Design Challenges in the Developing World

Facilitator's Guide

TechXcite Discover Engineering

Module Overview

In this TechXcite: Discover Engineering module youth are introduced to the challenges of engineering in resource-poor environments. In many countries, access to electricity can be limited or even nonexistent. In the first half of the module, students learn ways to overcome this limitation. In the second half of the module, students learn about efficient bridge design and are challenged to design a bridge with minimal materials and minimal waste, much like the challenge taken on by actual engineering students from the Milwaukee School of Engineering working with Engineers Without Borders.

This curriculum is intended for use with youth in middle grades in informal settings, such as after-school programs and summer camps. However, it has also been successfully implemented in formal school contexts, homeschool content, and with youth in elementary and high school.

Activity 1: Create an innovative, low-cost lighting solution.

Activity 2: Build a water wheel and learn how to extract work from water.

Activity 3: Explore tension and compression in bridges.

Activity 4: Explore shapes and learn why trusses are made up of triangles.

Activity 5: Youth use their knowledge of bridges to design the strongest and most cost-effective bridge. They then build and test the bridges as a class.

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TechXcite: Discover Engineering

TechXcite is an informal engineering program partnering 4-H Youth Development/Family and Consumer Sciences at North Carolina State University, National 4-H Council and the Engineering K-PhD Program at Duke University's Pratt School of Engineering. It was initially funded by a five-year grant from the National Science Foundation.

In 2000, Drs. Ybarra and Klenk created an informal after-school engineering program at Rogers-Herr Middle School in Durham called Techtronics, which spread to additional schools across North Carolina and other states. The TechXcite: Discover Engineering curriculum builds on the Techtronics foundation by implementing hands-on, exploratory, engineering learning modules in 4-H Afterschool programs nationwide. Other after-school programs and even formal in-school and home-school programs have chosen to use the TechXcite curriculum. TechXcite is an engaging, substantive, experiential and inquiry-based curriculum centered on engineering, while using technology, applied science and mathematics learned in school. TechXcite's mission is to encourage youth in both rural and urban settings to pursue careers in engineering and technology.

TechXcite is the product of a collaboration of twelve 4-H leaders at land grant universities, two leaders at National 4-H Council and a team at Duke University.

Online Support

The TechXcite website (techxcite.org) contains additional material to facilitate implementation of this module. There are videos, Facilitator's Guides, Youth Handouts, and kit inventories with vendors and pricing for each item required. Although the curriculum is written with a focus on middle school youth, it has been successfully implemented at both the elementary and high school levels. Anyone can download copies of the Facilitator's Guide and Youth Handouts from our website. There are links to additional resources for information about the module topics and ideas for further activities and exploration.

Training Videos

Each module comes with a set of training videos found on its curriculum page (techxcite.org/curriculum). These videos serve as a companion to the Facilitator's Guide. An introductory video provides an overview of the material and concepts. The corresponding video for each activity then covers basic setup, Facilitating the Activity, and helpful tips for facilitating that activity. It's recommended that instructors watch all of the videos before starting the module.

Using this Guide

The Facilitator's Guide for each activity follows the same format. Below is what you can expect to find in each section. At the beginning, you will be given basic information about the activity. This includes:

- Time Required
- Group Size – Suggested number of students per group.
- Materials List
- Youth Handouts – These will need to be copied.
- Getting Ready – What you need to do before the activity and approximately how much time it will take you.
- Learner Outcomes
- Vocabulary

Introduction and Activity Closure

The Introduction and Activity Closure are scripted. You may read these sections verbatim to students. Instructions that are not to be read to students, as well as answers to questions, are in brackets/italics.

Facilitating the Activity

This section contains step-by-step instructions for facilitating the activity. Students have their own procedure in the Youth Handouts.

Exploration Questions

Provides possible answers to the Exploration Questions found at the end of each activity in the Youth Handouts. After the students have a chance to answer the questions individually, instructors should hold a class discussion. The main purpose of this section is to encourage critical thinking and to promote the exchange of ideas.

Activity 1: Lighting Without Electricity

Time Required: 45 minutes **Group Size:** 3

Materials List

Each group needs:

- Corrugated cardboard box (Not included in kit)
- Clear plastic bottle (16 oz; Not included in kit)
- 4 Binder clips
- Photoresistor
- 2 Alligator wires
- Pencil (At least 5" long; Not included in kit)
- Digital Multimeter

Each class needs:

- Scissors
- Clear packaging tape
- Water (Not included in kit)
- Paper towels (Not included in kit)

Youth Handouts:

- "Lighting Without Electricity"

Getting Ready (20 minutes)

- Obtain 16 oz plastic bottles from a recycling bin and medium to large cardboard boxes to use as houses (one for each group).
- Determine how students will fill their bottles with water.
- Build an example light probe and take a couple test readings to ensure you are familiar with how to measure resistance with the multimeter.

Learner Outcomes

- Explain that many people around the world must design technology without electricity.
- Explain that engineers can design simple solutions that make a difference in people's lives.

Vocabulary

Word	Definition
Appropriate technology	Devices used primarily in developing countries that are easy to use and build, but less costly than similar devices found in industrialized countries.
Resistance	The opposition of a material to the flow of electricity. Measured in ohms.

Activity 1: Lighting Without Electricity

Introduction

Over the next few activities, we'll be looking at special challenges faced by engineers designing technology for people in developing countries.

Today, we will explore how people light their houses when they don't have electricity. [*Start by showing the video about the use of bottle lights in the Philippines (http://youtu.be/CR6vnFR8AnU), if possible. If not, describe the video or show pictures.*] Developed in Brazil and the Philippines with the help of engineering students at MIT, the Liter of Light project provides solutions around the world.

In this activity, we're going to build a skylight made from a plastic bottle filled with water. But rather than guess at how well our skylight is working, we'll take actual measurements using a light probe, just like a real scientist. And like a real engineer, you will experiment with different skylight designs to find one that works the best.

Facilitating the Activity

Part A: Building the Skylight

1. Place students in groups.
2. Distribute the Youth Handouts and materials. You can have the students work through the handouts on their own or you can lead the students through the activity in front of the class.
3. Carefully cut about 2-3 inches down each corner of the cardboard box.
4. Bring the two longest flaps together so they touch and overlap about one inch. Pinch and secure them using metal clips.
5. Turn the box on its side and trace the edge of your roof on the short side-flaps. Cut the flaps into a triangle shape along this line.
6. Next, trace the bottom of the bottle on the inside of a long flap and cutout the circle to make a hole in the roof for the bottle.


Activity 1: Lighting Without Electricity

7. Tape up the roof edges and secure with more clips, if necessary.
8. Place the water-filled bottle, upside down, in the hole and attach with clear tape.
9. Below the water bottle, in the side of the box, create a small hole (1/4" diameter) for the light probe about one inch up from the base of the box. Leave a small flap of cardboard above the hole to shade the opening from overhead ambient light, which may throw off the measurements.

Part B: Creating the Light Probe

Note: Once the light probes are built, do not try to take them apart as the delicate photoresistor can be easily damaged. Save them for reuse during next class.

10. Carefully bend the metal wire leads of the photoresistor so that it faces away from the pencil when it is taped down. Make sure the two leads are separated so that they don't touch each other.
11. Connect an alligator wire to each lead of the photoresistor. Then tape the alligator wires to the pencil.
12. Using a ruler, place marks on the side of the pencil at 1" intervals.
13. Finally, connect the two free ends of the alligator wires onto the multimeter probes. It doesn't matter which way you hook up the meter; you can swap the two probes and it will work the same.
14. Ask students to guess how the probe works.

    [*The photoresistor's electrical resistance changes depending on how much light strikes its surface. The brighter the light shining on the photoresistor, the lower its electrical resistance. The battery inside the multimeter is used to power electricity through the component connected between the red and black multimeter probes in order to determine how much it resists the flow of electricity.*]

Part C: Testing

15. Students will work as a team. They should decide who will hold the light probe, who will hold the multimeter, and who will write down the readings. The person holding the light probe must be sure that the photoresistor faces up towards the skylight during all the readings.
16. They will open up the small flap on the side of the building, insert the light probe until it extends 1" inside the building (using the markings on the pencil as a guide), and record the resistance reading in the table provided in the Youth Handout.
17. Repeat the measurement with the light probe inserted at 2", 3", 4", and 5".
18. They will then calculate the average of their five resistance readings and record it in the table. Ask students why an engineer or scientist might want to calculate the average value of all the readings.

    [*It is difficult to compare one skylight design to another by looking at all 5 readings of each design. By taking the average of the readings we can judge the total result making it easier to compare designs. You also may wish to explore with students the downside of using the average.*]

Activity 1: Lighting Without Electricity

19. Now students will be allowed to experiment with the goal of improving the skylight design. Remind them that lower resistance values are better because the more light that hits the photoresistor the lower its resistance.

    Note: There are a variety of things students can experiment with. How much of the bottle is inside vs. outside the roof? How is the bottle orientated (pointed end inside vs. outside the house)? Does filling it with water help or does an empty bottle work just as good? What about the type of liquid (apple juice, water mixed with soap, etc)?

Activity Closure

The first step of any engineering design process is to identify the problem. For the Liter of Light project (aliteroflight.org), the challenge was to find a way to brighten up the homes of thousands of people living in impoverished and over-populated areas with no access to electricity. Windows were not an option because the houses were too close together to let in light. A skylight was necessary, but it couldn't leak, and traditional glass skylights were expensive. Fortunately, Liter of Light found a solution to this problem in **appropriate technologies**.

Appropriate technology is the design of tools, techniques, and systems that are "appropriate" to the specific context of their use. For Liter of Light and many other organizations working to design solutions for developing countries, this means creating something that's easy to use and build, improves upon inefficient traditional devices, and is less costly than similar devices in industrialized countries. The bottle light, made of inexpensive local materials and easy to install, is a great example of this type of solution. [*If possible, show the step-by-step video on how to make a real bottle light (http://youtu.be/rYTIYUUK70I).*]

Exploration Questions

1. What are the pros and cons of using the bottle light built in this activity?

   [*Pros: Most of the materials can be obtained locally, anybody can do it, inexpensive, does not require electricity, no fire risk, etc. Cons: Roof leaking when it rains, doesn't work at night or as well when it's cloudy, the water might develop bacteria, people might not follow the instructions correctly, etc.*]

2. How does the Liter of Light design address the potential problems identified in the previous question?

   [*The glue prevents leaking. The step-by-step instructions are easy to follow so that anybody can use them. Chlorine is used in the bottles to prevent bacteria growth.*]

3. What are some other examples of appropriate technology? Why it is appropriate?

   [*A few examples from other TechXcite modules might be a solar oven or rainwater collection*.]

Activity 2: Moving Water

Time Required: 60 minutes **Group Size:** 2

Materials List

Each group needs:

- 25 Plastic cups
- 2 Pieces of cardboard (Not included in kit)
- Wooden dowel (1/4" or 5/16" dia, approximately 2 ft long)
- 2 Pencils or pens (Not included in kit)
- String or ribbon (Optional)

Each class needs:

- Stapler
- Scissors
- Pitcher (2 liters)

Youth Handouts:

- "Moving Water"

Getting Ready (15 minutes)

- You will need to find cardboard for the water wheels. Look for large boxes near a recycling bin and cut them open with scissors.
- Set up a location to test the water wheels. The water will make a mess so pick a spot outside or lay down plastic or a pan to catch the water.

Learner Outcomes

- Explain how work can be extracted from water.
- Explain the difference between potential energy and kinetic energy.

Vocabulary

Word	Definition
Kinetic energy	Energy that an object has because of its motion.
Potential energy	Energy that an object has because of its position.
Revolution	One complete turn of a rotating body.

Activity 2: Moving Water

Introduction

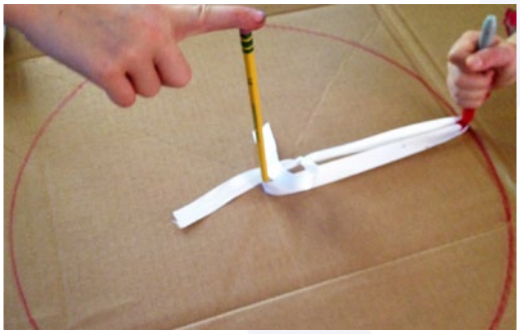
In this activity, you're going to design a water wheel. Have you ever seen a water wheel, or watermill? [*Show photo below.*]

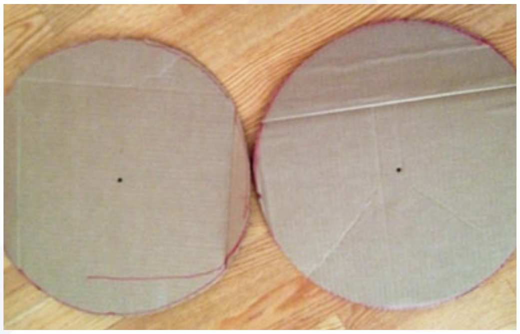
Water wheels have been used for centuries to turn free-flowing water into useful forms of power. The goal of this activity is to design the most efficient water wheel possible. You will measure its efficiency by counting the number of **revolutions**, or spins, your water wheel completes when 2 liters of water are poured over it. The more revolutions your wheel makes the higher its efficiency.

Facilitating the Activity

1. Hand out the materials.
2. Have students plan their water wheel before drawing or cutting anything. How big or small do they want the water wheel to be? How many cups? Suggest arranging the cups on top of the cardboard to prevent gaps and figure out the diameter of their water wheel.

   Optional: You could even take planning a step farther and have students calculate the circumference of the circle in relation to the diameter of the cups.
3. After planning, students should draw a circle on one of the cardboard pieces. Note: Using 2 pencils and string or ribbon is an easy way to draw the circle.
4. Cut out the circle and push a pencil through the exact center to create a small hole.
5. Trace the first circle on the other cardboard piece. Add a hole to the center of this circle too.





Activity 2: Moving Water

6. Have the students attach cups all the way around the circumference of one of the circles using a stapler. The bottom of the cups should be facing the center of the circle.
7. Put the second cardboard circle on top of the cups, using a pencil to line up the centers. Staple each cup to the second cardboard circle.
8. Instruct students to remove the pencil and put a dowel through the center of their water wheel. They should then conduct a preliminary test of their design. The wheel should spin easily on the dowel. They may need to adjust their cups or center hole placement.
9. Have them draw an arrow on one side of their wheel and practice counting the number of revolutions (using the arrow as a reference point).
10. Have each group bring their water wheel to the testing area. Either two people can hold each side of the dowel or the water wheel can be positioned between two tables. If you are testing inside, make sure you have a large bucket to catch the water.
11. One team member will then slowly pour 2 liters of water into the cups on the side of the wheel. The other team member needs to count the number of revolutions. Let students experiment with different pouring speeds, pouring heights, and pitcher location above the wheel. Have them record the data from these tests in their Youth Handouts.

Activity Closure

Energy can be extracted from falling water and harnessed to do work by using a water wheel. Water at a higher elevation has **potential energy**, or stored energy. As it flows over the water wheel, it causes the wheel to spin converting the potential energy of the water to **kinetic energy**. This rotational motion can then be harnessed to do useful work such as irrigating crops, milling grain, or generating electricity.

Exploration Questions

1. How can work be extracted from water using a water wheel?
2. Did the height of the pitcher (when pouring water) effect the number of revolutions? Why?
3. What would you do differently if you were to build another water wheel?

Activity 3: Types of Bridges

Time Required: 30 minutes **Group Size:** Class

Materials List

Each group needs:

- Red marker

Each class needs:

- Large sponge or magic eraser
- Black marker
- Ruler
- Poster board
- Scissors
- 4 Large books (Not included in kit)
- 10-20 Quarters or 20-40 pennies

Youth Handouts:

- "Types of Bridges"

Getting Ready (15 minutes)

- Draw vertical lines on the side of the sponge as shown below. This will be used to demonstrate a

beam that is bending.
- Cut out two 14"x3" strips of poster board. Mark 1" from each end and mark the midpoint.
- Acquire 4 large heavy books of approximately the same size (dictionaries, phonebooks, etc).
- Currently these experiments are done as a class, but if you have enough materials, consider letting each group complete the experiment on their own.
- Optional: Students are asked to identify parts of bridges that are in tension or compression in this activity. This activity can be more fun for students if local bridges are used as examples. Take a few pictures of some local bridges and include them with the examples already on the worksheet.

Learner Outcomes

- Explain that tension is a pulling force and compression is a pushing force.
- Explain that bridges use both tension and compression to transfer force to the ground.
- Identify which portions of a bridge are in tension and which are in compression.

Activity 3: Types of Bridges

Vocabulary

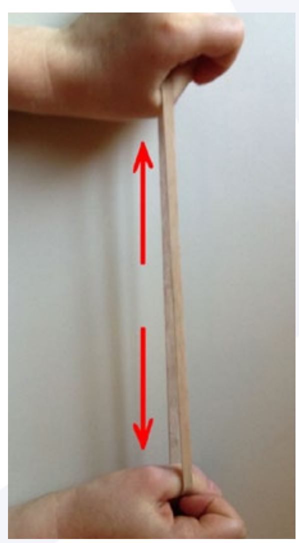
Word	Definition
Beam	A horizontal structural element spanning two supports.
Compression	A force that squeezes.
Tension	A force that stretches.
Pier	A solid vertical support designed to bear heavy loads.
Span	The distance a bridge crosses.

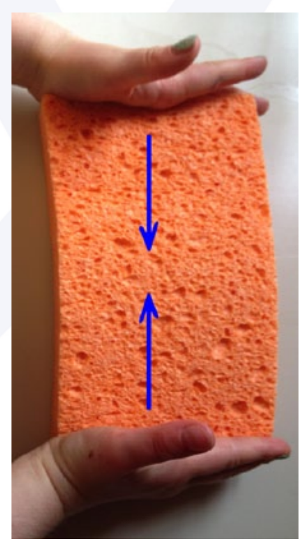
Introduction

Engineers Without Borders is an international organization that provides opportunities for engineers to use their skills to help people in countries all over the world. Just like the bottle light, these appropriate technology projects are typically low cost and high impact. Projects include irrigation, drinking water systems, and solar power systems to provide light or charge mobile phones. As of 2012, Engineers Without Borders had arranged 350 projects in 45 developing countries. Many of these are carried out by college students, as there are 180 university chapters in the United States.

One such group, from the Milwaukee School of Engineering, made a huge difference for a village in Chosavic, Guatemala. The only road to Chosavic used to cross a streambed of a nearby river, but due to flooding, it was impossible to drive across during the rainy season (May to October). This effectively cut the residents of the village off from the rest of the world for months. Fortunately, the bridge designed with the help of Engineering Without Boarders solved the problem and enabled people from the village to use the road even in the rainy season.

Over the next few activities, we'll be learning how to design the most effective bridge using the least materials, since materials are expensive and getting them to the site can be difficult. We'll start by looking at how a bridge works.





The purpose of a bridge is simply to provide passage over an obstacle, such as a body of water or road. An individual bridge's design will depend on many factors from its specific function to the surrounding terrain to the funds available to build it. But no matter the design, the goal of its structure is the same: to safely transfer the force of something on top of it, such a car or a person, to the ground.

There are two main forces acting on bridges: tension and compression. Tension is a force that *stretches*. When something (like a rubber band) is pulled with too much force, it snaps. Compression is force that *squeezes*. When a beam is compressed it bends, and ultimately, may buckle. Some materials work better in compression and some materials work better in tension.

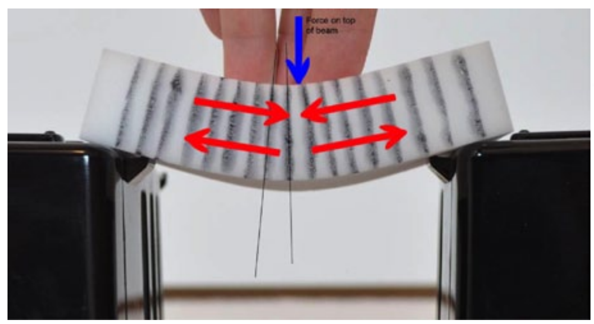
Activity 3: Types of Bridges

In this activity, we'll explore tension and compression and investigate a few types of bridges and how they transfer forces to the ground.

Facilitating the Activity

Part A: Tension and Compression

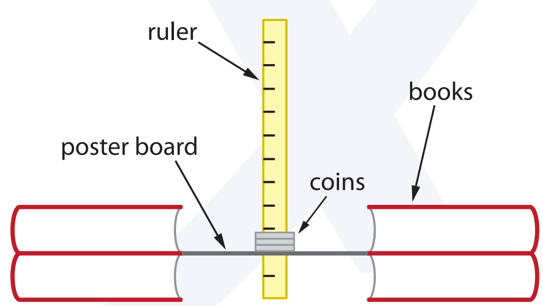
1. Place students in groups and give each group a handout.
2. Create two stacks of books that are approximately the same height and place the sponge with vertical lines drawn on the sides so that it spans the two stacks.
3. Explain that a beam bridge is the simplest type of bridge and consists of a **beam** supported by a **pier** at each end. The sponge represents the beam and the books are the piers.
4. Show students that when a force is applied to the top of the sponge, the lines on the sponge become closer together on top, showing that the top area is in compression. At the same time, the lines become further apart on the bottom, showing that the bottom area is in tension.



5. Ask students: "Are the piers that support the bridge experiencing tension or compression? Why?" [*Compression. The weight of the bridge is pushing down.*]

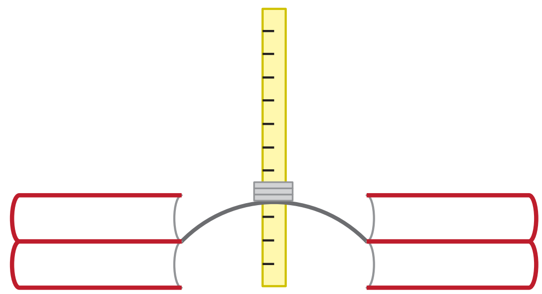
Part B: Beam vs. Arch

6. Next, take one of your 14"x3" strips of poster board and place 1 inch of each end between the books such that your new beam bridge has a 12" **span**.
7. One student will hold a ruler at the exact center of the bridge and measure the height of the poster board above the table.
8. Another student will add weights (quarters, pennies, etc) one at a time to the center.
9. After every 5 quarters, have the class take another measurement and record the height in their Youth Handouts. This can be done until you run out of quarters or until the bridge collapses.



Activity 3: Types of Bridges

10. Now take the other strip of poster board and fold the ends upward at the 1" mark. Tuck the end flaps under the top pair of books and push the piers together so that the bridge creates an arch.
11. Repeat Steps 7-9. What do the students notice? Which bridge held the most weight?
12. If time and materials allow, try the experiment with different spans for both the beam and arch bridge. Also try increasing and decreasing the arch height (while keeping the span the same). What happens? Why?



Activity Closure

There are many types of bridges but the two oldest designs are the beam bridge and the arch bridge. Beam bridges, as you found out, are the weakest of the three and become weaker as the piers move father apart. This is why beam bridges rarely span more than about 250 ft.

Fortunately, thousands of years ago the Greeks discovered the natural strength of the arch. The curved design of the arch conveys and distributes the force of the load, or weight, through its entire form and directly to the supports on either end, instead of straight down. Tension forces are almost completely negligible in arches, which is beneficial as common arch bridge materials such as stone and brick are strongest in compression.

Although arch bridges can span farther than beam bridges (typically up to 800 ft), they can be very complicated and expensive to build. They also require heavy and extensive foundations, which can be very impractical when trying to span large bodies of water. For this reason, suspension bridges are generally the best option for longer spans (2000 to 7000 ft).

Suspension bridges take advantage of tension to hold up the roadway that cars travel along. The road is actually suspended from two long steel cables that span the entire length of the bridge. This puts the two main piers in the middle in compression and the cable itself in tension.

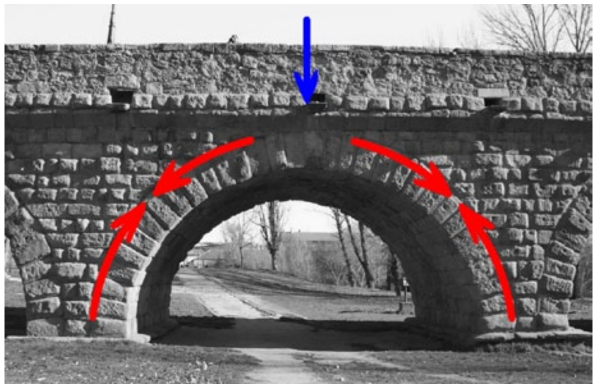
Can you name any famous suspension bridges? [*Possible Answers: the Golden Gate Bridge in San Francisco and the George Washington Bridge in New York.*]

Exploration Questions

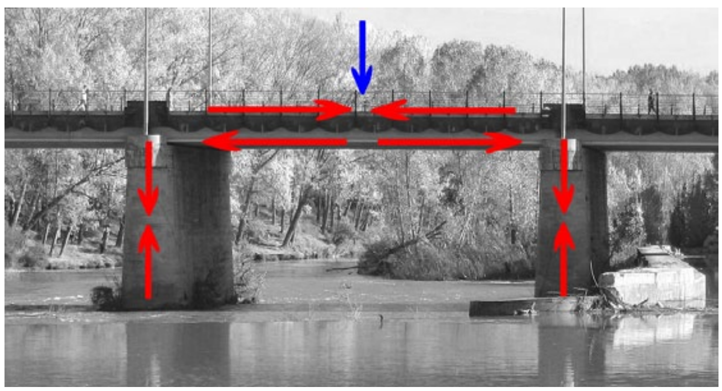
1. Draw arrows on the pictures below to indicate sections of the bridge that are in tension (←→) and sections that are in compression (→←). Identify the type of bridge.

   [*Ask students to come up and show how they indicated tension and compression on each of the bridges. If there are discrepancies, ask the students to discuss why they think sections are in tension or compression and help them figure out the answers. Below, load is shown in blue (students don't need to draw this in). Tension and compression forces are shown in red.*

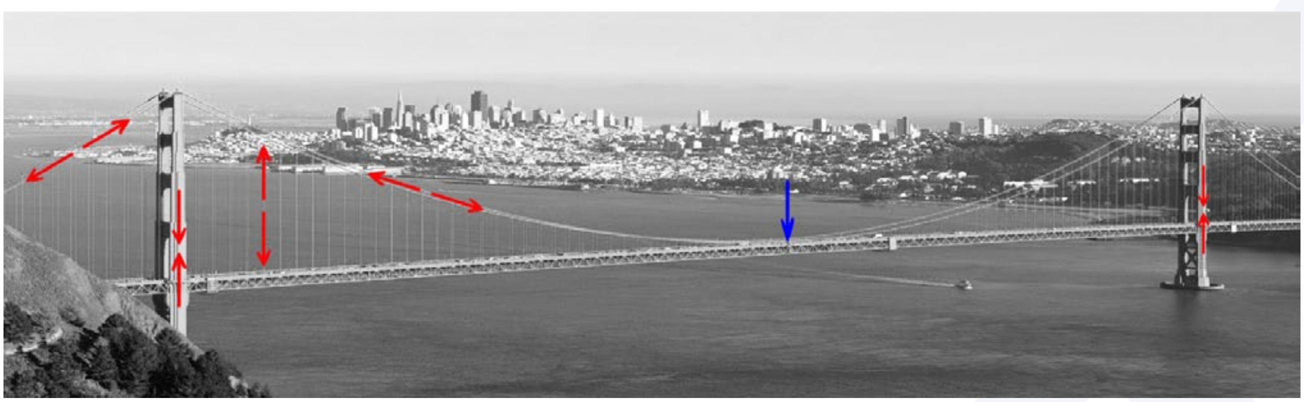
Activity 3: Types of Bridges



Type of Bridge: Arch Bridge



Type of Bridge: Beam Bridge



Type of Bridge: Suspension Bridge]

2. What materials do you think would work better in compression? What about in tension? Why?

   [*Materials like concrete are better in compression, while thin flexible materials like paper are better in tension. Some materials like steel are equally good in tension in compression*.]

Activity 4: The Strongest Shape

Time Required: 30 minutes **Group Size:** 3

Materials List

Each group needs:

- 30 Straws
- 30 Small paper clips
- 2 Cardboard pieces (11" x 5", Not included in kit)
- Quarters, pennies, or other small weights

Each class needs:

- Scissors

Youth Handouts:

- "The Strongest Shape"

Getting Ready (15 minutes)

- Cut the straws in half and cut the bendy parts off.
- Cut out two strips of 11" x 5" rectangular cardboard for each group.

Learner Outcomes

- Explain why a triangle is the strongest shape.

Vocabulary

Word	Definition
Truss	A rigid structural framework composed of triangles.
Polygon	A flat, closed shape with straight sides. (Ex: triangle, square, hexagon, etc.)

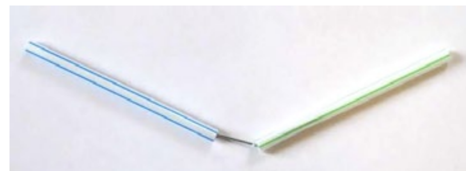
Introduction

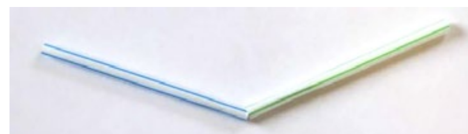
In the previous activity, we learned that arches could greatly increase the strength of a bridge. However, arches are not the only strong shape.

Today we are going to perform some experiments to test how well different shapes are able to bear weight. Like the arch, some shapes are naturally good at supporting weight and can withstanding strong forces without collapsing or deforming. Civil engineers use this knowledge to design buildings and bridges that can withstand strong winds and earthquakes, skyscrapers that are hundreds of stories tall, and bridges that can span thousands of feet.

Activity 4: The Strongest Shape

Facilitating the Activity





Part A: Exploring Shapes

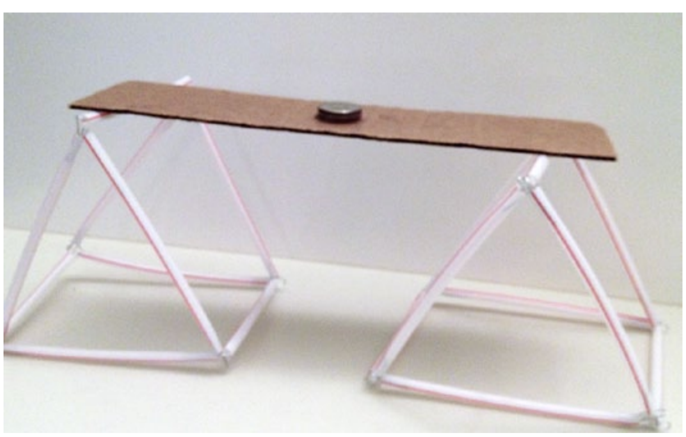
1. Place students in groups and give each group 5-6 straws and a handful of paper clips. The straws should already be cut in half.
2. Show the students how to connect two straws together by bending a paperclip and sticking a straw on each end (see photos).
3. Tell students to use the straws and paperclips to create and explore shapes. Their goal is to figure out which is the strongest shape and explain why.

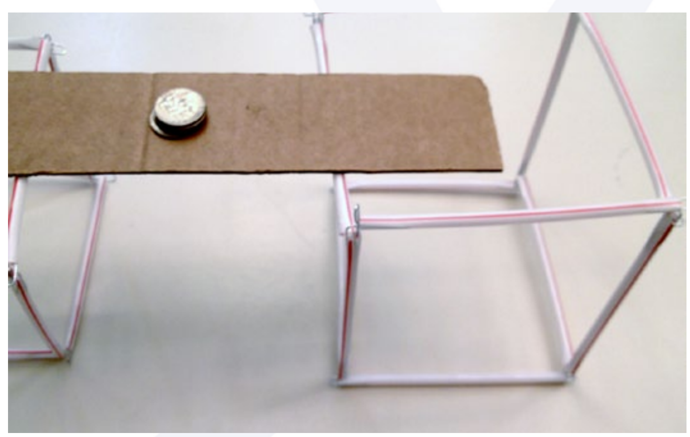
   Note: Some students may have learned that a triangle is the strongest shape prior to this activity, and it is okay if they tell you. In that case, ask them to demonstrate why using the materials to their partners.

Part B: Trusses

4. Pass out the remaining straws and paperclips.
5. Tell the students to create two triangular prisms and two cubes with the paperclips and straws.
6. They will then use one piece of cardboard to form a bridge between the triangular prisms and the other piece of cardboard to form a bridge between the cubes.

   Note: Students can decide how far apart the straw piers are, but have them make a note of it in their Youth Handouts (span should be measured from where the cardboard touches the straw, not the base). If you have time, let them experiment with different spans and even longer pieces of cardboard.
7. Have the students test their triangle-support bridge and square-support bridge by adding quarters, one at a time, to center of each bridge. Record the number of quarters each bridge holds before collapsing.

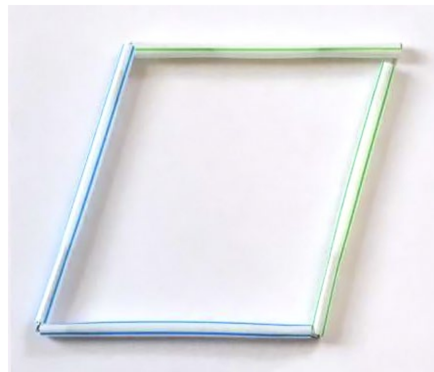




Activity 4: The Strongest Shape

Activity Closure

As we discovered in this activity, the triangle is the strongest shape. This is because the triangle is the only **polygon** that holds its shape even with flexible corners. To change its shape, a corner actually needs to break or the length of a side needs to change. A rectangle or square, on the other hand, can easily distort and bend into a different shape if too much pressure is applied causing the angles at the corners to change.



Since a triangle is the strongest shape, you see the triangle in many construction projects. When a number of triangles are put together, the structure they form is typically called a **truss**. Trusses are extremely common in modern bridge design and can be found in every type of bridge from beam to suspension. This is because trusses have an extremely high strength-to-weight ratio (very strong but also very light), which makes them very cost-effective.

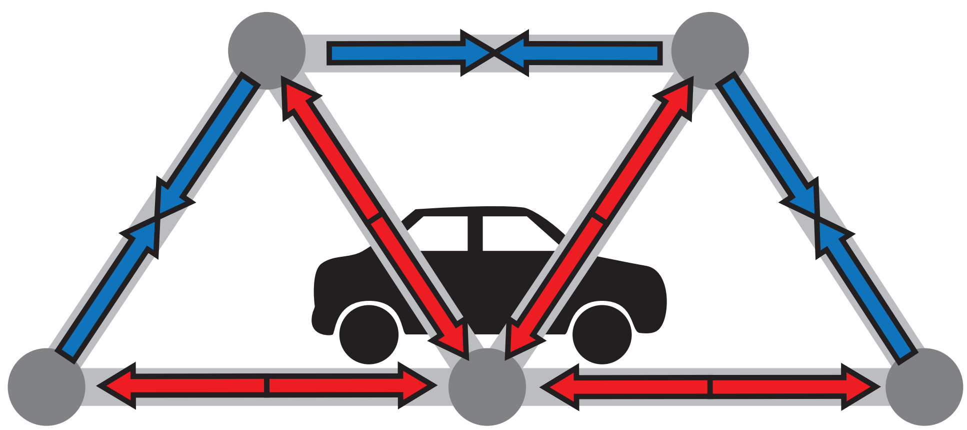
Activity 4: The Strongest Shape

Exploration Questions

1. Can you think of places other than bridges where you have seen trusses and triangle shapes used to make things stronger?

   [*Possible answers: bicycle frames, cross braces on wooden decks, the frame of a house if you see one during construction, sometimes chairs and furniture will have small trusses to help support the legs.*]

2. Draw arrows on the simple truss bridge below to indicate which beams are in tension (←→) and which are in compression (←→).



Activity 5: Creating a Bridge with Less

Time Required: 150 minutes (over 3 days) **Group Size:** 3

Materials List

Each group needs:

- Wood glue
- 4 Balsa wood pieces (1/8" x 1/8" x 36")
- Flat balsa wood piece (1/16" x 3" x 36")
- Long push pins
- Ruler
- Tracing paper
- Corrugated cardboard (Not included in kit)
- Newspaper (Not included in kit)

Each class needs:

- Hot glue gun and glue sticks
- Pennies
- Scale
- 2 Flat balsa wood pieces (1/16" x 3" x 36")
- Scissors
- Utility knife
- Calculators

Youth Handouts:

- "Creating a Bridge with Less"

Getting Ready (20 minutes)

- Use the utility knife to cut small squares from the flat balsa wood pieces for the gusset plates. For safety reasons, cut these yourself and do not allow students to use the utility knife.
- Find cardboard for students to build their bridges on. Look for large boxes near a recycling bin and cut them with the utility knife or scissors.
- Set up a material store where the students can buy materials. Leave a couple calculators there so they can calculate costs.
- Set up a location to test the bridges either between two stacks of books or two tables of the same height. Set them 24 inches apart. The bridges will sit on top of the supports.
- A glue gun is helpful on the final day for students to make last minute adjustments so they don't have to wait for wood glue to dry. On Day 3, set up a station for students and ensure they are using it under your supervision.
- Create bags of pennies (400 pennies is approximately 1 kg) or find 1-kg weights to test the bridges.

Activity 5: Creating a Bridge with Less

Learner Outcomes

- Explain that engineers use prototypes to test designs.
- Explain why engineers use a factor of safety when designing.

Vocabulary

Word	Definition
Gusset plates	A plate used to connect beams and strengthen the joint.
Factor of Safety	The ratio of the maximum stress that a structure can actually withstand to the stress it is designed to withstand.
Prototype	An early representation used to demonstrate or develop aspects of the final design.

Introduction

In this activity, you're going to design a bridge to connect Chosavic to Joyabaj in Guatemala. Each group will build a prototype of their potential design. Be creative. Based on what you learn from your prototypes, the class will select the best design for the bridge.

You will have to buy the materials from a class store. As the storeowner, I will be keeping track of the materials.

After you build the bridge, will there be probably be waste material. The Guatemalan government does not allow you to simply dump the material in the river. For that reason, you will have to pay to remove it. If you don't remove your waste material, the penalty will be substantial. Keep all of your excess material and it will be weighed at the end to determine the final cost of your bridge prototype.

Facilitating the Activity

Day 1: Building the Trusses (75 minutes)

1. Place students in groups.
2. Go over the following design constraints:
    a. *Must be able to span a 60-cm gap.* You can use heavy books or two tables that are the same height to represent the piers. The bridge will have to be somewhat longer than the span (60 cm) to rest on the piers.

    b. *Bridge cannot be glued (or attached in any way) to the piers.* The bridge supports will only be able to rest on the tops of the piers.

    c. *Must be designed with a safety factor of at least 2.* A factor of safety of 2 means that the bridge should be designed to safely hold twice the weight that it will actually have to hold in the real world. For example, if the maximum weight the bridge will ever have to hold is 1 kg (2.2 lbs), with a factor of safety of 2 the bridge should still be able to hold up to 2 kg (4.4lbs).

    d. *Only use the materials provided.*

Activity 5: Creating a Bridge with Less

3. Introduce students to the store and go over the materials.

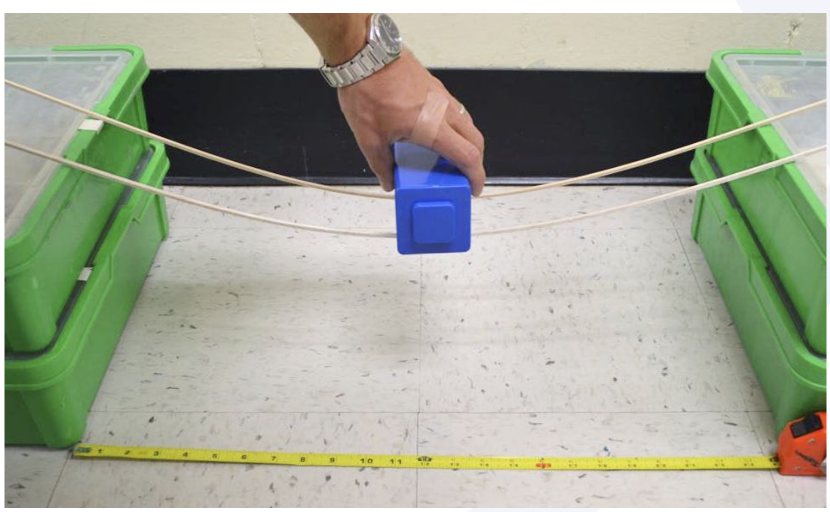
Item	Cost/Unit (Thousand $)	Unit
Roadway (1/16" x 3" x 36")	20	1 Piece
Beam (1/8" x 1/8" x 36")	5	1 Piece
Gusset plates	1	10 Plates
Wood glue	14	1 Bottle
Glue spreading tool	3	1 Paperclip

4. Explain that Gusset plates are small squares that fit just over the joints. They are not required but can help strengthen the bridge.
5. Remind students that at the end of the build they will be charged for any waste that needs to be removed from the construction site:

   Balsa wood waste removal cost = $1000 per 0.1 gram

   And if they are caught dumping waste rather than hauling it back to town, they will be charged a fine by the Guatemalan government:

   Dumping Penalty = $50K
6. Next demonstrate how the bridge will be tested. Create a simple bridge out of two 1/8" balsa wood beams and test it with a large weight. The beams will break. Tell the students that bags of pennies will be added, one at a time, to test their bridges. Note: There are about 400 pennies in a kilogram.
7. Pass out the cardboard and tracing paper.



Activity 5: Creating a Bridge with Less

8. Ask the students to follow the instructions provided in the Youth Handout for designing the bridge. The goal for the first day is to get through designing and building the two side trusses.

   Note: Make sure they keep track of materials and record their purchases in the Expenses table provided in the handout.

Day 2: Connecting the Trusses (30 minutes)

1. Have students gently remove the trusses from the cardboard and use wood glue to fix any broken pieces.
2. When they glue the cross bracings to the top and bottom, make sure the bridge remains wide enough for the roadway and that the road is not glued to it.
3. The glue will need to dry for 5-10 minutes. Students can either hold the two sides together or brace them with cardboard, books, or whatever else you have available. Just lean the books against the sides of the bridge with newspaper in between. This can be a bit frustrating, but it works as long as the students work together as a team.
4. Weigh each group's balsa wood scrap material (in grams). If they didn't keep track of their waste they will be charged with a dumping fee (single flat rate of $50K).
5. Have them calculate and record the total cost of their bridge, including the waste.

Day 3: Testing (45 minutes)

1. Set up the glue gun station, which can be used for touch ups on the bridges.
2. You will be testing the bridges, as a class, one at a time. To test a bridge, place it on the supports and place the roadway over the bridge. Then, place the bags of pennies near the center of the bridge, counting as you go. Keep adding weight until the bridge fails.
3. Have each group calculate their bridge's performance by dividing the number of pennies their bridge held by the total cost of the materials. The higher the performance score, the better the bridge (holds more weight per dollar).

Activity Closure

Some bridges are designed with trusses, some are designed with arches, some are designed with cables, and some are designed with a combination of all three. There isn't one type of bridge that is necessarily *best* and the type of bridge chosen for a project mainly depends on the location, goal, and budget. A good bridge can cost anywhere from a couple thousand dollars to a couple billion. The only thing that really matters is that the bridge is structurally sound and meets the needs of the community.

Activity 5: Creating a Bridge with Less

Exploration Questions

1. What is factor of safety and why is important?

   [*Factor of safety is the ratio of maximum structural capacity to the actual load it's designed to carry. Designing with a factor of safety allows for uncertainty in the design process. Calculations cannot always predict real-world circumstances and it is important that a structure or machine be able to safely handle whatever forces or loads it may encounter during its lifetime.*]

2. What was your performance score? List two changes you would make to your design that would improve its performance.

   [*Possible answers: use less material to increase cost effectiveness, add gusset plates to strengthen weak areas, etc.*]

Tools Used in this Module

Digital Multimeter

A multimeter is an electronic device that measures voltage, current, and resistance. The red probe is positive (+) and the black probe is negative (-). The selection knob should always be in the "off" position when the meter is not being used.

Each type of measurement has a range of possible settings, such as 2, 20, 200, etc. If your measurement exceeds the selected range, the multimeter will display a "1" which indicates overload or out-of-range. If this happens, simply adjust the selection knob to the next highest setting. If the displayed value has a negative sign in front of it, the probes are just "backwards". This won't hurt the meter.

Voltage

Voltage is measured in volts (V). You'll notice there are two different voltage settings on the multimeter: V--- for DC voltage and V~ for AC voltage. We will only be measuring DC voltage in these activities. DC means constant voltage, like a battery. AC means alternating voltage, like a wall outlet at home.

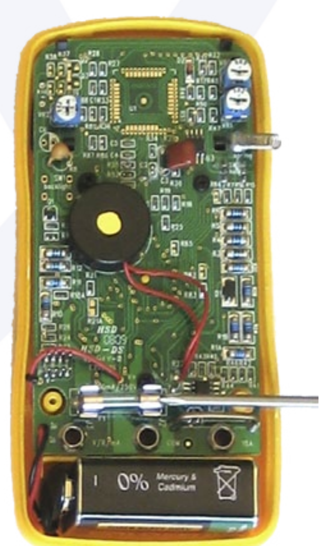
To measure a battery's voltage, turn the selection knob to a value slightly higher than the expected voltage. For example, to measure a 1.5 V battery, the meter should be set to the "2" position or higher in the V--- range. Touch the red probe to the positive (+) end of the battery and the black probe to the negative (-) end. If the battery is still good, the display value should be between 1.4 V and 1.6 V.

Resistance

Resistance is measured in ohms (Ω). To measure a resistor, turn the selection knob to a value slightly higher than the expected resistance. For example, to measure a 100 kΩ resistor, the meter should be set to the "200k" position or higher in the Ω range.

Use your fingers to pinch the meter probes against the metal wires coming out of each side of the resistor. It doesn't matter which way you hook up the meter probes. You will not measure a negative resistance if you swap the probes.

Replacing a Fuse or Battery



If the meter is used improperly, you may blow a fuse. To replace the fuse, remove the screws from the back and open the case. The fuse will look like a small glass cylinder with metal end caps. A picture of the opened meter is shown to the right with a screwdriver pointing at the fuse. Pop out the old fuse and replace it with a new 200 mA, 250 V fuse.

If the meter is left turned on, the battery will drain down. To replace the battery, remove the screws from the back and open the case. Pull the battery out, unclip the battery snap, connect a new 9 V battery, and reinsert it into the meter case.

Glossary

Appropriate technology
Devices used primarily in developing countries that are easy to use and build, but less costly than similar devices found in industrialized countries.

Beam
A horizontal structural element spanning two supports.

Compression
A force that squeezes.

Factor of Safety
The ratio of the maximum stress that a structure can actually withstand to the stress it is designed to withstand.

Gusset plates
A plate used to connect beams and strengthen the joint.

Kinetic energy
Energy that an object has because of its motion.

Pier
A solid vertical support designed to bear heavy loads.

Polygon
A flat, closed shape with straight sides. (Ex: triangle, square, hexagon, etc.)

Potential energy
Energy that an object has because of its height.

Prototype
An early representation used to demonstrate or develop aspects of the final design.

Resistance
The opposition of a material to the flow of electricity. Measured in ohms.

Revolution
One complete turn of a rotating body.

Span
The distance a bridge crosses.

Tension
A force that stretches.

Truss
A rigid structural framework composed of triangles.

Acknowledgements

Authorship Team

Dr. Ed Maxa, Associate Professor (retired 2010), Department of 4-H Youth Development and Family & Consumer Sciences, North Carolina State University.

Kate Guerdat, Former 4-H Extension Associate, Department of 4-H Youth Development and Family & Consumer Sciences, North Carolina State University

Amy Chilcote, 4-H Extension Associate, Department of 4-H Youth Development and Family & Consumer Sciences, North Carolina State University

Dr. Mitzi Downing, Department of 4-H Youth Development Cooperative Extension Service, North Carolina State University.

Kristy Oosterhouse, 4-H Program Coordinator, Children and Youth Institute, Michigan State University Extension

Dr. Jacob DeDecker, Program Leader, Children and Youth Institute, Michigan State University Extension

Steven Worker, 4-H SET Coordinator, University of California Agriculture and Natural Resources, Youth, Family and Communities, 4-H Youth Development Program

Lynn Schmitt-McQuitty, County Director & Science Literacy Youth Development Advisor, University of California Agriculture and Natural Resources

Dr. Matthew T. Portillo, 4-H Youth Development Program Advisor, Academic Assembly Council President, University of California, Butte County

Amanda Meek, 4-H SET Educator, University of Missouri Extension

Dr. Jeff Sallee, Assistant Professor and Extension Specialist 4-H Youth Development, Oklahoma State University

Dr. Gary A. Ybarra, Professor of Electrical and Computer Engineering, Duke University

Rodger Dalton, Research Associate, Duke University and President, Techsplorers

Dr. Paul Klenk, Research Scientist, Duke University

Wendy Candler, Curriculum Development / Graphic Design, Techsplorers

Curriculum Developers

Rebecca Simmons, Research Associate, Duke University

Dr. Paul Klenk, Research Scientist, Duke University

Dr. Gary A. Ybarra, TechXcite Principal Investigator, Duke University

Collaborative Contributors

Donna Patton, Extension Specialist, West Virginia University Extension Service

Sherry Swint, Extension Agent, West Virginia University Extension Service

Lynna Lawson, 4-H Youth Development Specialist, University of Missouri Extension

Robert B. Furr, County Extension Director, North Carolina Cooperative Extension

Carla Burgess, Youth Curriculum Reviewer, Duke University

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Layout, Graphics, & Design

Jenny McAllister, Adobe InDesign Layout, Techsplorers

Wendy Candler, Illustration / Graphic Design, Techsplorers

Illustration / Graphic Design / Website Design – Cuberis Design + Web Solutions

Leadership Team

Dr. Ed Maxa, Professor Emeritus (retired 2010), Department of 4-H Youth Development and Family & Consumer Sciences, North Carolina State University.

Allen O'Hara, Grant Manager, National 4-H Council

Gregg Tabbachow, Grant Manager, National 4-H Council

Dr. Gary A. Ybarra, Professor of Electrical and Computer Engineering, Duke University

Rodger Dalton, Research Associate, Duke University and President, Techsplorers

Research Team

Dr. Ed Maxa, Professor Emeritus (retired 2010), Department of 4-H Youth Development and Family & Consumer Sciences, North Carolina State University.

Dr. Mitzi Downing, Department of 4-H Youth Development Cooperative Extension Service, North Carolina State University.

Dr. Eddie Locklear, Director of National 4-H Afterschool Program (retired 2012)

Dr. Gary A. Ybarra, TechXcite Principal Investigator, Duke University

Rodger Dalton, Research Associate, Duke University and President, Techsplorers

Dr. Anne D'Agostino, TechXcite Program Evaluator, Compass Evaluation and Research Inc.

Program Management

Rodger Dalton, TechXcite Program Manager (2012-2014), Duke University

Dr. Paul Klenk, TechXcite Program Manager (2007-2012), Duke University

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