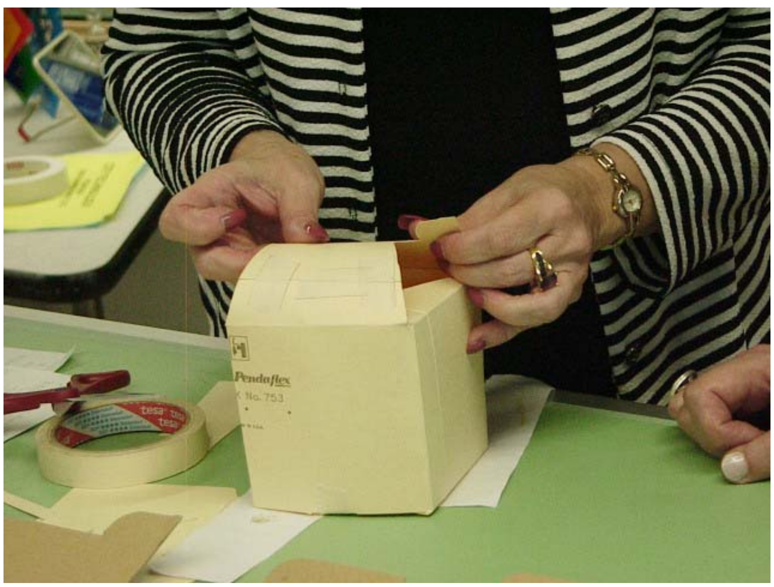
Packaging & Other Structures

Summary of Key Concepts

Packaging includes any technology designed to protect, contain, display, dispense or transport something. Every package is an example of a **structure**. A structure is anything designed to keep objects in place, by resisting the **loads** that would try to shift them. Some structures are large, complex, and expensive, such as bridges, towers and buildings. However, most structures are fairly simple, cheap and easy to find. These include bags, boxes, furniture, shoes, ladders, wall fixtures, and items of all kinds that have been glued, taped, stitched, stapled, sewn or woven.



Most of the time, structures are taken for granted. Only when a structure stops doing its job - when it **fails** - do most people think about how the structure is supposed to work. A structure fails when it experiences loads (or forces) that are beyond its capacity. The loads that bear upon a structure fall into three main categories:

1. **tension** forces, which pull on a structure, trying to make it longer;

2. **compression** forces, which push parts of a structure together, tending to make it shorter and fatter;

3. **shear** forces, which shift opposite sides of a structure in opposing directions.

Different kinds of structures are designed to resist these three types of loads. Tension structures are often suspended from a point higher up, and designed to resist gravity. String, rope, wire, cable and chain are strong in tension, so they are often used for this purpose. Hammocks, light fixtures, clotheslines and belts are all examples of tension structures. Compression structures typically rest on the ground or floor. They resist loads by "refusing" to be squashed appreciably. Some examples are the legs of a table, chair, or person; boxes supporting other boxes; canes, tires, and tree trunks. Points of attachment are generally designed to withstand shear. If one thing is not attached to another securely, they may shift in opposite directions, and the shear forces could win. A broken shoulder bag strap, which has pulled away from the bag, is an example of shear failure. Other examples occur when one side of something is moving and the other side is stationary, as with a broken CD case hinge, a torn-out shoelace, and the sheared- off side-view mirror of a car.

Most loads are not pure examples of tension, compression or shear, but involve some combination of the three. For example, a shelf works as a **beam**, supported at both ends, and subjected to a load somewhere in the middle. Because of the way it is supported and loaded, the top surface of a beam is compressed, while the bottom surface tends to get longer, and is therefore loaded in tension. For this reason, a broken craft stick has short broken fibers on the side where it was pressed, and much longer jagged fibers on the opposite side, which was in tension. Shear failure occurs here too, because these jagged fibers have to slip out of the natural adhesive that was holding them to the rest of the wood.

When a structure fails, it is not generally hard to determine whether it failed in tension, compression or shear. This analysis can be the basis for redesigning the structure to make it stronger, so it will be able to resist a larger load. To illustrate this point, we will discuss some of the failure modes of shopping bags. In each case, the type of failure suggests a remedy for strengthening the bag.

Flimsy plastic shopping bags usually fail when one of the handles gets longer and longer, and finally tears apart. Because it was due to pulling forces, this is an example of tension failure. When a taped handle of a paper shopping bag pulls out of its holder, the glue that held the handle in place has failed to resist the forces pulling the handle and bag in opposite directions. Therefore, this is a case of shear failure. A knotted-string handle may fail because the knot slips through the hole. This is an example of compression failure, because the knot was squeezed, making it smaller. Sometimes, the bottom of a paper bag gives way. The bottom of a bag functions as a beam. While its top surface is in compression, the bottom surface is subjected to tension. In some places, the paper might tear, which is an example of tension failure. In other spots, the glue might stop holding the two flaps together. Because the glue is supposed to keep the flaps from sliding in opposite directions, the weakening of the glue is an example of shear failure.

Pre-workshop Scavenger Hunt

Ask the participants to bring in any shopping bags they consider interesting or unusual.

Workshop Materials

- Rolls of pennies, or other appropriate weights. If penny rolls are used, you will need about thirty per group. Rolls are available from many banks, for 50 cents each. A box of fifty rolls costs $25 and weighs about 20 lb. After the workshop, you can sell the pennies back to the bank.
- Masking tape; marked or cut into two-inch lengths.
- Fairly heavy yarn or cord, marked or cut into one-foot lengths
- Hole punchers
- Scissors
- Package of small brown lunch bags (at least two or three per participant)
- Large collection of shopping bags, with at least several of each of the following handle types: cut-out, knotted string, glue-on, drawstring, heat-sealed, and clip-on. Make sure you have enough cut-out, knotted string and glue-on types, and they are large enough, for each group to test a few of these by putting one or both feet inside.
- Transparency films and markers (if overhead projector will be available)
- Copies of Bag Design Worksheet and Bag Testing Worksheet (see next two pages)

Bag Testing Worksheet

Handle Type (select one) A. Cutout B. Taped C. Knotted-string	**Prediction** Make a drawing showing how you think it will fail.	**Order** Predict which bag will be strongest and weakest.	**Test Results** Make a drawing showing how it actually did fail.

Bag Design Worksheet

Bag Design Make a drawing showing the design that you tested.	**Performance** How many rolls of pennies did it hold?	**Failure Mode** Make a drawing showing how it failed.

Directions to Participants

The following five pages provide a set of instructions for the workshop activities, suitable for copying to transparency films, PowerPoint slides, or chart paper, for use during the workshop.

1. Brainstorming & Scavenger Hunt

- List examples of packaging that could be acquired and brought into the classroom at zero cost.
- Look for examples of packaging in the workshop area, including your personal effects.

2. Guess My Categories!

- Select a variety of shopping bags.
- Sort them according to your own group's SECRET CATEGORIES.
- The other groups will have to guess your categories.

3. How do I Fail Thee?

(Let me Count the Ways!)

Select a few examples of the cut-out, knotted string and glued-on handles. For type:

- PREDICT how the bag will fail if used to carry too much weight.
- TEST the bag to see how it actually fails, by slowly pressing your foot in the bottom, while holding the handles. (Remove any shoes with pointed heels or soles).
- Use the Bag Testing Worksheet to RECORD your prediction for each bag type and COMPARE your prediction with the actual results of the test.

4. Brown-Bagging it

Turn a brown lunch bag into a shopping bag using one of these methods – keep it simple, no reinforcements!

- The cut-out handles:

  Cut a rectangular slot on each side.

- The taped-on handles:

  Make handles of string or twisted paper, and tape a handle on each side.

- The knotted-string handles:

  Punch two holes on each side, pass string through the holes on each side, and tie knots.

5. Failure Leads to Redesign

- Test your brown-bag shopping bag by loading it slowly with penny rolls, until it fails. Note carefully how it failed and record how many pennies it held. Then redesign your bag, and make a new one, CHANGE ONE THING ONLY, using no more than 2 inches of tape.
- Repeat as many times as possible. Each time, use the Bag Design Worksheet to:
  - Record the improvement you made.
  - Record the total number of penny rolls.
  - Record the latest failure mode.

RULES: Each redesign cycle makes only one improvement, and uses no more than 2 in. of additional tape.

Sample Workshop Agenda

Introductions (10 min.)

Brainstorming and Scavenger Hunt (15 min.)

Divide the participants into small groups. Ask each group to list as many different kinds of packaging as they can. Every item on the list should be something they could obtain at no cost, and bring into the classroom. In addition, they should look for physical examples of packaging within the workshop area, and among their own personal effects. These might include boxes, bottles, book covers, envelopes, walls, windows, fruit peels, skin and handbags. Activity #1 in Packaging provides a basis for this activity.

Sorting: Guess my Categories! (30 min.)

Divide all of the available shopping bags among the groups. Include both the bags you have provided, any bags the participants have brought in as part of the pre-workshop activity, and any bags found during the scavenger hunt. Ask each group to sort their bags, keeping their categories secret. The other groups then try to guess the sorting principles used by each group. If none of the groups sorted according to the methods of construction of the handles, encourage them to sort again, using these as the categories. See Activity #2 in Packaging.

Analysis: How do I Fail Thee? (30 minutes)

Remove all of the shopping bags except for examples of these three types: the cut-out, glued-on and knotted-string handles. The task is to predict how each type of bag will fail, when loaded to its limit, and then to test each one to see how it actually does give way. In addition, they should predict which bags will be hardest to break, and which ones will be easiest. The Bag Testing Worksheet (p. 95) should be used to record all predictions and data. No group should actually test a bag until they have predicted what they think will happen. The test method is to hold each bag by its handles, put one foot in the bag, and then gradually apply pressure until the bag just starts to break. Participants should remove shoes with sharp edges, such as high heels, before testing. At the end of this activity, each group should present its data, including both predictions and outcomes of failure modes for each type of bag, as well as the relative strengths of the bags.

Modeling: Brown Bagging it (15 minutes)

This and the next activity are based on the teacher story found on pp. 96-99 of Packaging, and the further discussion on-line at:
http://citytechnology.ccny.cuny.edu/Design_Packaging.html.

Ask each group to look carefully at the handles of three major types of shopping bags:

- **The cutout handles**: Found on the cheapest plastic bags, these consist of slots cut directly into the two sides of the bag.
- **The taped handles:** Found on cheap paper shopping bags, each of these is made of a separate piece of paper, which is added to the body of the bag, and held in place by a glued-on paper strip.
- **Knotted-string handles**: Found on glossy gift bags and fancy paper bags from upscale stores, these consist of a piece of string on each side, slipped through a pair of holes and knotted to keep each end in place.

After studying the various types of handles, each group is to select at least one of the three designs as a basis for turning a small brown lunch bag into a shopping bag:

- **The cutout handles**: Using a scissors, cut out a rectangular slot on each side of the bag.
- **The taped handles:** Tape on two eight-inch lengths of string, one on each side of the bag.
- **Knotted-string handles:** Use a hole punch make two holes on each side of the bag, near the top. Pass an eight-inch piece of string through the two holes on each side, and knot the ends so the string won't come out.

Some participants may interpret this activity as a contest to make the strongest bag. Strongly discourage them from attempting to reinforce or strengthen their bag in any way. Limit the amount of tape (for the taped-on handle only) to about two inches, and the amount of string (for tied and taped handles only) to two eight-inch lengths only, and do not allow any folding, knot tying (except for knotted-string handles), taping (except for taped handles) or any other reinforcing. In the next activity, they will be allowed to improve on these basic designs.

Design: Failure leads to Redesign (60 minutes)

This activity begins with the shopping bags created in the previous activity. The teachers load these bags with weights, such as rolls of pennies, to test their strength, by seeing how many weights they will hold. Each bag should be loaded gradually, until it fails.

Once the bag has failed, the group should use the Bag Design Worksheet to record the number of weights it held, and examine carefully how it gave way. They should look closely at any tears in the paper, points where the tape separated from the paper, or places where the string pulled through. Then ask them to redesign their bag based on a careful look at how their first design failed. For example, they may want to reinforce the places where the bag tore, improve the taping of the handles, or use more string, depending on what seems to be the weakest link in the original design. If they began by making rectangular cutout handles, ask them to compare their handles with those of commercial bags, which are always cut as circles or ovals. The redesign might consist simply of cutting different-shape slots.

Limit the amount of tape available for redesign to about two inches. Then they test their second design, again recording the number of weights held, and comparing the results with the outcomes from the first. This comparison will reveal how effective the modifications were. They should repeat this process, going through as many design cycles as time permits. Request that each group keep careful records of the failure mode at each stage in the redesign process, how many weights the bag held, and the changes they made to improve the design. Limit the additional amount of tape to two inches for each design cycle.

Do not discuss control of variables beforehand. This issue should come up in discussion during the course of the activity, or immediately afterwards. Activities #3 and #5 in Packaging develop lower- and upper-grade versions, respectively.

Sharing (30 min.)

Each group should share the results of their design activities. Specifically, they should describe the amount of weight and type of failure that occurred each stage in the design process, and explain what they did to redesign the bag. The concluding discussion could focus on the control of variables, as well as the role of design in the curriculum.

Workshop Tips & Strategies

Brainstorming and Scavenger Hunt

In the course of both activities, try to broaden the teachers' notion of what might qualify as a "package," which could include anything used to protect, contain and/or transport a solid, liquid or gas. Some examples would be natural packaging, such as fruit peel, human skin, egg shells, and cell walls; protective coverings of things, such as a suitcase, an appliance case, a pipe, a door, a window or a wall; nearly any article of clothing; string or tape used to hold something together; as well as balloons, bags, envelopes and nets.

Sorting

Some groups may sort according to superficial categories, such as color, style, printed message, paper or plastic, etc. Others may come up with construction method, ability to stand up, or whether the handles made of the same material as the bag. While these are more engaging categories, we find the method of making the handles to be the most interesting feature of shopping bags. We have identified six major types of handles, including the three described above under "Modeling." These are:

- **The cutout handles**: Found on the cheapest plastic bags, these consist of oval-shaped slots cut directly into the two sides of the bag.
- **The taped handles:** Found on cheap paper shopping bags, each of these is made of a separate piece of paper, which is added to the body of the bag, and held in place by a glued-on paper strip.
- **Knotted-string handles**: Found on glossy gift bags and fancy paper bags from upscale stores, these consist of a piece of string on each side, slipped through a pair of holes and knotted to keep it in place.
- **The heat-sealed handles**: thin plastic handles melted onto a bag made of the same flexible material.
- **The clip-on handles**: rigid plastic handles attached to a flexible plastic bag, one on each side, clamped on by tab-in-slot arrangements; and
- **The drawstring**: often found on bags from shoe stores and clothing stores, a single length of string is held by a heat-sealed hem around the top of the bag.

Of course, there are numerous variations that do not fit neatly into any of these categories. We have found bags with metal handles, rigid plastic handles that are heat-sealed, rather than clipped on, drawstrings made of plastic rather than string, etc. Also, bags vary considerably in the amount of reinforcement. Some knotted-string bags, for example, have as many as three layers of paper or cardboard holding metal grommets, so the string won't pull out! The intent of this activity is to focus participants on the basic categories, as well as some of the more interesting variants.

Analysis

Require each group to make a prediction before they test each type of bag. All predictions and actual outcomes should be written down. They may be represented by words and/or pictures. If possible, require the groups to share this data at the end of the activity.

Discourage participants from quickly pushing their feet through bags. By applying pressure slowly, they will make it more likely that the bag will fail at the weakest point only. Often, failure will occur at the handles rather than the bottom. It is useful to compare similar types of bags that have different level of reinforcement, such as knotted-string bags with and without metal grommets around the holes. Sometimes it will be clear how the reinforcement of the handle prevented it from failing before the bottom gave way.

Modeling

Emphasize that this is not a competition to make the strongest bag. By making their bags deliberately weak, they will learn far more about how bags actually fail, and be able to redesign their bag precisely to address the problems they uncover. If participants insist on reinforcing their bag, ask them how they know that their method of reinforcement actually makes the bag stronger, and if so, by how much. They should realize that they could answer these questions only by beginning with the simplest possible bag.

Redesign

This task uses the model from the previous activity as the baseline design. These bags will probably not hold much weight. Redesign proceeds by examining the mode of failure of the previous design, and trying to prevent it. Encourage the teachers to look carefully at what happens as the bags begin to give way. Where does the paper tear? How does the tape begin to separate? Does the string break or does it open up the hole in the paper? These observations provide the clues for making the next design stronger. For example, bags with cutout handles are almost certain to fail at upper corners of the cutouts. An important issue worth highlighting is the way that forces become concentrated near sharp corners and edges. For this reason, a rectangular cutout will fail much sooner than an oval slot. Reinforcing the corners with tape will strengthen the bags considerably. If the teachers are careful in examining the failure modes, and reinforce precisely those parts that are weakest, their bags will improve dramatically with each redesign.

Encourage the groups to save the bags after they have failed, and to make a new one each time. An excellent way to present the data from this activity is to line up all the broken bags in order, with a record of how many penny rolls each one held.

Once the teachers begin testing bags, there may again be pressure to compete over who can make the strongest bag. Strongly discourage this idea, and strictly limit the amount of tape available for each cycle of redesign. The purpose of the activity is to examine closely how incremental improvements affect the strength of the bag and shift the failure mode from one point to another. Each redesign should be based only on the failure of the previous one, and not on imagining what will make the strongest bag. Trying to make a strong bag immediately short cuts all of the learning about structures, and the role of failure in design (see "The Role of Failure in Design" in Chapter 4 of this Guide.)

Sharing

A good way to underscore the purpose of the design activity is to require each group to keep careful data, and to share it at the end. For each step in the redesign process, they should be able to explain:

- How the previous design failed;
- What they did to improve the design, based on their examination of the failure mode; and
- How many more units of weight the new design held compared with the previous one.

Beyond the basic data from the tests, these activities provide opportunities to discuss some important issues in design. You might point out that the limitation to two inches of tape is an example of a design constraint. How did this constraint affect the design process? What sorts of constraints do commercial shopping bag designers have to observe? What criteria do they aim for?