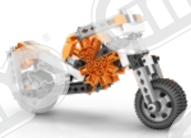
STEM Simple Machines Set

E96.1 THEORY

This set is covers the subject of Simple Machines in an encompassing and fascinating way. These mechanisms offer a mechanical advantage and are crucial elements of many machines and devices. They are designed to multiply or reduce force, increase or decrease speed and convert one type of motion to another. The set includes enough parts to create 60 working models that cover the subjects of levers, the wedge, the wheel and axle, the screw, the inclined plane, the pulley, as well as the more advanced gears and linkages! You can find easy-to-follow building digital instructions for all models along with detailed explanations of the different scientific principles applied. The methodology suggested combines theory with innovative experimental activities that lead to hands-on learning and engineering creativity.

Including Themes:


Engino® EDUCATION

9-12+

Edition: 05/23

Levers & Linkages

What we will learn

I guess you have already been to the playground with your friends and played on the see-saw game! Have you ever wondered how did your light friend manage to lift a heavier kid without a problem? Different types of machines and mechanical systems are all around us today. From a simple clock to a complex rocket, every machine uses energy to perform a certain task. These devices need to be energy efficient and this is made possible with the help of levers and other simple machines. In order to transfer this energy to different parts of a machine and change their motion we can connect many levers together. In this way we create series of levers called "linkages", which are very important in machine design and functionality.

The seesaw works on the principle of levers

This booklet of **Discovering STEM: Levers & Linkages** contains a comprehensive **theoretical section** with building challenges and interesting facts, so that you learn all about their applications in daily life. Discover all the scientific principles applied through **experimentation**, with step-by-step guides and thought provoking exercises. Follow the **building instructions** to build exciting models such as **a see-saw, a movable weight scale, a wheelbarrow, a parking gate, a toy with moving figures, a pantograph, Peaucelier-Lipkin and Hart linkages**. A lot more models are available online! Finally, take the revision quiz to test your newly acquired knowledge.

Pyramids in Egypt

History of levers and linkages

In prehistoric ages, levers were possibly the first tools used by man for moving large objects. During the construction of the Great Pyramid of Giza (about 2500 BC) the builders used "casing stones" (cut blocks of limestone) which weighed 2.5 tons each. In order to move these gigantic blocks, as there weren't any cranes around, ancient tools and methods were used: ramps, slides, boats, ropes and of course levers. The ancient Greek historian Herodotus mentioned that over 100,000 people (slaves) worked on the pyramid's construction for a period of more than 20 years.

Levers are described for the first time in around 260 BC by the ancient Greek mathematician Archimedes. Pappus of Alexandria mentions that Archimedes (287-212 BC) said the following phrase, expressing the mathematical principle that describes the functionality of levers: "Give me a place to stand on and I will move the Earth". The catapult used in ancient times and the trebuchet used in the medieval times also worked on the principle of levers. The latter was a siege engine that utilized gravity to launch projectiles at enemies by placing a large weight on the short end of the trebuchet's lever arm (acting as a counterweight) and then letting it fall.

Models of medieval trebuchets

A steam engine

Many scientists have been working on the development and practical usage of linkages over the last 200 years. During this period many problems, such as how to create a perfectly straight line with mechanical means were solved. New linkage inventions were essential in cloth making, power conversion and speed regulation. They were also used in many applications such as mechanical computation, typewriting and machining. These applications are the precursor of modern machines and many of them have now been digitalised and replaced by electronic technology.

Did you know?

The Watt's linkage is used in the rear axle of some car suspensions to prevent relative sideways motion between the axle and the body of the car. It consists of two horizontal rods of equal length mounted at each side of the chassis. In between these two rods, a short vertical bar is connected, which moves in an almost straight line. This linkage design is an improvement of the Panhard rod, because it dramatically reduces the sideways component of the axle.

Engino® "Watt's linkage" model

As far as linkages are concerned, even though they are used in almost any machine now, they were not well understood until the 18th century. The Industrial Revolution (between the 18th and the 19th century) proved to be the golden age for the development of linkages. During that time, the Swiss mathematician Leonhard Euler (1707-1783) made the first efforts for understanding linkage synthesis. But it wasn't until James Watt (1736-1819), a Scottish mechanical engineer, started working on the improvement of the Newcomen steam engine, that linkages gained a practical importance. In his double-acting engine he developed a parallel linkage ("Watt's linkage") that was able to cause a steam engine piston to move in an almost straight line.

Mechanical typewriter

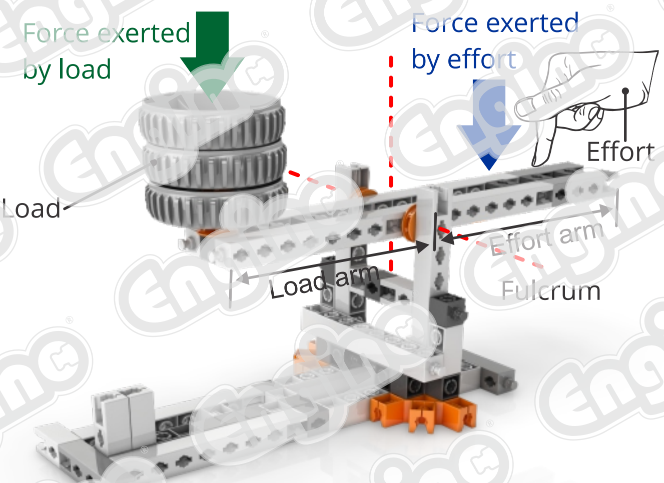
Nowadays, we use levers and linkages quite often in combination with other types of simple machines, making our lives much easier. From complex machines like cranes and cars to the most simple of devices like scissors and nail-clippers, almost everything works on the principle of levers and their connections! Furthermore, modern linkage design continues to advance, and ideas that used to take days for an engineer to complete are now calculated by computers within seconds. Nowadays, linkages are used in many machines in a variety of ways, changing the speed, force and motion of different parts, thus increasing machines' efficiency.

Lever crane

Definition of lever

A lever is a rigid bar (or rod) pivoted about a fixed axis called fulcrum. Take a look at the next picture. The character is using the lever principle in order to move a heavy object, by placing a wooden board under a small rock. The small rock acts as the **fulcrum** (or pivot), the large object that he is trying to move is the **load**, while the force he applies to move the object is called **effort**. The distance from the fulcrum to the point where the effort is applied is called **effort arm** and the distance from the fulcrum to the load is called **load arm**. You can see all these elements below, as they are applied on an Engino construction.

Archimedes is using a lever to move a boulder!



Elements of a lever

Classes of levers

There are **three classes of levers** and each class depends on the position of the effort (the force we apply), the position of the fulcrum and the position of the load. We are going to learn about each one in the pages that follow.

A linkage is the combination of two or more levers of the same or different class. These are connected together in order to create a mechanism, which can be used for transferring force or motion from one point to another.

Double levers

Two levers can be joined together and make a double lever. Scissors and nutcrackers are examples of such levers. The two lever arms are connected together by a joint, allowing the arms to swivel. In other words, a double lever is considered as a simple form of linkage.

Nutcracker (double)

Pliers (double)

Physical laws

Moment

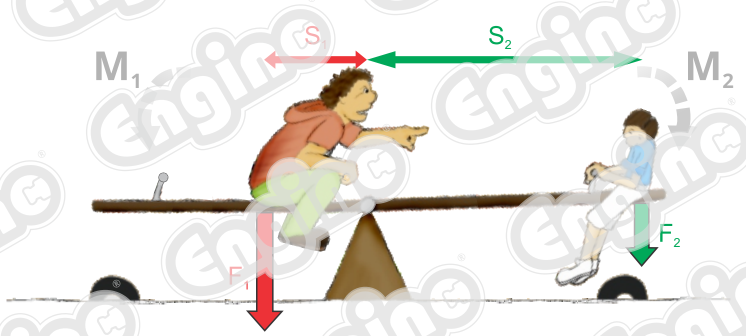
Now, that we know what a lever looks like, let's see how it works. When we apply a force on a lever away from the fulcrum we get a rotating effect which is called **moment** (M). This rotating effect is the product of the force (F) applied on the lever and the distance (S) between the force and the fulcrum measured in newton metres (Nm).

$$M = F \times S$$

Formula for moment (M)

"Moment" is a synonym for "torque", which is a basic concept in Physics and Engineering. Even though both terms express the same rotating effect, engineers use the terms according to the particular application. For example "torque" is usually used to describe a rotational force like a turning screw-driver, while "moment" is often used to describe a bending force on a beam.

Here is an example of this principle with a boy and a girl playing on a see-saw game. The boy (applying force F_1) is heavier than the little girl (F_2). In order to achieve balance, he sits closer to the center of the see-saw (fulcrum), at a distance S_1, while the girl sits at the edge of see-saw, Both the effort and the load are forces applied on a lever. Therefore, we have two moments: the anticlockwise moment caused by the effort and the clockwise moment caused by the load, at a longer distance S_2.



$$M_1 = M_2 \Rightarrow F_1 \times S_1 = F_2 \times S_2$$

Balance of moments: the left-side moment is equal to the right-side moment

When the lever is in balance (not moving) the anticlockwise (left-side) moment is equal to the (right-side) clockwise torque ($M_1 = M_2$). Subsequently, the left product $F_1 \times S_1$ is equal to the right product $F_2 \times S_2$. This formula expresses the basic principle of levers and is called **balance of moments**.

Mechanical Advantage (M.A.)

Levers belong in the category of **simple machines**. The ability of a simple machine to output a greater force than the input is called **mechanical advantage** (M.A.). This is calculated by dividing the value of the load to the value of the effort and is measured in pure numbers.

$$M.A. = \frac{Load}{Effort}$$

Formula for mechanical advantage

Did you know?

The ancient Egyptians used an innovative version of a lever crane to carry water from rivers to their canals. On one end of a large beam they attached a bucket and on the other they put a counterweight. After the water is lifted, the pole is moved to the other side, so that the water is purred into a channel. It was estimated that one person could lift 2,500 liters of water a day. Without the use of a lever, a person alone wouldn't be able to lift as much water.

Egyptian version of a lever crane

Velocity Ratio (V.R.)

Levers make our lives much easier by changing the way we work. Specifically, levers reduce to a great extent the amount of effort we need to move a load or complete a difficult task. This may create the notion that we gain something out of nothing. Can this be true? Unfortunately not, because as the saying goes "no pain no gain"!

If we observe more closely we will realize that even though a lever may reduce the applied effort, at the same time it increases the distance needed for us to apply the effort. This distance is much bigger than the traveling distance of the load. If we compare the two distances we get the velocity ratio (V.R.). In simple words, the V.R. formula (seen below) states that in order to lift a load 2 times bigger than the effort applied, the effort must cover a distance 2 times bigger than the load.

$$V.R. = \frac{Effort's\ distance}{Load's\ distance}$$

Formula for velocity ratio

First-class lever

This is the most common and simple type of lever, in which the support point lies between the two ends. The fulcrum is placed in the middle, while the input effort is on one arm and the output load on the other. You can see all these elements in the next figure. The mechanical advantage of the lever depends on both the distance of the load to the fulcrum and the effort to the fulcrum on the other side (load arm and effort arm). The closer the load is to the fulcrum, or the longer we apply our effort from the fulcrum, the more mechanical advantage is gained.

In the following images you can see some examples of first-class levers. Take a look at the pictures and try to identify where the load, effort and fulcrum are applied in each case.

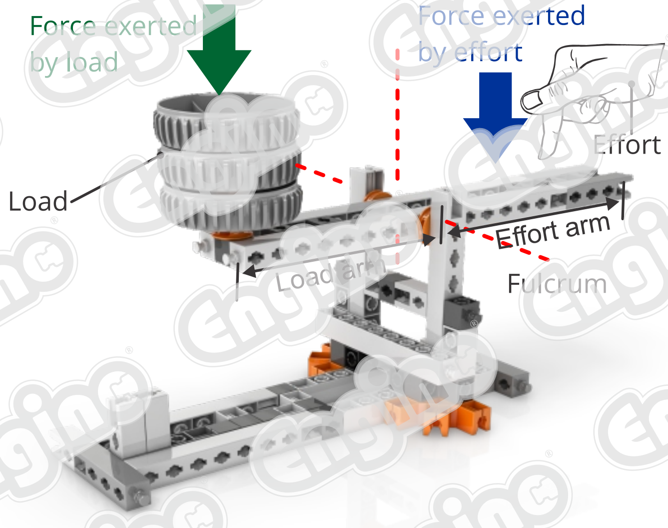


Diagram of first-class lever

Claw hammer

Scissors (double)

Pliers (double)

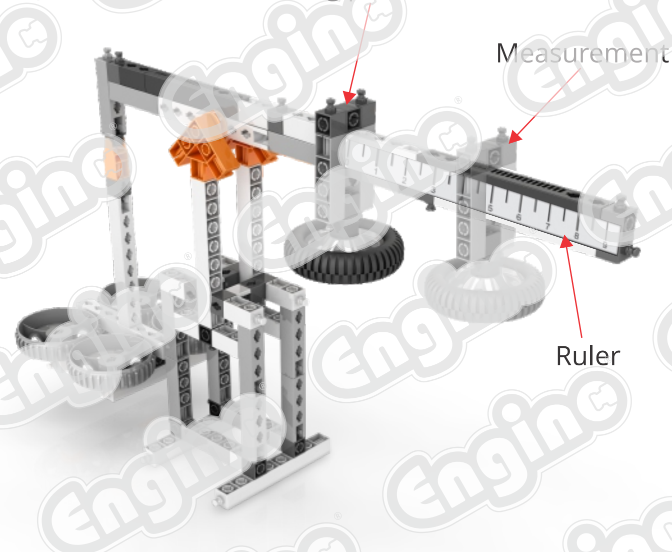
Building Challenge — instructions can be found online

Movable weight scale: you can create your own fairly accurate scale with your Engino model! First, balance the beam without any weight. This is the starting point (zero) and it should be about 7 squares from the fulcrum. Then, you will need a small object that you know its exact weight e.g. 100gr. Place it on the loading base and count the squares you need to balance the beam e.g. two more squares after your starting point. Attach a piece of paper on your scale and make a mark at the point of your reference weight.

Then create a ruler by dividing your piece of paper in equal spaces, marking each length according to your previous measurement. In our example, the first square from the starting position would be 100gr, the second 200gr, the third 300gr and so on. You can then divide these in smaller distances for more accuracy.

To use it simply place an unknown weight and balance the scale with the moving part. The indication on the ruler will be the weight of the object.

Build the movable weight scale model and follow the procedure above on how to measure the weight of small objects!



Engino® "movable weight scale" model

Building Challenge

instructions can be found online

Letter scale: a letter scale is a weight measuring device used for weighing relatively light objects. This type of scale is designed to be very accurate, as it is capable of measuring the slightest change in the weight of an object.

For that reason, the letter scale is used mainly in post offices for measuring the weight of envelopes, small packages or other objects.

Errors in accuracy scales: sometimes mechanical accuracy scales show errors when measuring weights. This is caused mainly by the friction between the different parts, which prevent it from balancing correctly. Errors can also be caused by the following:

- the air of the item is measured as well;
- temperature causes expansion or contraction;
- error in reference weight;
- misallignment over time;
- vibrations and seismic disturbances.

Letter scale

Engino® "letter scale" model

You can create your own Engino letter scale by following the building instructions found online. Use your scale to weigh different light objects, once you create a measuring ruler. Place some light objects on the scale (wheel) and trace the upward movement of the other end with a pencil on a piece of paper. You should end up with an arc shape (part of circle).

Mark the starting position where the scale is balancing without any weight. Place a small item of known weight on your scale and mark the position on the arc. Then create a ruler by dividing the arc in equal distances according to the known weight.

Building Challenge

instructions can be found online

Lever crane: a lever crane is a lifting device that is used mainly in ports for long shoring or in construction sites for moving large and heavy objects. Cranes have a large weight on one side, called counterweight, that helps the crane to balance. Otherwise it would tip over because of the weight difference.

Build the Engino lever crane model and try carrying some loads with it in order to test its strength. As you can observe, the crane can carry various objects using the principle of levers. The fulcrum is placed on two pulleys and the load is wrapped around the rope at the end of the crane. The effort is applied on the other end of the crane (in this case we use our hand). For larger objects, you should add more parts creating a bigger counterweight.

Engino® "lever crane" model