**Vocabulary**

- magnitude of force
- direction of force
- point and plane of application of force

# Lesson 4

## An Investigation into the Characteristics of a Force

**Learning Outcomes**

After completing this lesson you will be able to

- ❑ investigate to determine that the effect a force has on a structure depends on the magnitude, direction, and point and plane of application of the force

As you learned in Lesson 3, architects and engineers design and build structures knowing the types of forces that the structure will be exposed to. This knowledge allows them to make modifications to designs so that the structures can withstand the forces.

There are several characteristics to a force that designers must also be aware of when they are designing structures. These include the

- **magnitude of force**
- **direction of force**
- **point and plane of application of force**

Read the following article, and then use the template provided to explain how the characteristics of forces influence a chest of drawers.

## Forces and Structures

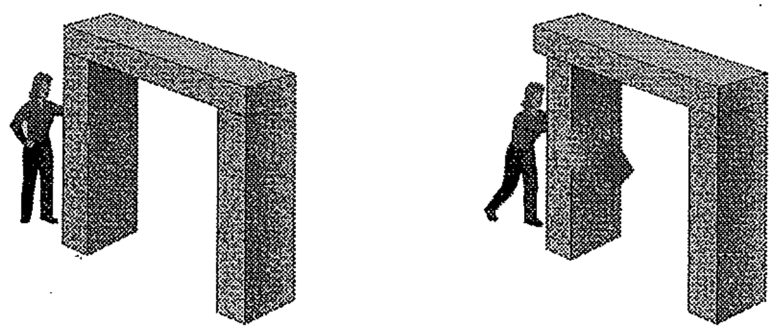
Why don't bumper cars cause serious injuries in amusement parks, while cars hitting each other on the road do? How can one force, such as the impact of one car hitting another in a crash, have a variety of effects? The answer is that forces are not created equal. The effect of a force on a structure depends on its magnitude, direction, and the point of application of the force.

### Magnitude of Force

Every force has a magnitude. **Magnitude** is a measure of how strong the force is. If you were to gently tap a nail on its head with a hammer, the nail would not be driven into the wood. The tap is a low magnitude force. If you struck the nail hard, you would have more success. A hard strike is a higher magnitude force. The structure in **Figure 1** will react differently to two forces of different magnitude.

**Figure 1**

Magnitude of force. In diagrams, the magnitude of a force is indicated by the length of the arrow.



a A weak force (low magnitude) is not enough to make the block move.

b A strong force (high magnitude) moves the block to the right.

### Direction of Force

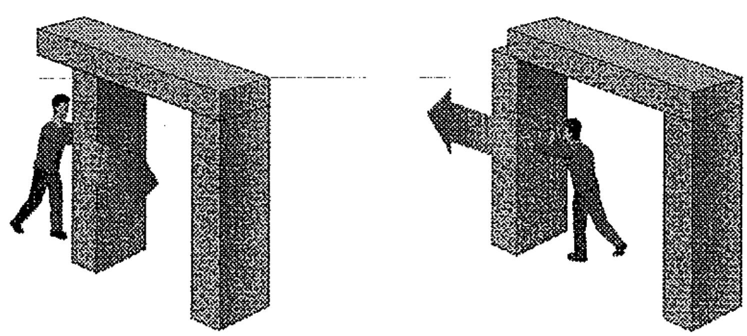
The effect of a force on a structure depends on the direction of the force. If a door says "push," it won't open if you use a pulling force. The structure in **Figure 2** will not react in the same way to two forces that have the same magnitude but different directions.

**Figure 2**

The direction of a force affects how a structure will react to it. These two forces have the same magnitude but different directions. Both forces will cause the structure to collapse.

a This force will cause the block to move to the right.

b This force will cause the block to move to the left.



*(continued)*

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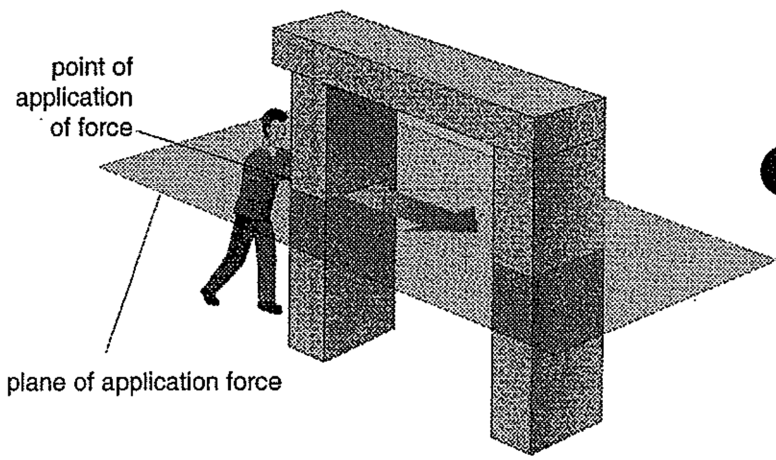
## Point and Plane of Application of Force

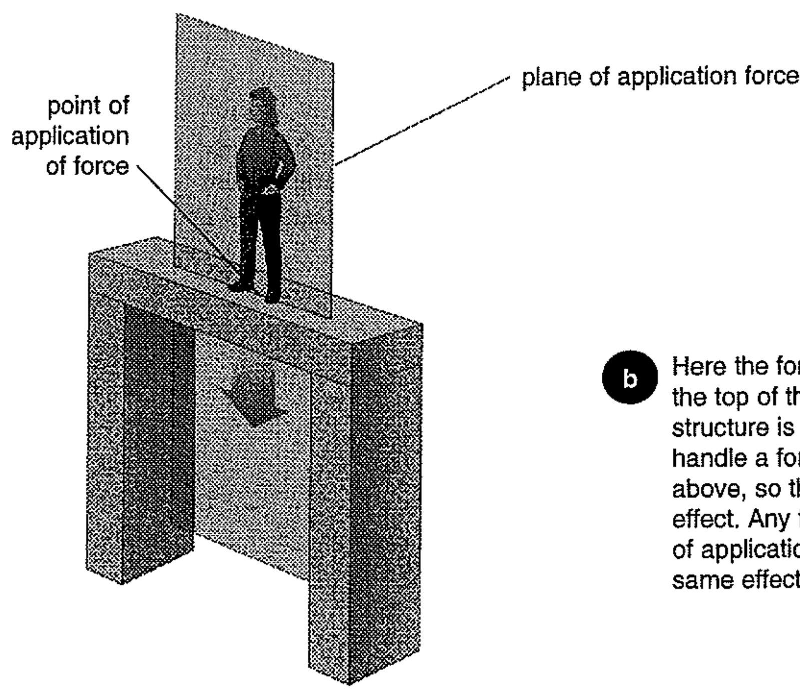
You may have tried to push a chest of drawers from the centre of a room toward a wall. If you push low on the chest, it will slide toward the wall. However, if you push with the same magnitude of force higher up, the chest may topple over. As you can see in **Figure 3**, the point and plane of application of a force make a difference.

**Figure 3**

Where and how a force is applied to a structure affects the results.




**a** As before, the force pushing on the block will cause the structure to collapse by moving the block to the right. Any force of this magnitude in the same plane (applied to the right or left of the point of application) will have the same effect.




**b** Here the force is pushing on the top of the structure. The structure is designed to handle a force applied from above, so the force has no effect. Any force in this plane of application will have the same effect.

## Three-Point Approach

| Characteristics of Forces | |
|---|---|
| | **Effect on Chest of Drawers** |
| magnitude of force | |
| direction of force | |
| point and plane of application of force | Pushing low on the chest will make it slide, pushing higher up may cause it to topple over |

## Learning Activity: Spaghetti Beam Bridge

Conduct an experiment to determine whether the size of the load needed to cause structural failure to a "Spaghetti Beam Bridge" (see the diagram at the end of the Experiment Report) differs at various points along the plane of a bridge.

Complete the missing portions of the Experiment Report below by conducting the Spaghetti Beam Bridge experiment. (You can refer to Module 1, Lesson 2 for more information about the scientific inquiry process.)

### Experiment Report

*Testable Question:* To determine if the point of application of a load affects the magnitude (amount) of load needed to cause structural failure.

*Independent variable:* ______________________________

*Dependent variable:* ______________________________

*Controlled variables*

1. type of spaghetti
2. number of strands of spaghetti
3. ______________________________
4. ______________________________

*Hypothesis:*

*Materials needed for experiment*:

- spaghetti
- two elastic bands
- disposable cup
- pennies (or other material that can be used as a load)
- stacks of books or two tables

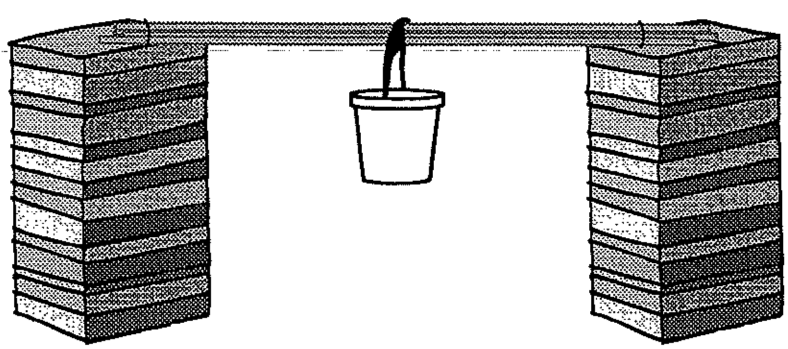
*Method:*

1. Place strands of spaghetti together and wrap the ends with elastic bands.
2. Place the "spaghetti beam" across an expanse made by stacks of books or two tables.
3. Hang a disposable cup in the middle of bridge, and slowly add pennies (the load) into the cup until bridge begins to bend. **Note:** If the bridge breaks, reconstruct the bridge using the same number of strands of spaghetti.
4. Using the chart provided, record the magnitude of the load (number of pennies in the cup).
5. Remove the pennies from the cup and repeat the test at three different points along the plane of the spaghetti bridge and record your information in the chart. Label the diagram to indicate where your tests were done.


*Observations:*

| Test Site | # of Pennies |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |

Label the diagram below.



*Conclusion:*

The point of application did/did not (circle one) affect the amount of weight that could be added before the bridge began to bend.

The strongest point of the bridge was:

_______________________________________________

The weakest point of the bridge was:

_______________________________________________

*Sources of error:*

## Notes

Vocabulary

- mass
- pillars
- gussets
- struts
- ties
- trusses

# Lesson 5

## Improving the Strength and Stability of a Structure

**Learning Outcomes**

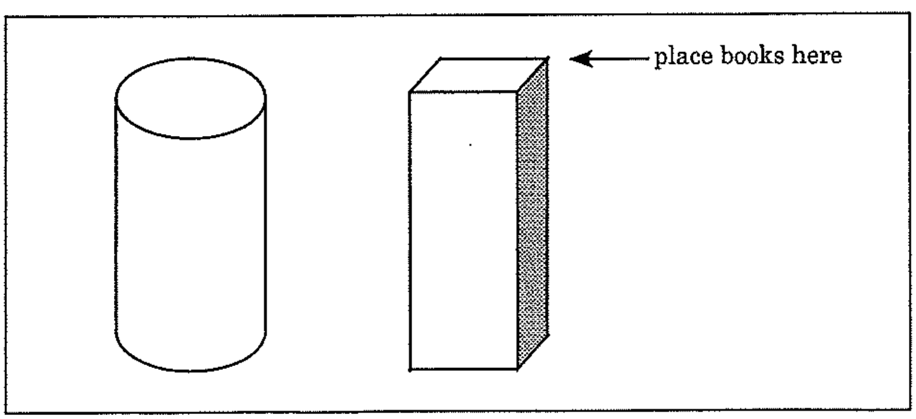
After completing this lesson you will be able to

- ❑ describe how common structural shapes and components can increase the strength and stability of a structure
- ❑ demonstrate methods used to increase the strength of materials
- ❑ determine the efficiency of a structure by comparing its mass with the mass of the load it supports

### Learning Activity: Structure Shape Test

To determine if the shape of a structure has an effect on the amount of load force (**mass**) it can withstand, complete the following activity.

Create a variety of different-shaped structures, using one piece of paper and an equal portion of tape for each. Examples of structures you can create include a cylinder, a box-like shape, or a prism shape.




**Note:** The shapes you create should all have minimal overlap of paper.

Predict which shape will hold the most books, and then test your hypothesis using a set of equally weighted books. Test each structure separately by placing one book at a time on top of the structure until structural failure occurs.

Which shape has the most structural strength?

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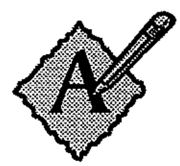
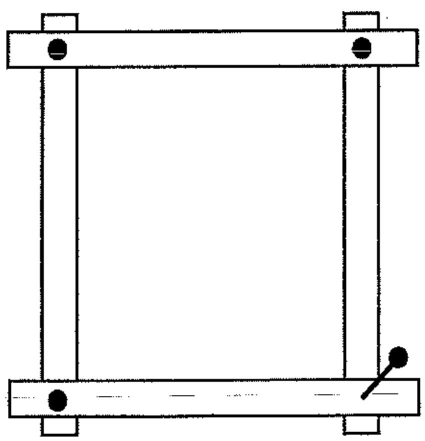
## Learning Activity: Stable Shapes



You'll need four straws and four straight pins for this learning activity. Using these materials, make a square like the following.



Now, push or pull on the sides of the square. What happens to the shape and structure? Write down your answer.

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_______________________________________________

_______________________________________________

_______________________________________________

_______________________________________________

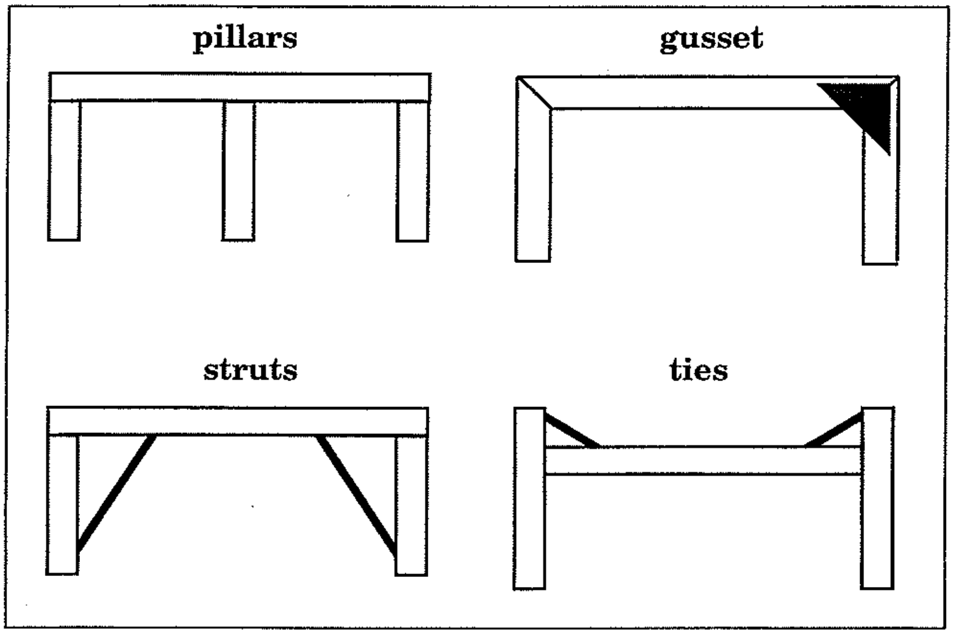
Try the following:

- If you could add one more straw to your square to make it more stable, how would you do it? Try making your square more stable by adding a straw.
- Diagram your results, and identify the shape that brought stability to the square.

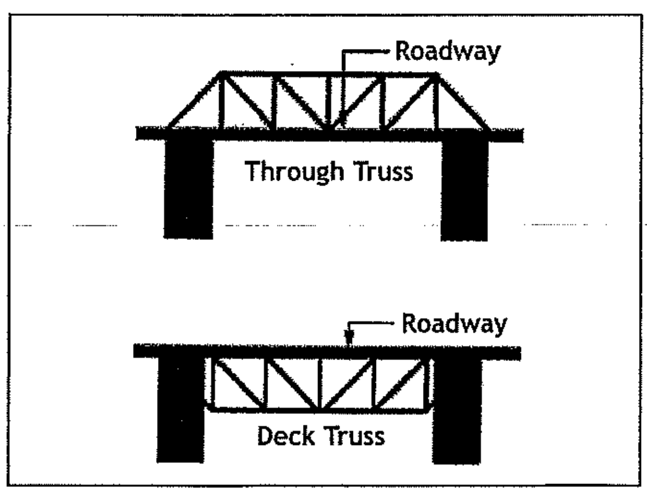
- Repeat the same procedure for a rectangle.

## Improving Strength and Stability

Square and rectangular structures are not the strongest or most stable structures, but they are easy to make. Engineers have developed adaptations to strengthen these types of structures. For example:




Engineers have also incorporated the strength of triangles into frames, called **trusses**, that link many triangles together. You'll see trusses in many types of structures, including houses and bridges. Here are two examples of bridge trusses.




**Would You Like to Know More?**
The following websites have lots of information and many activities relating to bridges, skyscrapers, and other types of structures.

<http://www.howstuffworks.com/bridge.htm>

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

### Components That Add Stability

In conducting the “Spaghetti Beam Bridge” experiment in the previous lesson, you discovered that the weakest point in a beam bridge is the middle. What design adaptations could you make to alleviate the problem and provide more support for your bridge? Draw and label a diagram.

## Learning Activity: Strength and the Penny-Paper Bridge

The overall strength of a structure can be increased by strengthening the materials used to build it. Let's investigate to determine ways to strengthen a simple beam paper bridge.

Begin by making a paper "bridge" by placing a piece of paper between two stacks of books. Now, place pennies on the bridge until structural failure occurs. Now alter the materials (paper) in some manner to make it stronger. Can you make a bridge that will hold more pennies than the previous one, following these guidelines?

- [ ] The span of the new bridge must be the same length as the span of the previous one.
- [ ] The type of paper used must be the same, but there is no limit on the quantity.
- [ ] The paper can be folded (e.g., corrugated).
- [ ] Small amounts of tape and glue may be used to create a box.
- [ ] Beams or I-beams can be used as bridge spans.

What did you do to strengthen the bridge?

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## Load Force Capacity Versus Mass of Bridge

You probably noticed that one way to make your paper bridge stronger was to add more paper. Adding more material can also help strengthen real-life structures, but there are two drawbacks to this. One drawback is cost. More materials means a greater cost. The other drawback is the increased mass of the structure and the resulting increase in the force of gravity. For example, if the ground is soft, the foundation of the structure may have to be reinforced to prevent the structure from shifting or sinking. Also, stronger joints are needed to hold the structure together.

One way to describe the relationship between the strength of a structure and its mass is to calculate structural efficiency, using the following formula:

$$\text{Structural efficiency} = \frac{\text{maximum mass of the load a structure will support}}{\text{mass of the structure}}$$

### Case Study

Imagine that two students are working together on a project for the provincial science fair. They have decided to enter a design project, and are looking for a method to build a bridge across a specific span with the least possible amount of materials, but still strong enough to carry a large load force.

They decide to make three different bridges and test them for structural efficiency. To determine which bridge is the most efficient, that is which bridge can carry the most load force (mass) and have the least amount of mass (bridge mass), they use the following formula:

$$\text{Structural efficiency} = \frac{\text{maximum mass of load}}{\text{mass of structure}}$$

Example: $\frac{20 \text{ grams}}{2 \text{ grams}} = 10 \text{ grams}$

The larger the resulting number, the higher the efficiency. Analyze the data recorded as a result of their tests to determine which of the three bridges has the greatest structural efficiency.

| Bridge | Maximum Mass | Mass of Structure | Structural Efficiency |
|---|---|---|---|
| #1 | 500 g | 100 g | |
| #2 | 60 g | 6 g | |
| #3 | 250 g | 5 g | |

### Questions: Testing Structural Efficiency

1. Which bridge has the greatest structural efficiency? Explain your answer.

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2. Write your own one-sentence description of what structural efficiency is all about.

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