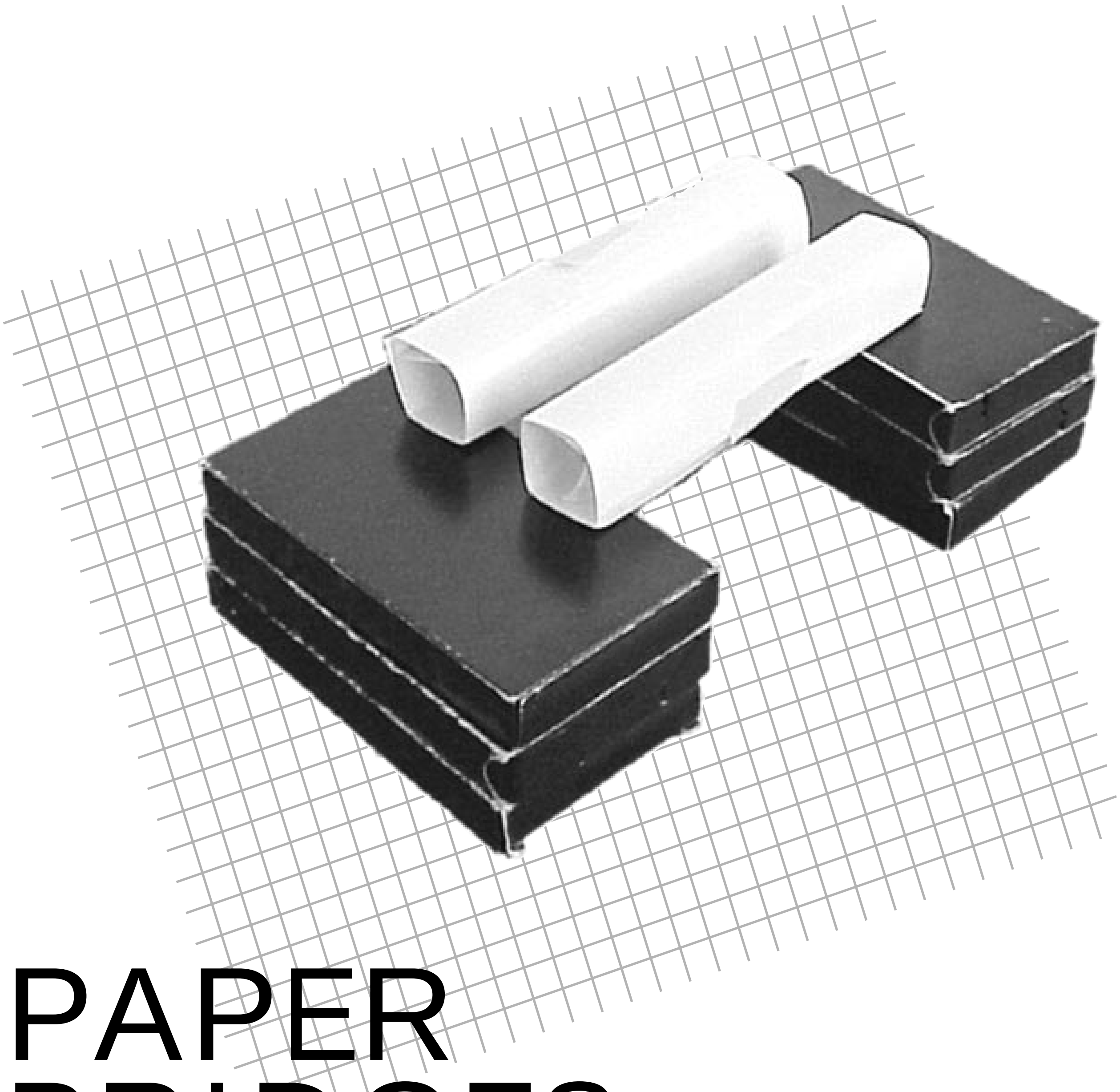

PAPER BRIDGES

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DESIGN IT! ENGINEERING IN AFTER SCHOOL PROGRAMS

Education Development Center, Inc.

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Activity 1: Inventing Your Own Paper Bridge

Your team of engineers is responsible for designing a bridge. You will be given the materials to do this and you will be told how big the bridge must be. Your job will be to make the bridge as strong as you can with the materials you are given.

The Challenge

Make a bridge that spans an 8-1/2 inch wide "river" using only four sheets of paper. Make the bridge as strong as you can.

Rules

- The bridge must sit on the riverbanks without any extra help. It must not be fixed to the riverbanks or held in place by hand or in any other way.
- No part of the bridge may touch the "water."

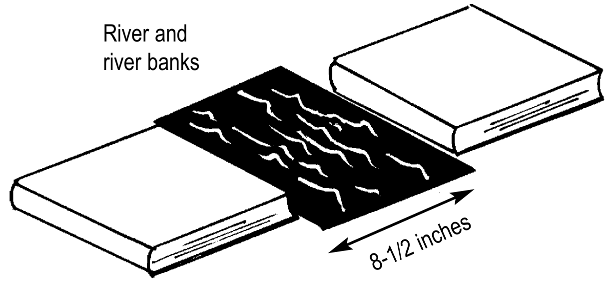
What Materials Do I Have?

- copy paper (8-1/2 x 11 inches)
- small drinking cup (paper or plastic)
- clear tape
- steel washers or nails
- cardboard square (4 inches x 4 inches)
- books or boxes
- *Data Sheet—Activity 1*

What Do I Do?

1. Take a sheet of regular paper and color it to look like a river. Make the water flow in the direction of the long side of the paper. Draw some fish, boats and an alligator in the river, if you like.

2. Lay your "river" on the table and place books or small cardboard boxes on either side (see figure at right). These are the river "banks." Make sure that the banks do not cover the river. The river banks must be exactly 8-1/2 inches apart. (That's how wide the short side of your paper is.)



3. Using only four sheets of paper (and a small amount of tape), make a bridge that reaches across the river. You may bend or fold the paper in any way you like. The bridge **must not be taped or fixed to the riverbanks and must not touch the water.**

4. If you make a mistake and want a new piece of paper, take a new sheet in place of the spoiled one(s). The bridge must still have **only four sheets of paper** in it when you are finished.

5. Test the strength of the bridge in the following way:
   a. Place the cardboard square in the middle of the bridge.
   b. Place the drinking cup on the cardboard.
   c. Begin adding load—washers or nails—until the bridge is just about to collapse.

6. Count how much load is in the cup when the bridge is just about to collapse and record the number next to your team name on the class data sheet.

7. Think about what worked and what didn't when constructing your bridge, and list your ideas on *Data Sheet—Activity 1.*

What to Think About

- Are there some shapes you can make your paper into that are stronger than others?
- Where is the weakest/strongest part of your bridge?

Data Sheet—Activity 1

Team Members: ____________________

____

____

What Works?	What Doesn't?

Activity 1: Inventing Your Own Paper Bridge

Preparing Ahead

1. Think about where there are interesting bridges in your neighborhood. See if you can make arrangements for the children to visit these bridges so as to observe how bridges are constructed.
2. Gather plenty of paper, at least 20 sheets for every child. Recycled copy paper is the best so you will not have to worry about "wasting" paper if the children want to redo some of their bridge designs.
3. Make a bridge yourself, and practice testing it with a cup of nails or washers. Notice what shapes or arrangements of the materials make the strongest structures.
4. Decide how you are going to group the children. Even though some children may want to work alone, teams of two or three are best for this activity.
5. Make a data chart for the whole class on a sheet of chart paper or on a chalk/white board. It should have one column headed "Team Name" and one column headed "Maximum Load." Team members will fill in the chart as they work on their bridges. There should be enough room on the chart for several entries for each team, as the maximum load of their bridges will increase with design improvements.
6. Prepare the cardboard squares.
7. Make a large version of the *What Works?* chart on *Data Sheet—Activity 1*.
8. Make enough copies of the Challenge Sheet, including *Data Sheet—Activity 1,* for each team.

Introducing the Activity

If there are bridges in your neighborhood, take some time to visit them with the children. For each bridge that you look at, ask the children:

- What do you think it was built for (road, rail, pedestrians, etc.)?
- What is it made of (wood, steel, concrete)?
- What part of it really makes the bridge stand up?
- What were the biggest problems in building each particular bridge?

Perhaps you don't have any interesting bridges in your neighborhood. In that case, ask the children to think about bridges they have seen or crossed. Perhaps there is a well known bridge in your city that they have all seen. If no bridge is available, show the children the pictures of bridges starting on page 73. Ask all the questions listed above. Finally, ask the children to group all the bridges you have looked at into two or three groups. Perhaps they will group them by size or by function, or perhaps they will group by design—suspension, steel girder, stone arch, etc.

Materials

FOR EACH TEAM

- copy paper (8-1/2 x 11 inches, recycled if available)
- small drinking cup (paper or plastic)
- clear tape
- steel washers or nails (heavy)
- cardboard square (4 inches x 4 inches)
- books or boxes
- *Data Sheet—Activity 1*

Once the initial conversation has run its course, hand out the Challenge Sheet and check that they understand the Challenge and the rules. After you have assigned roles to each team, hand out the materials for this activity and let the teams begin working.

Assigning roles

Make sure that roles are assigned in each team before the children begin working. If there are more or fewer than three children in each team, roles can be shared or doubled up. It is also important that roles be switched fairly often so that everyone gets a chance to fulfill each function.

THE CHALLENGE

Make a bridge that spans an 8-1/2 inch wide "river" using only four sheets of paper. Make the bridge as strong as you can.

RULES

- The bridge must sit on the riverbanks without any extra help. It must not be fixed to the riverbanks or held in place by hand or in any other way.
- No part of the bridge may touch the "water."

LEADING THE ACTIVITY

Let the children work at their own pace for a while. Have lots of spare paper handy and encourage teams to start again with new paper as often as they like (still using only four sheets at a time). As you talk with the children, ask any of the following questions (or other similar questions) to stimulate their thinking about how they are designing their bridges:

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- Why did you decide to place that piece of paper/tape in that position?
- Does it matter how tight/loose you roll the beams?
- Which shapes can you make your paper into that are the strongest?
- Where is the weakest/strongest part of your bridge?

Or you can ask them the three more general questions listed below to get them to think about what they are doing. You don't have to use exactly these words, and you don't have to ask the questions in exactly this order, but the intention is to stimulate the children's thinking about what's working and what is not, and to reinforce the idea that it is *their* job to figure something out if things aren't proceeding as they'd hoped.

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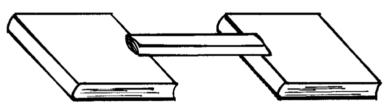
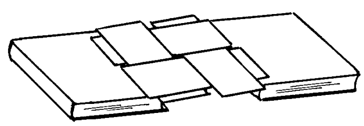
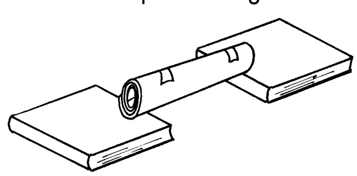
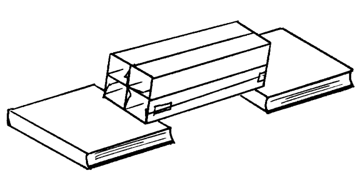
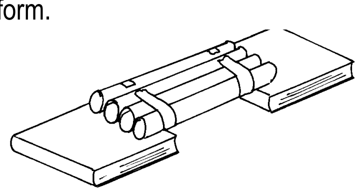
- What works (and what doesn't)?
- What have you tried (and what happened)?
- What has worked for other teams?

Do not give answers or solutions to their problems until they have made a sincere effort to answer one or all of these questions. Depending on how they answer them, you should ask follow up questions that keep the thinking going. If they are absolutely stuck and frustrated, by all means give them a hint.

Building strategies

Table 1.1 lists are some strategies children may use in this activity. As always, try to avoid simply fixing things for the children. Wherever possible, use questions to get them to think actively about how to improve the situation for themselves.

Table 1.1
Building strategies.

Bridge-Building Strategies	Comments	Design Lessons
Lay all four sheets across the river, or fold the sheets *together* or *separately* in half/thirds/fourths and lay across the river. 	Bridge bends in the middle. Folds open up unless taped shut.	Flat paper, even when very thick, has very little strength to resist bending.
Fold four sheets in half and tape in criss-cross fashion to make a square platform. 	This makes a very wide but weak bridge.	Flat paper, even when very thick, has very little strength to resist bending.
Roll four sheets into one round/square/triangular tube and tape. 	Very strong design, but too narrow to balance the load.	Thick walls on the tube make it stronger. Maximum strength is achieved if tube is tightly rolled.
Fold four sheets loosely into separate squares, triangles, or round tubes. Tape tubes together or spread out. 	Square tubes flop over on their sides. Triangular and round tubes are stronger but weak when loosely folded/rolled.	Materials can be strong in one direction but weak in another. Triangles are a strong shape.
Roll four sheets into separate, tight, round tubes and tape or lay together to make a platform. 	A strong design.	Tight rolling increases strength. Spreading tubes out makes the structure more stable.

Testing the bridges informally

Children usually want to test their bridges as they are building them. This provides them with immediate feedback, which could lead them to modify their designs. So, give each team a small square of cardboard, a cup, and some washers (or similar heavy material) to test their bridges. Point out the chart on the wall with team names and a space to write in the most weight carried. Tell the children that as each team tests and improves its bridge, the chief engineer should write (and update) on this chart the maximum (greatest) load carried so far.

SAFETY

If the children are using nails for the load, discuss how to use them safely.

LEADING THE DISCUSSION

After the children have had ample time to build and test their bridges, gather them together in a Discussion Circle to share what they have achieved so far. If your space allows you to, lead the whole group from one bridge to the next and spend a few minutes as a group examining each design and testing it. As you go to each bridge, have the "home team" explain their design to the group and tell what did or did not work well. Then test the bridge according to the following procedure.

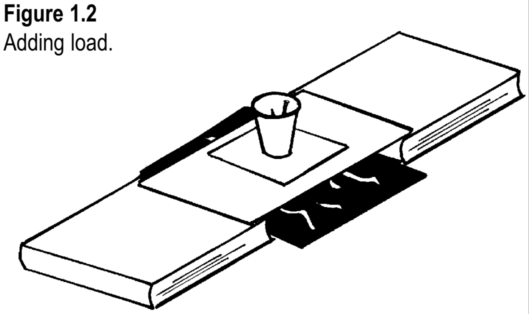
USEFUL TERMS

Load: The weight you place on the bridge.

Maximum Load: The greatest load that the bridge can hold without collapsing.

1. Ask the team members first, and then the rest of the group, for their predictions for its strength (how much load will it hold?). Have the children write their predictions on a piece of paper or in a notebook.
2. Ask both the team members and the group what design features (in their opinion) make this bridge weak or strong?
3. Place the cardboard square in the middle of the bridge, put the cup on the square, and begin adding load (see Figure 1.2).
4. When you see that the bridge is nearing its breaking point, stop adding load and ask for new predictions. Ask where the weakest point of this bridge is.
5. Add more load until the bridge *almost* fails. Try not to completely destroy the bridges even if the children want to. It's better to improve upon an existing design rather than having to start all over after every test. Record the maximum load on the group data chart.
6. Ask the children how close their predictions were to the actual outcome.

Figure 1.2
Adding load.



After you have visited all the teams, gather the whole group **away from all the materials** and ask them what they have learned about bridges. Give them a minute or so to write some ideas on their own *What Works?* charts. Then collect their ideas onto one large *What Works?* chart that everyone can see.

Activity 1: Inventing Your Own Paper Bridge

Rationale

The closest most people ever get to building a "bridge" is when they lay a plank or a board across a gully or a hole in the ground. A piece of 3/4-inch plywood makes a fine bridge across a 2-foot hole in the ground, and it is easy, even for a child, to manipulate it into place. When children try to make that kind of bridge stronger, their first tendency may be to make the bridge thicker and thicker by adding more boards on top of the first. In the backyard, or for potholes in the street, this strategy works very well. But it would not work for larger gaps.

If we scale up to the size of the Golden Gate Bridge in San Francisco, Calif., we could never find (or handle) the equivalent size piece of plywood. Now it would have to be over 100 feet thick (and over a mile long!) to span the harbor entrance, and it might very well disintegrate under the stresses of its own weight. And if the board were made of steel, the problem would be even worse. The bridge would not have to be so thick, but it would be so heavy that it would buckle and collapse from its own weight before a single truck or pedestrian stepped onto it. So bridge builders have figured out how to use much smaller amounts of materials to span large gaps like this. In this project, the children will do the same.

Introducing the Activity

Depending on where you live, you may be lucky enough to see many different kinds of bridges in your neighborhood. You may have stone (arch) bridges, wooden covered bridges, steel girder structures, highway overpasses, or suspension bridges (like the Golden Gate Bridge).

Paper can be made very strong when used to imitate the wooden or steel girder bridge design. So, during this early discussion about bridges, try to draw the children's attention to this kind of bridge (illustrated in Figure A.6 on page 76). These bridges were much more common a generation or two ago, but examples still exist in almost every town, often on railway lines or where an old road crosses a wide gap.

Leading the Activity

In their early attempts to build paper bridges, children often try to imitate the highway overpass design, perhaps because this is the bridge-like structure that they are most familiar with in their immediate environment. Actual highway overpasses are usually made of short reinforced (horizontal) concrete road sections held up by closely spaced vertical columns, often in the shape of a *T*. Unfortunately, this design does not translate well to paper construction; paper simply is not strong enough when used in this way.

As always in design projects, give the children fewer directions rather than more. Hands-on trial and error guided by thoughtful questioning from an adult is by far the best teacher in these matters. There are no wrong ways to make a structure, as long as the child is building in good faith. Children do sometimes come up with exceptionally odd ways of making buildings (from the perspective of an adult), but your job is not to correct them; it is to find out what thinking is going on behind the actions and entice the builders to consider the evidence for a more effective construction technique.

Children do not always immediately latch onto the idea of making tubes from their sheets of paper. This is actually the strongest way to use this kind of paper. If the children try some of the designs shown in Table 1.1, help them discover the best method, without telling them "the answer" directly.

Leading the Discussion

Formal discussions about design projects should be separate from the handling of the materials. Children often find it hard to switch from touching to talking, so it is important to make the transition very obvious. We suggest that the materials be left where they are while the children gather in a *Discussion Circle* away from the materials.

Discussions should be short at first, centering more on setting up the habits and routines of discussion rather than getting to the whole truth of the matter. Eventually both can happen, but it might take a while, so try to observe the following guidelines from the beginning of your work with *Design It!* projects:

- Keep the early discussion short (5–10 minutes).
- Insist that only one person talk at a time.
- Insist on taking turns. Work out your own way to keep it fair, but make the system clear and consistent (hand raising, etc.).
- Reflect. Repeat back to the speakers the essence of what they said so they will know that they were heard and whether they were understood.
- Separate construction problems from design "findings."

The discussion at the end of the first day will probably be dominated by issues relating to assembly of the bridges: how to roll the tubes, how to balance the load, etc. These are important issues for bridge makers, so be sure to leave plenty of time to discuss how children felt about and solved these problems. Use the questions listed on page 16 (and elsewhere) to probe the children about their thinking and their problem-solving process. Always try to follow a question and response with another question. This may frustrate children at first, but it is vital if they are to become thinkers themselves, rather than waiting for experts (such as you) to give them the answers. It is the kind of back-and-forth conversation that occurs all the time between engineers or scientists who are trying to solve a problem.

When you test the bridges in this and the remaining activities, try to make a ritual of having all of the children make pre-test predictions of how much load the bridges can carry. Always have the children write their predictions down before the test, and then be sure to find out how accurate the predictions were.

At first, with little experience thinking about the strength of paper bridges, the children's predictions may be way off base. However, try to encourage thoughtfulness in making predictions, and have the children explain why they made particular assumptions. Positively reinforce any instances of deliberate, logical predictions, even if they turn out to be wrong.

By the end of this activity, we hope the children have discovered the "beam"—a compact, horizontal piece of material that supports weight across a gap. Beams are used in house construction as well as in bridges. The important lesson that must eventually be learned about beams is that they get their strength from their depth (thickness) rather than their width. So if you have a limited amount of material and you need to make a bridge as strong as possible, it is better to make the beams thick and narrow, rather than wide and thin (see Figure 3.5 on page 44).

Note about teamwork

The roles that were assigned to the members of the teams will work best if you reinforce them often throughout the project, especially in the early sessions. During the discussion and sharing times, ask each team how the division of labor worked out. When asking for information from the team, ask who the presenter is and call upon him or her first. Also check if the ambassador learned anything from other teams and how others carried out their roles.

Some questions you might ask (not necessarily in this order) to get the conversation going are:

- What part of the bridge is the strongest?
- How did you change your bridge design to make it stronger?
- If you made tube beams, what was the best shape: round? square? rectangular?
- Which is better: a loose or tight tube?

During the discussion, try to draw out the following points. They will be very helpful as you move into Activity 2.

- Paper is stronger in the form of a beam rather than a flat sheet or board.
- A good shape for a beam is a cylinder (round tube) (see Figure 1.3).
- The tighter the cylinder is rolled, the stronger it seems to become.

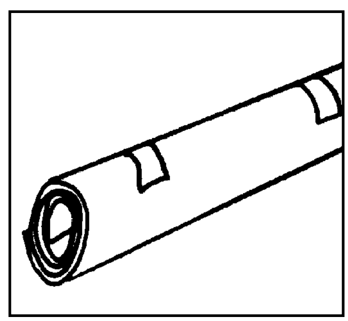


Figure 1.3
Cylinder.

Assessment

From time to time, try to step back from the action and ask yourself the following questions:

- Are the children having fun?
- Is this activity too hard/easy for them?
- Are they acting as cooperative teams?
- What manual/social/intellectual skills are they using?
- What are they actually learning about bridges?

In addition, look for the following bridge building skills:

- Do the children follow directions (written and spoken) accurately?
- Did they understand the challenge and the rules governing it?
- Do they fold and roll paper carefully and accurately?
- Do they rely heavily on tape to make their bridges strong?

Extension

If you have time, have the children make a second bridge that spans the *length* of the paper (11 inches). Use only six sheets of paper this time. Test it in the same way as you did the first bridge.