SCIENTISTS IN SCHOOL
SCIENTIFIQUES À L'ÉCOLE

Teacher Resource Package

Let us help you piece together the science!

Background Information an overview of the topic and theoretical concepts.

Hands-on Activities
Activity 1 - pen/paper activity
Activity 2 - short, easy-to-do activity (30-60min)
Activity 3 - short, easy-to-do activity (30-60min)
Activity 4 - longer activity (greater than 1 hr)
Activity 5 - complex activity

Teacher Resources
Literary Resources
Website Resources
Interactive White Board Resources
Multi-media

Student Resources
Literary Resources
Interactive Websites

Please help us improve our teacher resource packages!

If you have any feedback about this package or suggestions for new resources to include, please don't hesitate to contact us at: virtual@scientistsinschool.ca

Fending Off Forces

You're late for school! You react by jumping up, plunking your coffee mug down on the kitchen counter and running out the door. You probably didn't give it any thought but there were many forces acting on you in those few seconds. They range from the forces used to hold that daily cup of coffee, to the forces that our feet exert against the ground to get us moving and of course, the force of gravity. Forces are applied everywhere all the time!

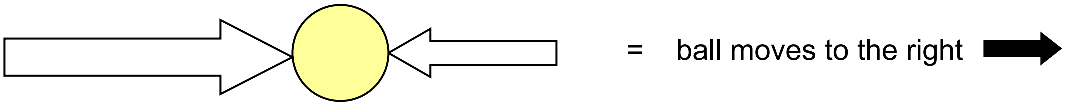
Background Information

Forces

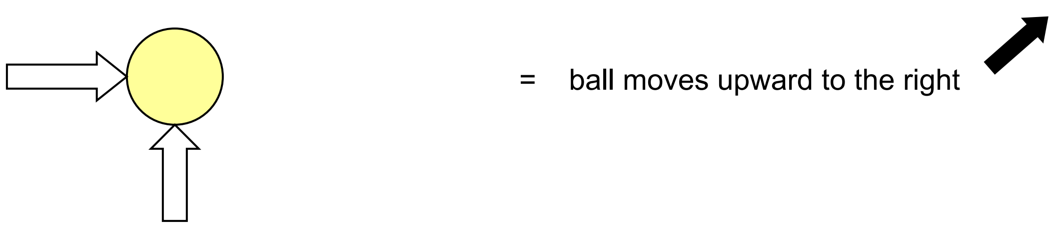
A force is a push or pull on an object. Forces have direction and magnitude and depending on these two factors, it can cause an object to change its speed, direction, shape or pressure within. Engineers use arrows called vectors to represent direction and magnitude of force, the larger the arrow, the larger the force. Newtons (N) are used to measure force. One Newton is equal to the force required to cause a mass of 1 kilogram to accelerate at a rate of 1 meter per second per second (m/s^2) in the absence of other force-producing effects. Sir Isaac Newton's laws of motion lay the foundation for the interaction of forces and motion.

Newton's first law is that an object will remain at rest or move at the same speed unless an unbalanced force acts on it. For example, if two people apply an equal force on a ball in opposite directions then the ball will not move and it is considered to be in equilibrium.

If one person pushed harder than the other, the ball would move in the direction of the larger force. The forces are considered unbalanced in strength.



If two people were applying forces in different directions, then the ball would move in the direction of the resultant force. The forces are unbalanced in direction.



Newton's second law describes the relationship between the force and an object's mass and acceleration. The larger the mass, the more force it takes to move it.

Force = mass x acceleration or F = m a

Newton's third law states that for every action, there is an equal and opposite reaction. For every interaction, there is a pair of forces acting on two interacting objects. The size of the forces on the first object equals the size of the force on the second object, yet the direction of the forces are opposing.

External Forces Acting on Structures

External forces are forces that act on a structure from the outside. The most common external force is the downward pull of gravity which is defined as the force that attracts two objects. If an object has a mass, then it will have gravitational force. Galileo Galilei was a famous scientist from the 16th century who studied the effects of gravity. One of his well-known experiments involved dropping balls of differing mass from the Tower of Pisa. He discovered that balls fell at the same acceleration despite their different mass. This discovery disputed previous claims by another scientist, Aristotle, who believed that a larger mass would fall faster than a smaller mass.

Galileo also discovered that air resistance will have a greater effect on an object of less mass. As the acceleration on Earth is a constant 9.8 m/s^2, then the equation $F = m \times a$, would be $F = m \times 9.8\ m/s^2$, showing that the force of gravity is in direct relation to its mass. For example, if a feather and a book were dropped at the same time, the feather would fall slower due to the relationship between air resistance and the feather's light mass and surface area. The larger gravitational force from the book overcomes the force from air resistance and therefore, it falls faster. If this experiment is repeated in a vacuum, that eliminates air resistance, then they would fall at the same time. This has been demonstrated during the Apollo 15 moon walk in 1971, where both a hammer and feather were dropped at the same time and they fell at a constant rate.

Gravitational force on a structure consists of two components:

- dead load, defined as the weight of the structure;
- live load, defined as the weight of anything that is in or on the structure.

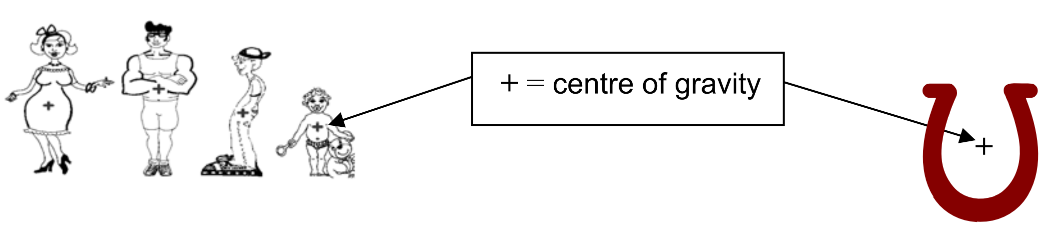
For example, the dead load of a school is the weight of the materials used to construct it such as concrete, steel, brick and glass. The live load is the weight of the people, furniture and computers that are inside the building and this load may fluctuate hour by hour.

Working against the force of gravity is the external force that exerts an upward applied force in the opposite direction. If the structure can not exert an internal upward force to balance out the force of gravity, then the structure will likely collapse or deform. For example, when a book sits on a desk, the book does not move. The force of gravity works opposite the push of the desk equally such that the forces are balanced. If the book was quite heavy and the force of gravity would be more than the desk can push to hold it up, then there would be an unbalanced force. This would result in the desk buckling and the book falling.

In order to support a load, structures use certain shapes that can withstand the force. The triangle is considered a strong shape as it does not deform easily under a load. A square on the other hand, can shift under a heavy load into a parallelogram. If a brace is placed diagonally on a square, it creates triangular shapes within it and this strengthens the shape.

Centre of Gravity

The centre of gravity of an object is the exact centre of its mass such that it is equally balanced. Sometimes this point can actually be concentrated on the outside of an object (e.g. horseshoe).



Engineers design structures so that the centre of gravity is lower as this makes the structure more stable. They can achieve this by adding more mass to the lower part of the structure, by widening the base, by creating a deep foundation or by their selection of different building materials. For example, the CN tower is a solid structure that is very stable due to its low centre of gravity. The tower widens at the base and it has a concrete and steel foundation that is 6.7 m thick containing 17% of the concrete used in the entire building.

Internal Forces: Tension, Compression, Shear and Torsion

Internal forces are forces that act on an object from within. Tension is a pulling force resulting in an object that is stretched or lengthened. Compression is a pushing force resulting in an object that is compacted or squeezed together. Shear is an internal force that tears materials apart by pushing an object in opposite directions, such as scissors that cut paper in half. Torsion is a force that acts on an object by twisting its ends in opposite directions, such as opening a jar.

Engineers must choose materials that withstand internal forces in order for the structure to be stable and safe. In ancient times, pyramids were built with limestone as Egyptians discovered this material was very strong in compression. They also cleverly used the fact that limestone has poor tensile qualities to their advantage by applying wet wooden wedges to split the rock. They would soak the wedges with water and as the wood swelled the limestone would split.

In modern structures, stone or concrete are preferred building materials due to their ability to withstand substantial compression. For example, concrete pillars and columns are used to support large structures such as bridges. If a structure fails under compression, it will buckle. In 1907, American architect Theodore Cooper designed the cantilever Quebec bridge to span 550m over the St. Lawrence River. Unfortunately, the design was flawed as there were significant compressive stresses on the lower horizontal lengths of the bridge. On August 29, 1907, during construction, the bridge collapsed and killed 75 workers.

Engineers use steel in construction due to its tensile and elastic properties. For example, steel struts or cables are commonly used to build truss and suspension bridges. A structure that is pushed to its tensile limit will fail by snapping. The Calgary Saddledome, home of the NHL's Calgary Flames and the 1988 Olympics, is an example of a tensile structure. It was designed in 1983 and boasts a saddle shaped roof that has no pillars to block spectator views. The roof is held in place by a network of cables in tension that support pre-cast concrete panels. This structure has held up and stayed strong, despite the devastating 2013 floods in Alberta.

Calgary Saddledome,
Source: Maureen, Wikimedia Commons

Cantilever Quebec Bridge (rebuilt 1917)
Source: GBoivinT, Wikimedia Commons

Forces and Mechanical Systems

Mechanical systems or simple machines, such as inclined planes, pulleys and wheels, can help us change the way work is done by either reducing the force needed or shortening the distance to move an object.

Work = Force x distance (W = F x d) (measured in Newton meter (N m) or Joules (J)).

The less force to move an object a specific distance will result in less work being done. For example, the amount of work and force needed to push a basketball would be less than the force needed to push a rock of a similar size over the same distance. Some mechanical systems may help us reduce the force needed without necessarily reducing the work. For example, an inclined plane can help move a heavy box by moving it over a longer distance and therefore requiring less force to do the same work.

Forces and the Environment

Structures also have to be able to withstand unpredictable forces from the environment caused by wind, earthquakes, hurricanes, snow and ice. In order for the structure to be useful, it must be able to withstand these forces and maintain its strength and stability. In Vancouver, engineers are constantly improving structures with reinforcements and specialized materials, such as rounded glass panels, to build modern buildings that can withstand the shaking force of an earthquake and minimize injuries. The impact of unpredictable forces was seen during the great ice storm of 1998 that affected Ontario, Quebec and the eastern provinces. Freezing rain caused significant ice to accumulate on power lines and trees. These structures could not withstand the added weight and collapsed resulting in power loss to over 4 million people across the region for a number of days.

Fun Fact: CN Tower

Did you know that the CN tower is the tallest free-standing structure in the Western Hemisphere? The tower is designed to withstand winds up to 418 km/hr and earthquakes up to 8.5 on the Richter scale! This structure can withstand a lot of force from the environment!

Activity 1: How Heavy is your School Bag?

Time: 30-60 minutes

Other Applications: Math, Language

Key Terms: mass, weight, gravity, external force

Group Size: Individual

Materials:

- ☐ copy of "How Heavy is your School Bag" datasheet per student (included)
- ☐ pencils
- ☐ calculators
- ☐ bathroom scale
- ☐ student's backpacks or school bags

Fun Fact: Gravity Anomaly in Canada!
The Hudson Bay region has lower gravity than other parts of the world. Because the Earth has uneven mass, there is uneven gravity!

Learning Goal: Students will learn the difference between mass and weight by comparing weights on different celestial bodies of the solar system and understanding the effects of gravity.

When a person weighs themselves, they measure their weight on Earth, based on the gravitational force of Earth. If they were to measure themselves on the moon, then mass would be the same yet their weight would be less since the moon is lighter than the Earth. The equation to calculate weight is:

Weight = mass x acceleration of gravity (in m/s^2) or

or **W = m x g,** in Newtons (N).

Procedure:

1. Hand out copies of the datasheet "How Heavy is your School Bag?"
2. Review the terms of mass, weight, acceleration and how to calculate weight:
   a. mass (m) = a physical body of matter, is the quantity measured in grams (g or kg);
   b. acceleration of gravity (g) = change in velocity (speed) measured in m/s^2;
   c. weight (W) = measurement of gravitational force acting on a mass, equation Weight = mass (m) x acceleration of gravity (g), measured in Newtons (N).
3. Ask students to measure the weight of their backpacks or school bags on Earth in kg on a bathroom scale and record it on their datasheet.
4. Ask them to make predictions on whether the bag will be heavier (+) or lighter (-) on different celestial bodies of the solar system.
5. Ask students to circle their prediction where they think the bag will be the lightest and where it will feel the heaviest.
6. Once predictions are recorded, provide the students with the gravitational pull factors compared to Earth and have them enter the values on their datasheets.
7. Ask students to complete the datasheets by calculating their bag's "new" weight on each different celestial body of the solar system by using the equation

   $W_{planet} = W_{earth} \times (\text{gravitation pull factor})_{planet}$.

Observations:
The gravitational pull factor compared to Earth and a sample completed datasheet for a backpack that weighed 15 kg is included below. The backpack will weigh the most on the sun and the least on Pluto.

Planet / Moon / Sun	Prediction if your bag is heavier or lighter	Gravitational pull factor compared to Earth	Your bag's "new" weight (kg)
Sun	Heavier (+)	28.00	420
Mercury	Lighter (-)	0.38	5.7
Venus	Lighter (-)	0.91	13.65
Earth	Same	1.00	15
Moon	Lighter (-)	0.17	2.55
Mars	Lighter (-)	0.38	5.7
Jupiter	Heavier (+)	2.54	38.1
Saturn	Heavier (+)	1.08	16.2
Uranus	Lighter (-)	0.91	13.65
Neptune	Heavier (+)	1.19	17.85
Pluto	Lighter (-)	0.06	0.9

Discussion:
Discuss with students what they think walking would be like on planets with a higher gravitational pull and a lower gravitational pull. Alternatively, the students could be encouraged to demonstrate how they might walk on the sun or the moon. The sun has the highest gravitational pull thus it would be harder to walk on the sun besides the fact it is too hot! Pluto has the least gravitational pull and therefore we would feel lightest on this celestial body.

What would engineers have to do differently to build stable structures on these planets? Planets like Jupiter would need structures built with much stronger materials since it has a higher mass and therefore stronger gravitational pull. Conversely, a structure on Mercury does not need to be as strong since it has a small mass and lower gravitational pull.

Fun Fact: Gravity is everywhere!

The massive sun has gravity that holds all the planets in their orbits. Gravity decreases with distance otherwise we would be pulled towards the sun instead of the Earth! Astronauts feel weightless in space, only because they are falling at the same slow speed as their spaceship towards Earth and don't feel anything pushing against them.

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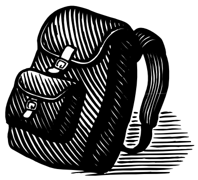
Name: ______________________________



How Heavy is your School Bag?

Weight of your school bag: __________________ kg

Celestial Bodies of Solar System	**Prediction** (heavier or lighter than on Earth)	**Gravitational pull factor compared to Earth**	**Your bag's "new" weight (kg)**
Sun			
Mercury			
Venus			
Earth			
Moon			
Mars			
Jupiter			
Saturn			
Uranus			
Neptune			
Pluto			

Sample calculation of weight on different planets:

Weight of school bag on Earth = 15 kg

Weight of school bag on the Earth's moon:

$W_{moon} = W_{earth} \times (\text{gravitation pull factor})_{moon}$

$W_{moon} = 15 \times 0.17 = 2.55$

Activity 2: Check Out Those Internal Forces

Time: 60-90 minutes

Other Applications: Math, Language

Key Terms: tension, compression, load, gravity, internal force

Group Size: small groups

Materials per group:

- ☐ copy of "Check Out Those Internal Forces" datasheet (included) and pencil per student
- ☐ 2 spring clamps
- ☐ Newton spring scale (1-5N) - optional
- ☐ 10 sets of 500 g mass or equivalent mass such as bag or boxes of sugar, flour, rice, pasta
- ☐ plastic bags to hold mass
- ☐ tape

Materials per group for tensile tests:

- ☐ paper plate and styro-foam plate of similar size
- ☐ paper bag and plastic bag of similar size
- ☐ licorice and gummy worm of similar size

Materials per group for compression tests:

- ☐ small paper cup and plastic cup of similar size
- ☐ empty aluminum pop can and empty plastic bottle
- ☐ kitchen sponge and large marshmallows
- ☐ two pieces of cardboard

Learning Goal: Students will learn about internal forces acting on objects by performing simple tension and compression tests on different household materials.

Scientists and engineers use compression and tensile testing to verify the suitability and selection of materials for building structures. Strength tests are measured by the force it takes to snap under tension, buckle under compression or deform an object over the unit of area. It is measured as N/m^2 or Pascal (Pa).

Tension testing is performed by pulling a test object apart until failure (snapping or deforming permanently). The tensile strength is measured by the force it took to snap the object over the cross sectional area of the object.

Compression testing is performed by placing an object in between plates and applying a crushing force to the object until it buckles or deforms permanently. The compressive strength of a material is the force it took to buckle the object over the cross sectional area.

Procedure:

1. Hand out copies of the "Check Out Those Internal Forces" datasheet.
2. Review the concepts of tension and compression testing.
3. Students can verify the force of gravity of the mass using a Newton spring scale. If Newton spring scales are not available for each group, this step could be demonstrated or explained to the class. Place a 500 g mass in a bag and attach it to a Newton spring scale via an S hook. The force should measure 5N. If a solid mass is not available, use a 500 g bag of rice, flour or sugar as an alternative.
4. For tension testing, two objects of similar area will be used to compare the amount of force the material can take before it snaps (up to 50 N). Using the datasheet, predict which one will be the strongest (✔) and which will be the weakest (✖):
    a. paper vs styrofoam plate
    b. paper vs plastic bag (note: masses can be placed inside the bags for this set instead)
    c. licorice vs gummy worm
5. To perform a tension test, clamps are attached to either end of a test object. Attach a 500 g mass to the lower clamp and hold up the object from the top clamp. Observe the object for failure or deformation and record any physical changes to the material. If the object fails, record how much force was applied to cause the object to fail and go to step 7.

6. If the object does not fail, add another mass (500g). Continue to add more mass until the material fails (snaps) from the tension. Record any physical changes to the material and how much force it took to make the material fail (5 N per 500 g mass). If it does not fail, observe and record if the material lengthens (permanent deformation). This will provide information on how elastic the material is.
7. Repeat steps 5-6 for the two other sets of similarly sized materials. Measure and record physical changes as well as the magnitude of force that caused the objects to fail.
8. To perform a simple compression test, an object will be placed between two flat pieces of cardboard and mass added on top of it. Students will compare two similar sized objects. Using the datasheet, predict which one will be the strongest (✔) and which will be the weakest (✖):
    a. plastic vs paper cup
    b. aluminum soda can vs disposable plastic water bottle (tape can and bottle to cardboard on both ends, students may need to use their hands slightly to balance mass when testing)
    c. sponge vs marshmallows (place as many to cover same area as sponge)
9. Place a measured mass (start with 500g or 5N) and continue to add until the object buckles or deforms permanently.
10. Record the physical changes and how much force it takes to fail the compression test (buckling or deforming permanently) on the datasheet. What happens to the shape of the material when the mass is removed?
11. Repeat steps 9-10 for each set of comparable sized objects. Measure and record results on datasheet.

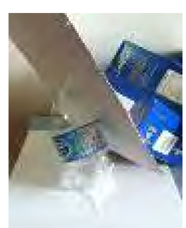
Observations:

Sample pictures of tension tests:




Sample pictures of compression tests:



The following table illustrates sample results for the tensile and compression tests using the suggested materials. In summary, the paper plate, paper bag and licorice are stronger materials when tension is applied. The paper cup, aluminum soda can and sponge are stronger materials when they are compressed.

Test	Material	Force at failure (N)	Physical Changes	Material	Force at failure (N)	Physical Changes
Tension Test A	styrofoam plate	35 N	no change at first then rips apart	paper plate	50 N +	no change
Tension Test B	one handle of paper bag	50 N +	some bending of handle but does not fail	one handle of plastic bag	40 N	handle stretches, deforms and then snaps
Tension Test C	licorice	45 N	stretches, deforms permanently	gummy worm	10 N	stretches then snaps
Compression Test A	paper cup	45 N	no change at first, then slight collapse	plastic cup	20 N	crumpled in centre
Compression Test B	plastic water bottle	25 N	no change and then collapses on bottom half	aluminum soda can	50 N +	no change
Compression Test C	kitchen sponge	20 N	Temporarily deforms, retains shape	large marsh-mallows	10 N	flattens out, mostly permanently

Discussion:
Discuss with students their results for the simplified tension and compression tests. Were their predictions correct? What surprised them? For example, perhaps they were surprised that the styrofoam failed before the paper plate, that licorice is pretty strong, or perhaps that the water bottle does not support as much force as a metal can.

When comparing similar objects with different material, which one had more tensile and compressive strength? If they were hosting a picnic would they buy paper or Styrofoam plates for the meal? What kind of plates would they buy for dessert? What kind of candy might be easier for your teeth and jaws?

Discuss their observations of how different materials fail (snap/buckle) or deform? Their observations during the tensile test may be that the styrofoam plate ripped whereas the plastic bag slowly deformed. During the compression test, the plastic bottle and cup crumpled and stayed deformed whereas the sponge was elastic and the mass was removed, it returned to its original state.

Extension:
Ask students to bring in different household materials of similar sizes to test and compare – e.g. different types of cardboard/boxboard boxes, chalk vs crayon, nylon vs sock, etc.

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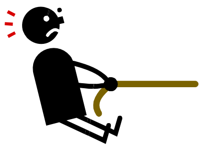
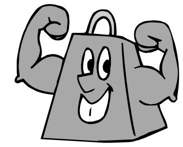


Check Out Those Internal Forces!



Tension test

Material	Predict (✓ or X)	Force at failure (N)	Physical Changes	Material	Predict (✓ or X)	Force at failure (N)	Physical Changes
styrofoam plate				paper plate			
one handle of paper bag				one handle of plastic bag			
licorice				gummy worm			

Compression test

Material	Predict (✓ or X)	Force at failure (N)	Physical Changes	Material	Predict (✓ or X)	Force at failure (N)	Physical Changes
paper cup				plastic cup			
plastic water bottle				metal soda can			
kitchen sponge				large marsh-mallows			

Activity 3: Dome for a Home!

Time: 60-90 minutes

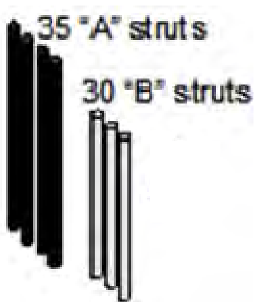
Other Applications: Math, Art, Language

Key Terms: triangulation, tension, compression, forces

Group Size: 4-6 students

Materials per group:

- ☐ 30 one colour of straw (non-flexible) per group (colour A)
- ☐ 35 a second colour of straw (non-flexible) per group (colour B)
- ☐ 31 pipe cleaners
- ☐ measuring tape or ruler
- ☐ scissors

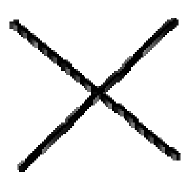


Learning Goal: Students will learn about the strength of triangles by building a geodesic dome structure.

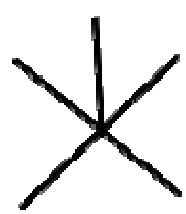
A dome is one of the strongest types of structures. They are curved in nature, have no angles or corners and do not need any columns for support. They have been used in many ancient civilizations. A notable structure is the Roman Pantheon that was built in 100 AD, still stands today and is the world's largest unreinforced concrete dome. Many of these ancient stone domes were built using the concept of arches however engineers realized they were too heavy. A triangle is the only polygon that holds its shape and therefore triangulation is useful for structural stability. In the 1950's, the geodesic dome was designed from triangles of lightweight materials.

Procedure:

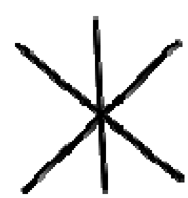
1. Provide student groups with sufficient straws, pipe cleaners, rulers and scissors. The straws represent the struts of the structure and the pipe cleaners represent the connectors. Suggest the groups organize tasks such as measuring straws, cutting, labeling, constructing connectors, etc.
2. Cut 35 straws of colour A so they are 18.5 cm long.
3. Cut 30 straws of colour B so they are 16.4 cm long.
4. Cut 31 pipe cleaners (that are 30 cm in length) into 2 x 12 cm with 6 cm leftover.
5. Twist 2 pieces of 12 cm pipe cleaners in the centre to create a 4–way connector. Repeat step to make 10 4-way connectors.
6. Twist 2 pieces of 12 cm pipe cleaners in the centre to create a 4-way connector and then add on a leftover 6 cm piece of pipe cleaner at the centre to create a 5-way connector. Repeat step to make 6 5-way connectors.
7. Twist 3 pieces of 12 cm pipe cleaners at the centre to create a 6-way connector. Repeat step to make 10 6-way connectors.



10 pieces of
4-way connectors



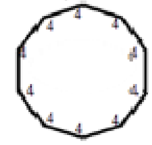
6 pieces of
5-way connectors



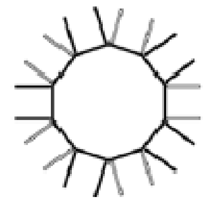
10 pieces of
6-way connectors

Numbers represent connectors.
Dark lines represent colour A.
Light lines represent colour B.

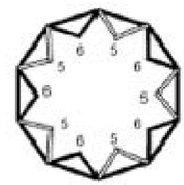
8. Create the base of the dome by using all 10 of the 4-way connectors to attach 10 colour A straws together. There should be 2 pieces of each connector left up in the air to attach on the next layer of the dome.



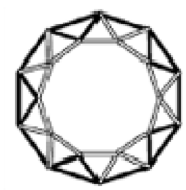
9. Starting at one connector, attach a colour A straw to one of the pieces of each 4-way connector. Attach a colour B straw to the remaining piece of the 4-way connector. Move to the next connector and add a B straw, then an A straw. Continue this pattern AB, BA, AB, BA, etc. until all the connectors have a straw piece on them.



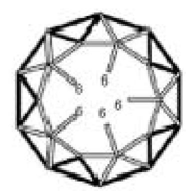
10. Using a 5-way connector, attach 2 adjacent A straws together to make a triangle shape. Repeat for 4 more sets of A straws and 5-way connectors. Using a 6-way connector, attach 2 adjacent B straws to make a triangle shape. Repeat for 4 more sets of B straws and 6-way connectors.



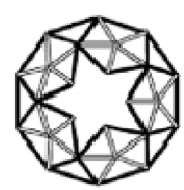
11. Use 2 pieces from each connector and attach 10 colour B straws to connect the triangles. There should be 1 piece available on top of the A-A triangles and 2 pieces available on top of the B-B triangles from each connector left for the next layer of the dome.



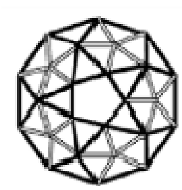
12. Add 5 colour B straws to the connectors where only 1 piece is available (the A-A triangle). On the other end of these straws, add 5 of the 6-way connectors, leaving 5 pieces on the connector available to use.



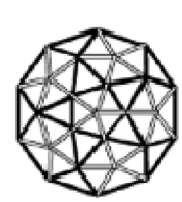
13. Attach 2 colour A straws onto the connectors that have 2 pieces available (the B-B triangle), and use the 6-way connector to secure the other end. Repeat for 4 more sets of 2 colour A straws, making a star shape.



14. Attach 5 colour A straws on the connectors leaving 1 piece on the 6-way connector available. This creates a pentagon shape at the top of the dome.



15. Seal the dome by placing 5 colour B straws onto the pieces of the connector and closing the top using the last 5–way connector.



Discussion

Some suggestions for questions to lead a discussion about their dome construction or for further research are provided below.

- Did they assign tasks to each member?
- Did they encounter any difficulties such as measurements or following the instructions?
- Where do they see domes in use? Some examples include Epcot in Disney, Cinesphere IMAX theatre in Ontario Place as well as some playground structures are open geodesic dome structures. Domes were used in ancient times and many are still standing such as the Pantheon in Rome.
- What properties do domes have that are unique? Dome structures have no corners and they are round or spherical.
- What makes them strong and efficient? Domes are strong and use less material which reduces the building cost. Domes have 30% less surface area which also results in less heating and cooling requirements then conventional rectangular buildings.
- What is a geodesic dome? What shape do they see within the geodesic dome structure that offers strong support? The dome is made up of many triangles. The triangular elements distribute the stress over the structure making it more rigid.
- What are some internal and external forces that affect structures? Gravity, wind and snow. Imagine these forces impacting the dome. What would happen to the dome structure compared to a rectangle structure? The spherical shape makes it hurricane resistant as there are no corners to cause turbulence in the air.
- How do the materials used in dome structures today differ from ancient domes? Ancient domes were made of materials such as stone, concrete and wood. Modern geodesic domes can be made of aluminum, wood, glass and plastic.
- Why are there not more dome structures in use today? They are complicated structures to build and this leads to high construction costs. It is difficult to waterproof a dome structure. Logistically, it is difficult to create rooms within the curved structure.

Extensions

1. Two other options for creating domes are provided below and the projects are dependent on the group size and materials available.
    a. For group sizes of 2-3 students, a smaller geodesic dome can be similarly created with pipe cleaners and straws. The finished size of the dome is 25cm. For this dome structure, follow the instructions provided above. Cut the colour A straws to a finished length of 6.2cm. Cut the colour B straws to a finished length of 5.5cm. Cut the pipe cleaner pieces to be used to create the connectors to a length of 4 cm (such that each arm is approximately 2 cm long).
    b. The entire class can create a large geodesic dome made from newspaper and magazines, staples and tape. The struts are created by rolling up newspaper and they are joined together with tape instead of connectors. The finished dome size is approximately 200 cm. The website http://www.pbs.org/wgbh/buildingbig/educator/act_geodesic_ho.html (19/08/15) provides detailed instructions.
2. Compare the strength of the geodesic dome to a cube. Build a 12 cm x 12 cm x 12 cm cube using straws and 3-way pipe cleaner connectors. The joints of the geodesic dome and cube can be strengthened using either tape or glue. Place weights (magazines or mass on top of piece of cardboard (e.g. 2 hockey pucks or approximately 320 g) and compare how much the structures can hold and how the structure looks after the mass is removed. The geodesic dome can support the weight whereas the cube becomes deformed. How can the cube be strengthened? If the cube is made with 4-way connectors then an extra brace can be added which would create triangles.

Activity 4: Building the Pyramids!

Time: 60-90 minutes

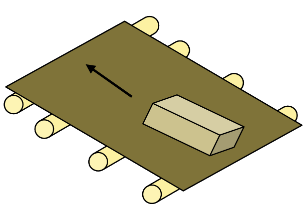
Other Applications: Social Studies, Math, Language

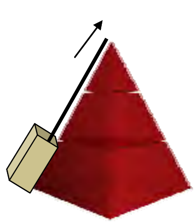
Key Terms: mechanical systems, sledge, inclined plane, load, gravity

Group Size: Small groups (2-4 students)

Materials per group:

- ☐ copy of datasheet "Building the Pyramids!" per student (included)
- ☐ 5 pencils
- ☐ clay (500 g block)
- ☐ Newton spring scale (5N)
- ☐ Cotton, sisal or synthetic household twine for 'rope'
- ☐ sandpaper sheet (any grit from 40-120)
- ☐ 20 cm x 20 cm cardboard
- ☐ books (at least 10 cm in height)
- ☐ protractor
- ☐ ruler





Learning Goal: Students will learn how mechanical systems can help reduce the amount of force required to perform work. They will pretend to build Egyptian pyramids and compare the work of building by hand to the work using different mechanical systems such as wheels and an inclined plane.

Simple machines that Egyptians may have used to move large stones to build pyramids include:

a. rollers/sledges (like a sled with rollers underneath) that would help to reduce the force needed to transport stones to the building site;

b. inclined planes that would decrease the force required to lift stones up to higher levels.

Procedure:

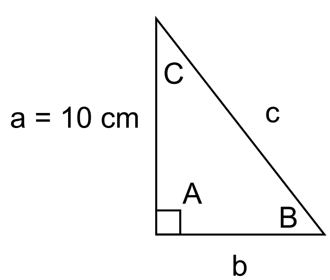
1. Hand out copies of the datasheet "Building the Pyramids!".
2. Review how to calculate work and the different simple machines used to help reduce work. Take a vote and predict which type of simple machine will reduce the workload the most and the least.
3. Provide groups with a 500g piece of dried clay to simulate a stone that would be used to build the pyramids. Provide a rope long enough to tie around the "stone".
4. Attach the rope to a Newton spring scale. Measure and record how much force it takes to drag the "stone" across sandpaper for 10 cm (to simulate the desert in Egypt).
5. Have students create a simple machine to move the stone across the desert. One idea may be to create a sledge using pencils and cardboard piece. Assist where required by suggesting that a sledge could be made by laying 5 pencils on the desk (to simulate rollers) and placing a piece of cardboard on top. Ensure that the pencils are evenly spaced under the cardboard. Attach the spring scale to the "stone" and place it on the cardboard. Measure and record how much force it takes to pull the "stone" 10 cm using rollers/wheels. Calculate the workload for moving the stone with/without simple machines.
6. With the stone attached to the spring scale, measure and record how much force is required to lift the stone 10 cm high.
7. Have students create a simple machine to move the stone up the pyramid using books and a piece of cardboard. One idea may be to stack books so they are 10 cm high and lay cardboard against them on an incline. Adjust the incline angle using a protractor so that the angle is 51 degrees, which simulates the great pyramids. Lay the "stone" at the bottom of the inclined plane and measure how much force it takes to pull the "stone" up to the height of 10 cm. Also measure and record the distance the "stone" had to travel to reach 10 cm high. Calculate the workload for moving the stone with and without simple machines.

Observations
The following chart show some sample measurements and calculations.

	Force (N)	X	Distance traveled(m)	=	Work done (N m) or (J)
Moving “stone” across the desert	3.5 N	X	0.1	=	0.35 J
Moving “stone” across the desert on rollers / sledge	0.5 N	x	0.1 m	=	0.05 J
Lifting the “stone” up	5.0 N	X	0.1	=	0.5 J
Lifting the “stone” up using inclined plane	4 N	x	0.129 m	=	0.516 J

Discussion
Discuss with students their observations and calculations. The following questions may assist in leading the discussion:

- How is work related to the force it takes to move the stone and distance it travels? Work is the amount of force it takes to move the stone a certain distance. W = F x d.
- Did the simple machines reduce the workload to move the “stone”? If so, why did they help? The sledge helped reduce the force needed to move the stone by reducing the friction with sand and utilizing rollers to help move the stone.
- Why use an inclined plane if the workload did not decrease? The inclined plane helped make the job easier to lift the stone by using 2 smaller forces - up and forward. The overall workload was about the same but the force to move the stone was less as the stone moved over a longer distance.
- If you couldn’t measure the distance a stone travels on an inclined plane, is there an alternative way to calculate the distance the stone traveled to reach a height of 10 cm? The known parameters are a = 10 cm, A = 90^o and B = 51^o. The unknown parameter is c = distance stone travels on inclined plane. Students can draw then measure this triangle. When drawing the triangle, a = 10 cm and they can calculate the angle of C = 90^o – 51^o = 39^o. Once they draw the line c at 39^o, they can then draw the base of the triangle (b) at a 90^o angle from (a). At this point, the distance traveled (c) can be measured.

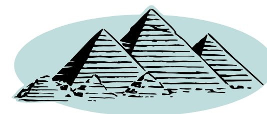


Fun Fact: Ancient Romans were great engineers!

They engineered strong long lasting structures such as bridges, aqueducts and roads that are still standing today. Romans developed concrete which is a stronger composite material consisting of limestone and rocks. Volcanic ash was added to concrete to make it fast drying and waterproof. This allowed it to be used underwater!

Name: ______________________

Building the Pyramids!



	Force (N)	X	Distance traveled (m)	=	Work done (N m) or (J)
Moving "stone" across the desert		X	0.1	=	
Moving "stone" across the desert on rollers / sledge		X	0.1	=	
Lifting the "stone" up		X		=	
Lifting the "stone" up using inclined plane		X		=	

<u>Sample Calculation for Work:</u>

Work = Force x Distance or **W = F x d** measured in Newton metres (N m) or Joules (J)
If it takes 5N of force to lift a stone 10 cm, therefore
W = 5 x 0.1 m = 0.5 J

Activity 5: Do as the Romans did, or Not!

Time: 60-90 minutes

Other Applications: Art, Social Studies, Language

Key Terms: load, external forces, environment, gravity

Group Size: Pairs

Materials:

- ☐ copy of "Do as the Romans did, or Not!" datasheet per student

Materials for Ancient Aqueduct per group:

- ☐ 2 blocks of clay (2 x 500g)
- ☐ 2-4 plastic drinking cups
- ☐ 50 cm x 100 cm cardboard for base
- ☐ cutting tool for clay (such as a ruler or plastic knife)

Materials for Modern Aqueduct per group:

- ☐ 40 – 80 cm of 1-1.5" diameter clear vinyl plastic tubing
- ☐ funnel
- ☐ pieces of cardboard to be cut or folded at varying heights to represent support columns
- ☐ paper towel/toilet paper rolls to support tubing (can cut groove in them)
- ☐ 50 cm x 100 cm cardboard for base
- ☐ tape & scissors

Materials for Testing:

- ☐ 2 empty plastic cups
- ☐ water

Learning Goal: Students will build and compare modern and ancient aqueduct systems.

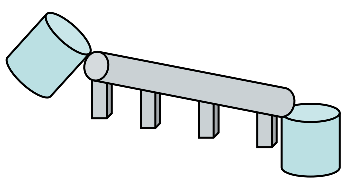
An aqueduct is a bridge used to move water over an obstacle. The Romans refined aqueduct construction to supply water to their cities. They created aqueducts from different materials (either masonry or concrete) and utilized the force of gravity and arches to transport fresh water from the mountains. Today, similar aqueduct systems are used however the materials and design are different.

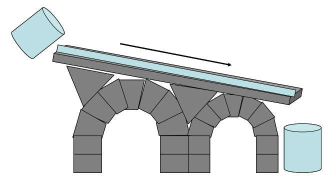
Procedure:

1. Divide the class in half such that one half will make a model that simulates an ancient Roman aqueduct and the other half will simulate a modern aqueduct.
2. Hand out a copy of "Do as the Romans did, or Not!" datasheet per student. Ask students to work in pairs and research and study how aqueducts are made, materials used and the architectural design(s) of them. Complete the research datasheet and sketch a design for their aqueduct.
3. For the groups building an ancient Roman aqueduct, provide them with 2 blocks of clay (500g each), cutting tools, piece of cardboard to build on and small cups to represent rock support columns.
4. For groups building a modern aqueduct, provide them with plastic tubing, funnel (for top of tubing), cups, cardboard to build on, scissors and tape.
5. An optional challenge to offer the students is to create an aqueduct through a mountain. Provide the students with a shoebox to represent the mountain. Tunnels, using paper towel rolls as support, can be built through the shoe box. Connect their aqueducts through the mountain to the other end ensuring both ends are accessible.
6. Check each group to ensure the aqueducts will allow water to flow down by the force of gravity. If required, ask students to adjust to make sure their aqueducts will be effective before they set.
7. Let the aqueducts dry overnight.
8. The following day have the students test their aqueducts. Take a small cup and place it under the lower end of the aqueduct.
9. Fill another cup with water and test their aqueducts by pouring water slowly from the higher end of the trough and ensuring water ends up in the other cup at the lower end of the trough. Did all of the water move through? What is the flow of water – fast or slow? How could the design be improved?
10. Complete the datasheet. Have each group or at least one group from ancient and modern day aqueducts present their findings.

Discussion:
Discuss how the aqueducts work and what makes the water flow. In ancient times, aqueducts were developed to move water from the mountains to their cities by using the force of gravity. How could the aqueducts continue through mountains? They used another important structural design by building tunnels.

What materials did the ancient Romans use to build aqueducts? They constructed aqueducts using concrete, masonry and bricks in raised arches. What do modern day aqueducts look like today? Today aqueducts are built using pipelines made of steel. How are they the same or different than the ancient Romans? Aqueducts are similar as both styles use gravity to move water and tunnels to transport through mountains. The world's largest aqueduct is the Thirlmere Aqueduct in North West England, which is 155 km long, and it was built between 1890 and 1925. It consists of pipes, streams, tunnels, dams and aqueducts.





Extension:
As an art extension, ask students to decorate their design with scenery that would depict either an ancient civilization (e.g. adobe homes, trees, stone roadways) or modern era (e.g. skyscrapers, buildings and cars).

Fun Fact: Combine it for the better!

The first composite material, two or more materials combined to make an even better material, was made in 1500 BC by the Egyptians. They combined mud and straw, called the adobe brick, and created a material that was much stronger then just mud alone. These days we see composite materials in construction all the time, e.g. reinforced concrete (concrete and steel bars) and plywood (layers of wood fibres laid in different directions).

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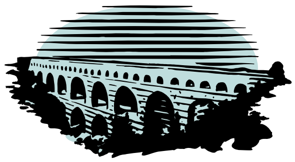
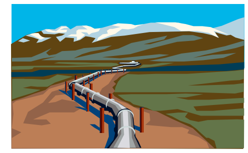


Do as the Romans did, or Not!!



Your aqueduct (circle):   Ancient   Modern

Research Notes	
Why build aqueducts?	
What materials are used to build an aqueduct?	
What are some factors to consider in the design of an aqueduct?	
Sketch Your Aqueduct Design	
Test Your Design **What happened?** **Suggest Ideas for Improvement**	

Literary Resources

Megastructures. Ian Graham. 2012. Firefly Books. ISBN 978-1-77085-111-5. A book on all types of structures.

Pyramids! Avery Hart &Paul Mantell. 1997. Williamson Publishing. ISBN 1-885593-10-4. A book with activities related to ancient Egypt.

Website Resources

http://www.physics4kids.com/files/motion_intro.html *(19/08/15)*
A comprehensive website on motion including forces, Newtons laws of motion and gravity.

https://www.pbslearningmedia.org/collection/forces-and-energy/#.X9qFz3qSIPY
A large selection of experiments (e.g. making a birds nest, standing on cups, columns, building tower with cups and marshmallows, etc.).

http://www.teachersdomain.org/resource/phy03.sci.phys.mfw.lp_shapes/ (*19/08/15)*
Experiments on shapes that make structures strong (tension and compression).

http://www.byexample.com/projects/current/dome_construction *(19/08/15)*
A comprehensive website on building geodesic domes.

http://www.civilisations.ca/cmc/exhibitions/civil/egypt/egca01e.shtml *(19/08/15)*
Review of ancient Egyptian architecture.

http://www.essential-humanities.net/western-art/western-architecture/roman-architecture/#.Uh5-jX_ueSo *(19/08/15)*
Review of ancient Roman architecture.

Multi-media

http://www.youtube.com/watch?v=35Atgmoz9R0 8:07 min *(19/08/15)*
http://www.youtube.com/watch?v=cDrjr0Pwrws 9:05 min *(19/08/15)*
Two complimentary teacher resource videos on forces acting on structures.

Student Resources

Literary Resources

Earth Friendly Buildings, Bridges and more. Etta Kaner. 2012. Kids Can Press Ltd. ISBN 978-1-55453-570-5. A book that reviews foundations, bridges, tunnels, domes, dams.

Building Amazing Structures series (Skyscrapers, Bridges, Dams, Tunnels). Chris Oxlade. 2000. Heinneman Library. A series of books on how to build different structures.

Amazing Built Structures. Nicolas Brasch. 2010. MacMillan Library. ISBN -9781420268997. A book on technology used to build well known structures around the world.

Inclined Planes – Science Matters. Jennifer Howse. 2010. Weigl Publishing Inc. ISBN 978-1-60596-035-7. A book on using inclined planes.

Bridges and Tunnels – Investigate feats of engineering. Donna Latham. 2012. Nomad Press. ISBN 978-1-936749-52-2. A book on engineering bridges and tunnels.

Ancient Rome! Avery Hart & Sandra Gallagher. 2002. Williamson Publishing. ISBN 1-885593-60-0. Reviews ancient Roman culture, architecture, empire.

Canals and Aqueducts – Smart Structures. Julie Richards. 2004. Smart Apple Media. ISBN 1-58340-347-7. A book reviewing aqueducts and canals.

Interactive Websites

http://www.sciencekids.co.nz/gamesactivities/materialproperties.html *(19/08/15)*
An interactive game to testing different materials.

http://www.pbs.org/wgbh/buildingbig/lab *(19/08/15)*
Test out different materials, shapes, forces, loads and discover their effect on structures.

http://www.sciencekids.co.nz/pictures/structures.html *(19/08/15)*
Pictures and information of famous structures around the world.

http://www.pbs.org/wgbh/buildingbig/bridge/index.html *(19/08/15)*
PBS website on different bridges, tunnels, dams, domes.

“Fat Birds Build a Bridge!” *(10/11/13)*
An interesting puzzle game App for Ipad/Ipod for building and testing bridges.

“Link!” *(10/11/13)*
A game App for Ipad/Ipod that uses principles of civil engineering to create stable structures.

“Bridge Constructor Playground” *(10/11/13)*
A game App for Ipad/Ipod for building bridges.

References
In addition to resources listed above, the following websites were also used to develop this package:
http://www.instron.us/wa/home/default_en.aspx *(10/11/13)*; http://www.desertdomes.com/dome2calc.html *(10/11/13)*.

SCIENTISTS IN SCHOOL SCIENTIFIQUES À L'ÉCOLE | Get kids excited about science

Science Education Through Partnership

Scientists in School is a leading science education charity that reaches more Kindergarten to Grade 8 youth than any other science non-profit in Canada – more than 700,000 in the 2018-19 school year.

Through our hands-on, inquiry-based science, technology, engineering, math (STEM) and environmental classroom and community workshops, we strive to ignite scientific curiosity in children so that they question intelligently; learn through discovery; connect scientific knowledge to their world; get excited about science, technology, engineering and math; and have their interest in careers in those fields piqued.

By making science a verb - something you do - our workshops allow children's natural curiosity to reign, inspire kids to see themselves as scientists and engineers, and make connections between science and the world around them. This sets the stage for a scientifically-literate future generation who will fuel Canada's economic prosperity and think critically about the scientific challenges facing our society.

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The McLean Foundation, The Saint John's School Legacy Foundation, Xerox Canada

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Community Foundation of Lethbridge & Southern Alberta, Dwight & Karen Brown Family Fund: Ottawa Community Foundation,
Guelph Community Foundation, LabX Media Group Charity Fund at the Huronia Community Foundation, Municipality of Clarington,
Perth and District Community Foundation, Scarborough Garden and Horticultural Society,
Society of Petroleum Engineers Canadian Educational Foundation, South Bruce Community Liaison Committee,
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