# Building Stonehenge

Kane ROE Countywide Institute Day

27 February 2015

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**A message from the village elders:**

Brothers and sisters!  The Great Chief, with the approval of the shamans, has decreed that a new monument be constructed within the circle of Stonehenge.  This new monument will be pleasing to the spirits of our ancestors. It will allow us to count the days of the season and help us choose when to plant and harvest.

Our village has been given the task of constructing a trilithon using three of the largest stones ever to be moved by mortal man.  Other villages have been given similar tasks.  The first village to complete its task will be awarded special honors!  Any village which does not complete the appointed task by the Midsummer Sunrise will suffer unspeakable punishment.  We must not fail.  All hands to the ropes!

Stonehenge Trilithon, 2500 BC

Lintel (7 tons)

Upright (45 tons)

7.3 m
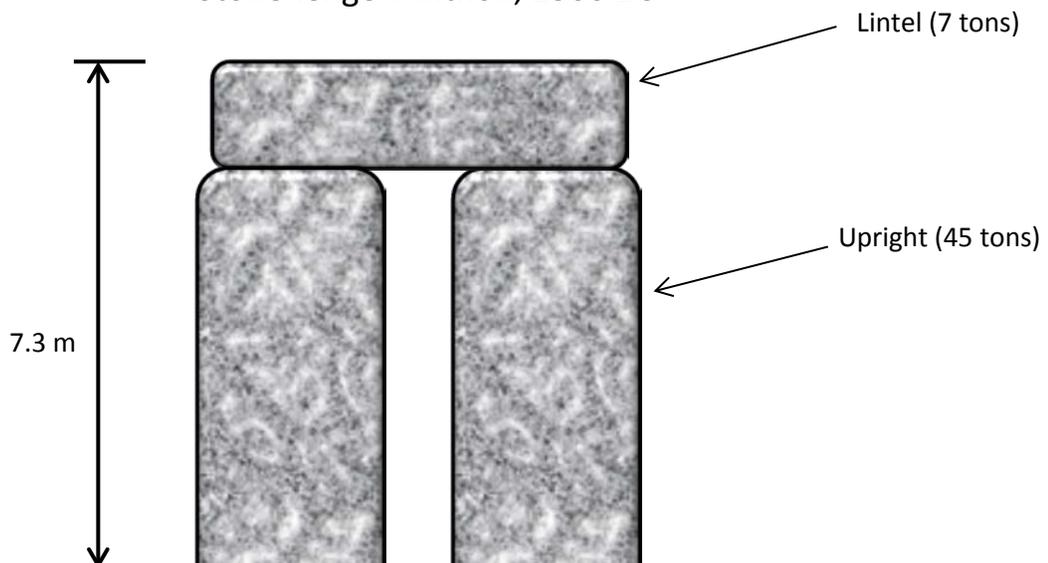
# Building Stonehenge

Building Stonehenge is a series of problem centered activities in which students in grades 8-12 use simple machines to construct a scale replica of a Stonehenge trilithon. Using only materials available to Neolithic engineers and a scaled quantity of force, students must devise a way to lift heavy stones into the proper position without ever touching them with their hands. The activities integrate STEM content and processes with an examination of one of the most intriguing questions from history: how did Neolithic people, using only the most basic stone-age tools, manage to build an edifice as impressive as Stonehenge?

There are three ways to use these activities:

1. An examination of the relationships between force, work, and energy within a system
2. A culminating project demonstrating mastery of those relationships
3. A hands-on integration of history with the practices of science and engineering

The remainder of this document assumes an interest in the first option.

## Prerequisite Knowledge

Students should have a working knowledge of algebra and SI units. They should have at least a conceptual understanding of force, mass, weight, friction, and potential energy. All of these concepts could be introduced with this project, but additional time and resources would be required.

## Relevant Standards

| Source | Designation | Description |
|---|---|---|
| NGSS Disciplinary Core Ideas | HS-PS.3.A | Definitions of Energy |
| | HS-PS.3.B | Conservation of Energy and Energy Transfer |
| | HS-PS.3.C | Relationship between Energy and Force |
| | HS-ETS1.A | Defining and Delimiting Engineering Problems |
| | HS-ETS1.B | Developing Possible Solutions |
| | HS-ETS1.C | Optimizing the Design Solution |
| NGSS Science and Engineering Practices (6 of 8) | Practice 1 | Asking Questions and Defining Problems |
| | Practice 2 | Developing and Using Models |
| | Practice 3 | Planning and Carrying out Investigations |
| | Practice 5 | Using Mathematics and Computational Thinking |
| | Practice 6 | Constructing Explanations and Designing Solutions |
| | Practice 7 | Engaging in Argument from Evidence |

| NGSS Crosscutting Concepts (4 of 7) | Concept 2 | Cause and Effect: Mechanism and Explanation |
| | Concept 3 | Scale, Proportion, and Quantity |
| | Concept 4 | Systems and Systems Models |
| | Concept 5 | Energy and Matter: Flows, Cycles, and Conservation |

## Logistics

Building Stonehenge involves three hands-on activities with extensive opportunities for collaborative problem solving.  The entire project will require four to six hours of instructional time, depending on students' prior knowledge and the teachers' decision on whether to integrate viewing of the PBS documentary video.

The following assumes a class of 18 to 30 students divided into six groups.  The optimum group size is four students.

Building Stonehenge requires a lab or classroom with level surfaces (desks or tables) to support seven 2'x4'pegboards.  As these activities will span several days, horizontal storage space will be needed for the boards and other materials between sessions.

If multiple classes plan to build Stonehenge concurrently, then a separate set of some materials will be needed for each class.  The entire cost for one class of 18 to 30 students is approximately $330.

## Materials List

| Item | number | typical unit cost | Can be shared between classes? |
|------|--------|-------------------|-------------------------------|
| 2' x 4' peg boards | 7 | $8.00 | no |
| single pulley | 15 | $2.00 | yes |
| double pulley | 15 | $2.50 | yes |
| Spring scale (5N or 10N) | 15 | $5 | yes |
| Ball of string | 8 | $5 | yes |
| Concrete bricks | 14 | $0.50 | no |
| Concrete ½ bricks | 7 | $0.50 | no |
| Jumbo craft sticks | 120 | $0.03 | no |
| Narrow craft sticks | 120 | $0.03 | no |
| Small rocks | 30 | 0 | no |
| Pad of 3"x3"post-it notes | 6 | $1.50 | yes |
| Dowel rods, ¼"x 24" | 24 | $0.35 | no |
| Dowel rods, ¼"x 12" | 24 | $0.25 | no |
| Dowel rods, ¼"x (5" or 6") | 72 | $0.20 | no |
| Dowel rods, ¼"x (1" or 2") | 24 | 0 | no |
| Green spray paint | 3 | $3.50 | no |
| Table clamps | 14 | $2 | yes |

## Room Arrangement

Each group of 3 to 5 students has a peg board for building their model trilithon.  On these "modelling boards", students will operate within a set of constraints meant to simulate the actual conditions faced by the Neolithic engineers who designed and supervised the construction of Stonehenge.

In addition to these modelling boards, there is one peg board set aside for experimentation.  This last board, called the "play table", is for students to test various types of simple machines.  At the play table, students need not follow the strict constraints of the modelling board.  This is where they will explore the relationships between force, work, energy, mechanical advantage, and efficiency in simple machines.  Only one play table is available for the entire class.  Here students from different groups will have to share the equipment, and hopefully their discoveries, with each other.

## At the Modelling Board

When building their trilithon, students are bound by the following constraints:

1. You may only use the materials provided, or approved by, the teacher.

2. Never touch the stones with your hands.

3. Stones must be pulled, never pushed (unless you have tools that can measure pushing force).

4. All pulling is done through a spring scale (so it can be measured).

5. All pulling must be level or downward, never upward (since the workers are on the ground).

6. The total pulling force must never exceed 5 N.  This represents the pulling force of 500 workers. No more are available.

Students will have many questions about the modelling constraints over the course of the project. When they ask, have them put the question in writing on a sticky note.  Make them use complete sentences.  Put your written answer on the same note and have the students put the note on a special section of your wall, the FAQ section.  When the next student asks about modelling constraints, be sure they have checked the wall first.  Let them know that asking good questions is part of their grade.

## Activity 1: Across the Salisbury Plain

Give students their handout and read aloud the message from the village elders.

If you choose to use the PBS NOVA video, show Part 1 of 4, Stones at a Sacred Site (18 minutes long).

Each group receives the following materials:

| Item | number |
|---|---|
| 2' x 4' modelling board | 1 |
| single pulley | 2 |
| double pulley | 2 |
| Spring scale (5N or 10N) | 2 |
| Ball of string | 1 |
| Concrete bricks | 2 |
| Concrete ½ bricks | 1 |
| Jumbo craft sticks | 12 |
| Narrow craft sticks | 12 |
| Small rocks | 5 |
| Pad of 3"x3"post-it notes | 1 |
| Dowel rods, ¼"x 24" | 2 |
| Dowel rods, ¼"x 12" | 2 |
| Dowel rods, ¼"x (5" or 6") | 12 |
| Dowel rods, ¼"x (1" or 2") | 4 |
| Table clamps | 2 |
| scissors | 1 |

The task is for students to move one of their large stones across their modelling board from one end to the other. Before beginning the pull, students may either lay the stone on rollers, or a sled of their construction. They may use their hands to get the stone onto its rollers or sled.

Once they are ready, drop a few small rocks on the modelling board about one foot in front of their stone so that a straight pull to the far end is impossible. Enjoy their howls of protest. They will have to go around the small rocks. After they have successfully moving their first large stone, inform students that their second large stone must be brought from another distant site.

Place the lintel stone beneath the center of their board to model the rolling hills of the Salisbury Plain. Students now prepare and pull their second stone over the hill to the far end of the board. Congratulate them with a cheer after both stones have made the journey.

## Activity 2: Raising the Uprights

If you choose to use the PBS NOVA video, show Part 2 of 4, Raising the Sarsen (11 minutes long).

Give students their handout for Activity 2 and a copy of the Science Concepts handout.

Their task is to raise one of the larger stones from the ground into an upright position.  The stone may begin on the ground or it may begin on the rollers or sled students used in the previous activity.

Students will need to build one or more simple machines to accomplish this task.  Before they build anything, however, they must first formulate a Plan of Action and get your approval before proceeding. To obtain your approval, students complete the Plan of Action worksheet and get your signature. Details on using the Plan of Action worksheet are explained later.  Basically, students must do some calculating and testing at the play table to verify that their plan can succeed.

Pulleys were not actually available to the original builders, who had yet to discover the wheel. If you are a history purist you may exclude their use.  There are several ways to build a trilithon without pulleys. On the other hand, pulleys are a fascinating simple machine and the more options students have for solving the problem, the more enjoyable the experience will be.

If using pulleys, students will need to build timber towers from which to suspend their pulleys.  The base of timbers may be anchored in the holes of the modelling board.  Ropes may be used for additional support.  Any structure built in this way must be free-standing, supporting its own weight and that of any pulleys without the need for students to balance it or hold it up by hand.  The same is true of ramps, timber cribs, and anything else they choose to build.

The real test of such structures comes when they must bear the weight of a stone.  If it collapses and drops the stone, cry out loudly and lament the loss of the dozen workmen who were crushed.  Allow students to struggle, rebuild, and try again.  Their ultimate triumph will be that much the sweeter if they must first overcome some mishaps.  That being said, if time is running short, and one group is in particular difficulty, you might allow a helping hand "just this once".

Tell students to call you over when they are getting close to the final moment of truth so you can witness the event.  When their stone settles into the upright position lead the class in three cheers!  Do this for every group, not just the first to succeed.

## Activity 3: Raising the Lintel

If you choose to use the PBS NOVA video, show Part 3 of 4, Twenty Degrees to Vertical (25 minutes long).

Give students their handout for Activity 3 and a copy of the Science Concepts handout.

Students begin by placing both of their uprights in the standing position and may freely use their hands to do this. The lintel may begin on the ground or it may begin on rollers or sled as it would have been transported to the site.

Their task is to raise the lintel on top of the uprights to complete the trilithon. As with the previous activity, a Plan of Action worksheet must be completed and presented for your signature before students are allowed to build whatever machine or structure they wish to use.

As each group finishes, allow them to assist students who are still working.

When all are completed, show the final part of the PBS NOVA video, Raising the Lintel (8 minutes long).

## The Plan of Action Worksheet

Completing the worksheet ensures that students are learning about energy, work, and forces. Make them sell you on their plan. Challenge it and see if every member of the group can explain both the logic and the mathematics. Don't sign it until you feel they have an adequate understanding of the scientific concepts involved.

## Science Concepts Involved in Building the Trilithon

At the Play Table there should be several copies of Science Concepts Involved in Building the Trilithon. They can be placed in plastic page protectors and attached to the holes in the Play Table by paper clips or twisty ties. This is a two page summary of the mathematical underpinnings of mechanical potential energy, work, force, mechanical advantage, and efficiency. It includes links to information and simulations on the internet. Encourage students to explore these ideas as a group. Help them as necessary, but encourage them to work it out for themselves first.

## Suggestions for Evaluation of Learning

The Plan of Action worksheets are the most important evidence of learning, regardless of what happens on the modelling board.  Teachers should develop a rubric which fits their unique requirements but the following is offered as one suggestion.

| Activity 1 | Was the task completed successfully? | 0 or 5 points |
|---|---|---|
| Activity 2 | Plan of Action Worksheet | |
| | first block | 0 or 8 points |
| | second block | 0 or 8 points |
| | third block | 0 or 8 points |
| | fourth block | 0 or 8 points |
| Activity 2 | Was the task completed successfully? | 0 or 5 points |
| Activity 3 | Plan of Action Worksheet | |
| | first block | 0 or 8 points |
| | second block | 0 or 8 points |
| | third block | 0 or 8 points |
| | fourth block | 0 or 8 points |
| Activity 3 | Was the task completed successfully? | 0 or 5 points |
| All activities | Did the group ask good questions about constraints? | 0 - 6 points |
| All activities | Individual participation | 0 - 15 points |
| | | Total points = 100 |

## Teacher Resources

Videos:

There are many free videos available on Youtube about Stonehenge.  Most focus on the archeology or the more speculative theories about the monuments' origin and purpose.

The best video made about the construction of Stonehenge aired on the PBS NOVA series and is titled Secrets of Lost Empires 1: Colosseum - Stonehenge.  It can be purchased online at www.shoppbs.org for $18.  Look for item# WG40709.  In this video, an actual life-size trilithon is erected using some of the same ideas your students will use.  This is the PBS NOVA video referenced earlier in this document and its use is highly recommended.

Secrets of Stonehenge (PBS NOVA S38E05) is a video about the most recent archeology at the site although it does not delve deeply into science of how it was built.  Find it at:
http://video.pbs.org/video/1636852466/ or on Youtube

Websites:

Most Stonehenge websites are full of pseudoscience or advertising for commercial products.  Wikipedia is actually one of the better sites, along with:

http://www.english-heritage.org.uk/daysout/properties/Stonehenge

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Professional Learning Day; February 27, 2015

**Student Pages**

**Building Stonehenge – Activity 1**

**Across the Salisbury Plain**

A message from the village elders:

Brothers and sisters! The Great Chief, with the approval of the shamans, has decreed that a new monument be constructed within the circle of Stonehenge. This new monument will be pleasing to the spirits of our ancestors. It will allow us to count the days of the season and help us choose when to plant and harvest.

Our village has been given the task of constructing a trilithon using three of the largest stones ever to be moved by mortal man. Other villages have been given similar tasks. The first village to complete its task will be awarded special honors! Any village which does not complete the appointed task by the Midsummer Sunrise will suffer unspeakable punishment. We must not fail. All hands to the ropes!

Your group represents a village with 500 workers. Your task is to construct a trilithon consisting of three heavy stones. The two larger stones will eventually be raised into an upright position. The smaller lintel stone will go on top.

The first task is to move one of the larger stones across the modelling board from one end to the other. Before beginning the pull, you may either lay the stone on rollers, or a sled of your own construction. You may use your hands to get the stone onto its rollers or sled.

Inform your teacher when you are ready to begin the pull.

From now on, the following constraints must be obeyed while working with stones on your modelling board:

1. You may only use the materials provided, or approved by, the teacher.

2. Never touch the stones with your hands.

3. Stones must be pulled, never pushed.

4. All pulling is done through a spring scale.

5. All pulling must be level or downward, never upward.

6. The total pulling force must never exceed 5 N. This represents the pulling force of 500 workers. No more are available.

During the project you will likely have many questions about the modelling constraints. Put your question in writing on a sticky note and hand it to your teacher. Your teacher will write an answer on the note. Post the note to whatever surface your teacher has selected as the FAQ wall. Check the wall frequently so you can benefit from answers to questions others have asked.

Keep an eye on what other groups are doing. Call out if you see them violating any of the modelling constraints!

The large stones each have a mass of approximately 2.13 kg.

The lintel stone has a mass of approximately 1.1 kg

When your teacher has given permission, pull the stone across the modelling board. You may be asked to move the other large stone as well.

Good luck!

**Student Pages**

**Building Stonehenge – Activity 2**

**Raising the Uprights**

Your next task is to raise one of the larger stones from the ground into an upright position.  The stone may begin on the ground or it may begin on the rollers or sled you used in the previous activity.

You will need to build one or more simple machines to accomplish this task.  Before you build anything, however, you must first formulate a Plan of Action and get your teacher's approval before proceeding. To obtain that approval, you must complete the attached Plan of Action worksheet and get your teacher's signature.

Each member of the group should be prepared to explain and defend everything written on the Plan of Action worksheet.

## At the Play Table

Use the materials and information at the Play Table to help you understand the following concepts:

- Gravitational potential energy
- Work
- The relationship between work and changes in energy
- The mechanical advantage of simple machines
- The efficiency of simple machines

Information about simple machines can be found in textbooks and on many online sites.  Research can augment and reinforce what you learn from using materials at the play table.

## At the Modelling Board

Remember your modelling constraints.

You may wish to build timber machines or structures to help you complete the task.  The base of timbers may be anchored in the holes of the modelling board.  Ropes may be used for additional support.  Any structure built in this way must be free-standing, supporting its own weight and that of any pulleys without the need for students to balance it or hold it up by hand.

If you have additional questions about the constraints, remember to check the FAQ wall and if you don't find an answer there, write out a question to submit to the teacher.

When you are ready to make your final pull to raise the upright, call your teacher over to witness.

# Stonehenge Plan of Action Worksheet

Describe your plan of action in at least three complete sentences.

Sketch your plan with emphasis on any machines or structures you intend to build.  Include dimensions.

Explain what you did and learned at the Play Table which gives you confidence that this will work.

Show mathematical calculations suggesting that this plan can work.

On a separate page, calculate the

    increase in height of the stone's center.

    stone's increase in potential energy.

    work to be done on the stone.

    force applied by the machine to the stone.

    mechanical advantage of the machine.

    force applied by the pullers to the machine.

## Student Pages

## Building Stonehenge – Activity 3

## Raising the Lintel

Begin by placing both of your uprights in the standing position. You may freely use your hands to do this. The lintel may begin on the ground or it may begin on rollers or sled as it would have been transported to the site.

Your task is to raise the lintel on top of the uprights to complete the trilithon. As with the previous activity, a Plan of Action worksheet must be completed and presented for signature before you are allowed to build whatever machine or structure you wish to use. Each member of the group should be prepared to explain and defend everything written on the Plan of Action worksheet.

When you are ready to make your final pull to get the lintel in place, call your teacher over to witness. Once you are done, assist other groups who are still working.
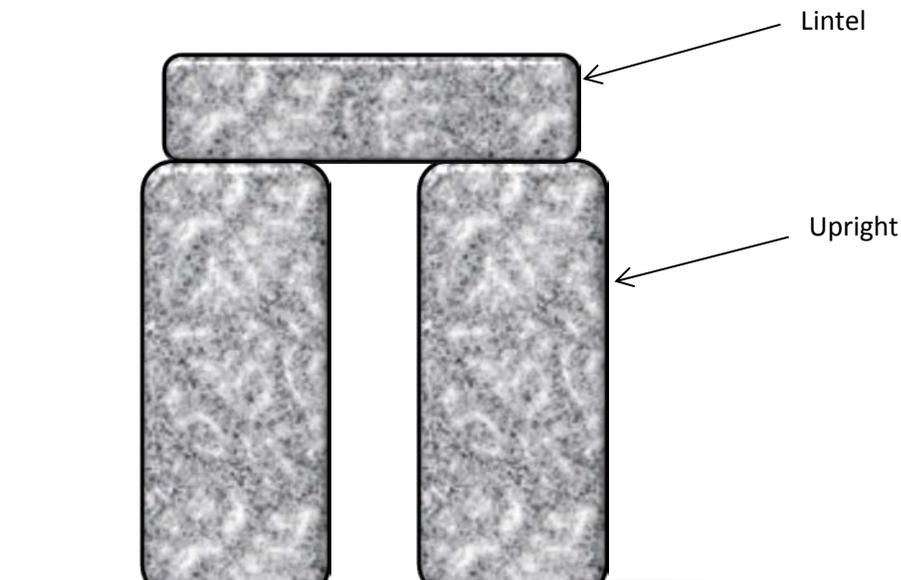
Lintel

Upright

# Stonehenge Plan of Action Worksheet

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Sketch your plan with emphasis on any machines or structures you intend to build.  Include dimensions.

Explain what you did and learned at the Play Table which gives you confidence that this will work.

Show mathematical calculations suggesting that this plan can work.

On a separate page, calculate the
       increase in height of the stone's center.
       stone's increase in potential energy.
       work to be done on the stone.
      force applied by the machine to the stone.
      mechanical advantage of the machine.
      force applied by the pullers to the machine.

# Science Concepts Involved in Building a Trilithon

## Summary of the relationships between energy, work, and force

To move a stone upward requires increasing its potential energy. The change in its energy will depend on the change in the height of the stone's center.

$\Delta U_g = mg\Delta h$

> where: $\Delta U_g$ is the change in the stone's energy (measured in joules)
> $m$ is the mass of the stone (measured in kilograms)
> $g$ is the local strength of gravity (9.8 m/s$^2$)
> $\Delta h$ is the change in height of the stone's center (measured in meters)

Note that the quantity **mg** is also the weight of the stone measured in newtons. So we might also say that $\Delta U_g$ = weight x change in height.

The energy of a system can only be increased if an outside force is doing work to increase it. Lifting a stone takes work. The amount of work needed is equal to the increase in the stone's energy ($\Delta U_g$).

> **W** = $\Delta U_g$          both work (**W**) and energy are measured in joules

Doing work requires applying a force which produces movement in the direction of the force. The amount of force and movement can be related to the work done on the stone as follows:

> **W** = **Fd**  where:  **F** is force (measured in newtons) applied directly to the stone
> **d** is distance moved (measured in meters) by the stone's center

To lift an object generally requires an upward force equal to the object's weight. Note that both force and weight are measured in newtons. If you are only lifting one end of the object, while the other end remains on the ground, the required lifting force will only be half of the objects weight.

Since you are restricted to pulling with 5 newtons of force, you obviously can't lift the stone directly. You will need the help of a simple machine.

## Summary of Simple Machines

Simple machines can't increase the amount of work you do. Instead, they allow you to do your work by using less force. The tradeoff is that you must apply that lesser force over a greater distance.

How effective a machine is at reducing the required force depends on the machine's construction and dimensions. We describe this effectiveness as **Mechanical Advantage** or **MA**.

**MA** = $F_{out}$ / $F_{in}$

Where: $F_{out}$ is the force applied by the machine to the stone (= weight of the stone being lifted)

$F_{in}$ is the pulling force applied by the spring scale (never greater than 5 newtons)

You can determine the mechanical advantage of a machine by experimenting at the Play Table or researching simple machines on the internet.

A mechanical advantage of 2 means that you could, in theory, lift an object with a weight that is twice your pulling force. Unfortunately, real machines always lose some energy due to friction. They are not 100% efficient. A machine with a theoretical MA of 2 might only allow you lift a weight which is <u>almost</u> twice the pulling force. Keep that in mind as you make your plans. Testing at the play table can help you avoid problems later on.