts covered in this unit into their design. The projects are designed for students to work in pairs to complete the final structure. Several teams of students or the whole class may work together on different parts of a larger structure. For example, when building a circus act one pair may build a high wire balancing act while another team may build the "dogs riding on bicycles" act. The different acts can then be put together for the whole circus. It is helpful for the students to have a building journal where they design, plan out, and reflect on their building during the project. (See attached journal for sample.)

- Design and build a circus act
- Design and build a junk yard with a derrick to move heavy things
- Design and build a arcade game which grabs things (such as candy)
- Design and build a drawbridge

Engineer: _____ Date: _____

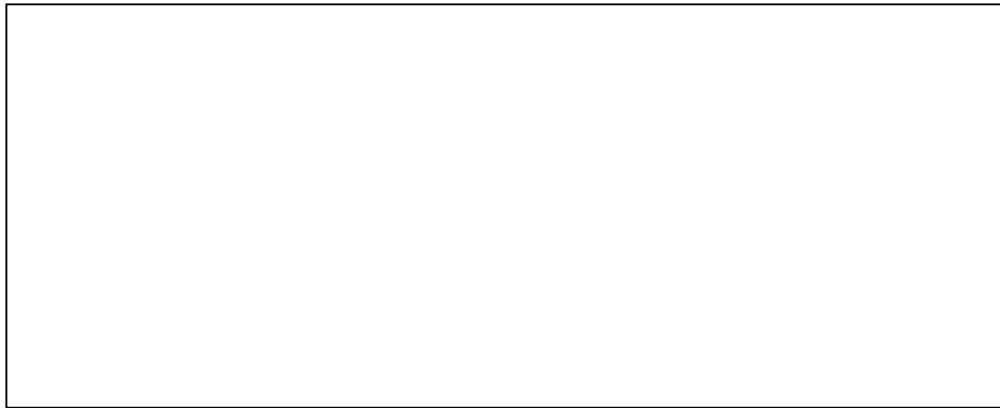
Partner: _____

Structures: Final Assessment Challenge

- Complete the Challenge statement on what you plan to build.

Challenge: To build a _____

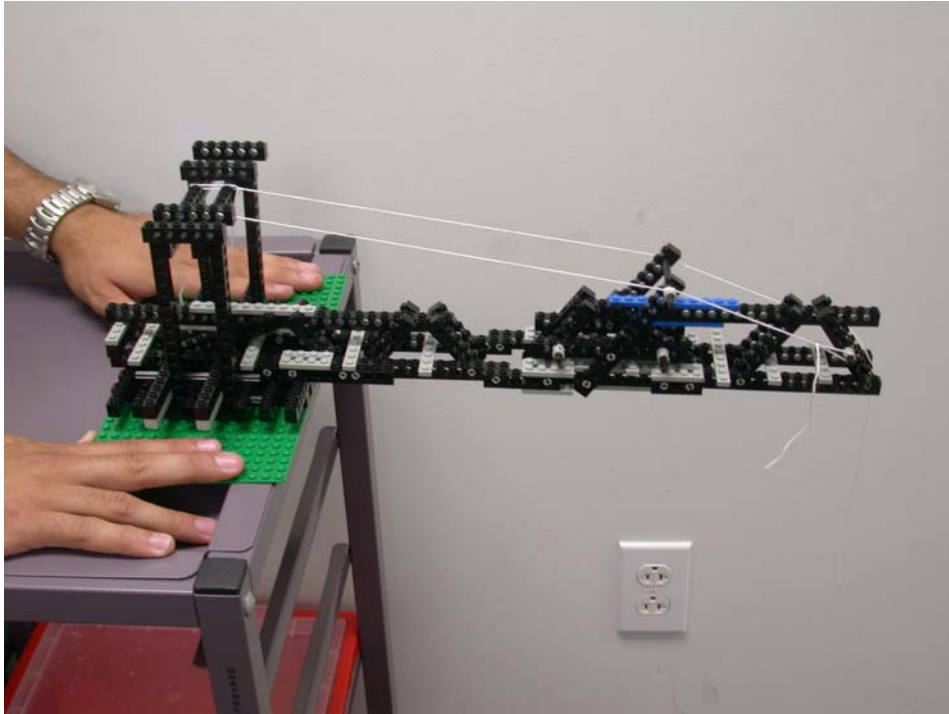
- Draw your idea:



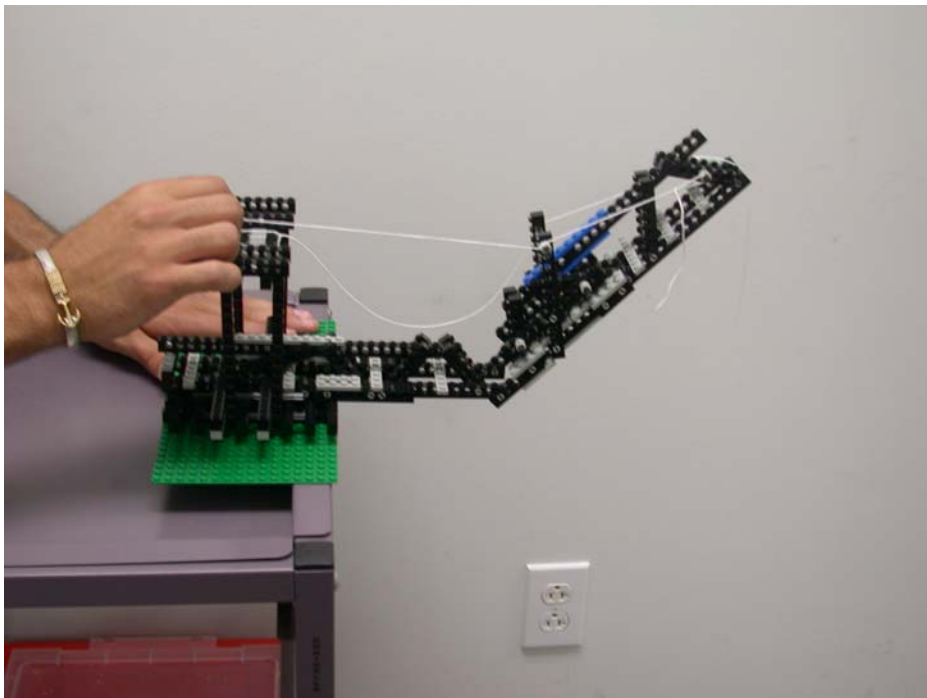
2. Write about your idea:

Sample Ideas

A Derrick



The Derrick- foldable



Resources

Where to Buy Lego building pieces?

- General Lego pieces

Your local toy store - If you need lots of basic bricks or building elements, this is the best and usually cheapest place to buy them.

- Beams, Bricks, Gears, etc.

Specialized LEGO pieces are made by LEGO DACTA

LEGO DACTA materials are sold in the USA by

Pitsco LEGO-DACTA

Phone: 1-800-362-4308 (call for a free catalog)

Web Address: www.pldstore.com

Where to find more help and curriculum links?

- Tufts Center for Engineering Education's Curriculum Site

<http://www.cceo.tufts.edu/curriculum>

Where to discuss LEGOS and ask questions?

- LEGO Users Group Network

<http://www.lugnet.com>

- General education

<http://www.lugnet.com/edu/>

- Robolab

<http://www.lugnet.com/robotics/rcx/robolab>

Where to find out about how engineering stuff works?

- How Stuff Works

<http://www.howstuffworks.com>

Where to find out about structures, such as towers, bridges and other things?

- PBS Building Big

<http://www.pbs.org/wgbh/buildingbig/>

- PBS Nova- Bridges

<http://www.pbs.org/wgbh/nova/bridge/build.html>

- Exploratorium

<http://www.exploratorium.edu/structures/index.html>

- Bridges in the US

<http://member.nifty.ne.jp/bridges/usae.htm>

- Skyscrapers

http://www.bc.edu/bc_org/avp/cas/fnart/fa267/20_sky.html

- Skyscraper Museum

<http://www.skyscraper.org/>

- Architecture

http://www.bc.edu/bc_org/avp/cas/fnart/fa267/

- Sightseers Guide to Engineering

<http://www.engineeringsights.org/>

- The Franklin Institute

<http://sln.fi.edu/structures/structures.html>

- The Big Dig

<http://www.bigdig.com/>

