Teacher Tune-up

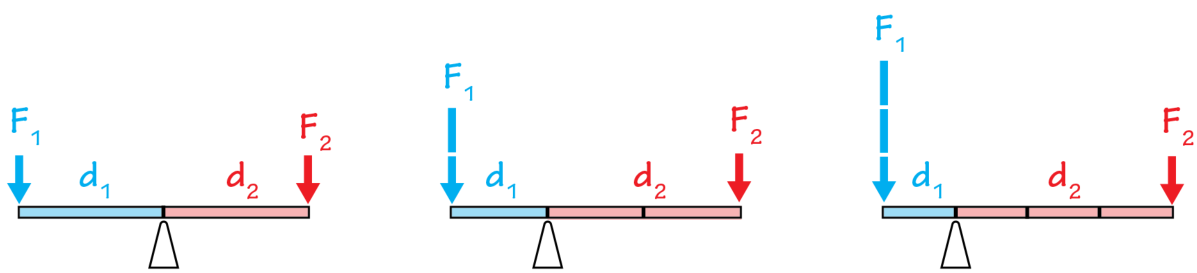
Quick Content Refresher for Busy Professionals

What are the different classes of levers?

The lever is one of six so-called simple machines that change the magnitude and/or direction of forces. (The others are the wheel and axle, the pulley, the wedge, the inclined plane, and the screw.) Every lever has three main features: a fulcrum, an effort, and a load.

- The **fulcrum** is the pivot point.
- The **effort** is sometimes called the input force.
- The **load** is sometimes called the output force, or resistance.

The relative distances between these three parts are crucial in determining the *mechanical advantage* of a lever—whether and how much it multiplies or diminishes force. Mechanical advantage is the ratio of effort to load (input force to output force). To understand how the distances between parts of a lever determine mechanical advantage, consider the images below of three perfectly balanced levers.



Three class 1 levers in balance. *A class 1 lever has its fulcrum between effort and load. The effort and load could be at either end of these levers, depending on whether one wants to multiply or diminish the input force. (The first lever, with equal distances, neither multiplies nor diminishes force; it only changes the direction of the force.)*

These pictures illustrate the fact that the product of force and relative distance from the fulcrum is equal for effort and load: $F_2 \cdot d_2 = F_1 \cdot d_1$. (In these examples, $1 \cdot 1 = 1 \cdot 1$, and $2 \cdot 1 = 1 \cdot 2$, and $3 \cdot 1 = 1 \cdot 3$.) If we divide both sides of the equation by $F_1 \cdot d_2$ then we get $F_2/F_1 = d_1/d_2$. When F_1 is the effort and F_2 is the load, these two ratios are both expressions of mechanical advantage. (Just swap the subscripts on the letters if you want to reverse the efforts and loads; real-world lever systems, like pliers or scissors, often have a common-sense effort end and load end, but mathematically they're reversible.)

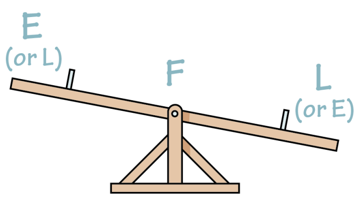
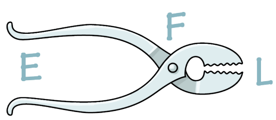
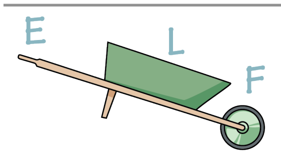
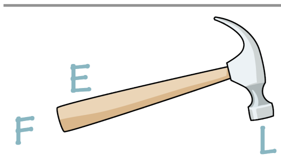
In the third century BCE, Archimedes summed up these relationships in the Law of the Lever: "Magnitudes are in equilibrium at distances reciprocally proportional to their weights." He quipped that he could move the whole earth if he had a place to stand and a long enough lever (presumably with a fulcrum much nearer to the earth than to himself!).

If the lever's ability to multiply force seems like sorcery, a violation of conservation of energy, consider this: since force times distance is equal for effort and load, and work is defined as force times distance, the work that you get out of a lever is equal to the work you put in. So energy (the capacity to do work) is conserved.

This equal input and output of work, while varying the ratios of forces and distances, is common to all six of the simple machines. For example, a system of pulleys that lifts a load one meter for every two meters of rope you pull on doubles the force of your work by cutting the distance in half.

There are three classes of levers, categorized according to the arrangement of fulcrum, effort, and load. The illustrations above show class 1 levers, which have the fulcrum between the effort and the load. Class 1 levers are what we often think of first when we think of levers and leverage. But there are also class 2 levers, where the load is placed between fulcrum and effort; and class 3 levers, where the effort is placed between fulcrum and load. (A mnemonic for remembering which part of a lever goes in the middle for each class of lever is **FLE 123**.)

The table below gives examples of each class of lever.

	Arrangement of fulcrum (F), effort (E), load (L)	*Examples*	*Does the direction change?*	*Mechanical advantage*	*Is effort or distance amplified?*
 In Class 1 levers, the fulcrums are between the effort and the load. Their mechanical advantage depends on where the fulcrum falls between the load and effort. Class 1 levers *reverse the direction* of the force. 	E———F———L fulcrum at halfway position	Seesaw	Yes	= 1	Neither
	E————>F—L fulcrum nearer to load	Pliers	Yes	> 1	Effort
	E—F<————L fulcrum nearer to effort	Rowboat Oar	Yes	< 1	Distance
 In Class 2 levers, the load is between the fulcrum and the effort. This class always has a mechanical advantage of more than one (amplifying the effort), since the effort moves further than the load.	E<——>L<——>F load anywhere between fulcrum and effort	Wheelbarrow Nutcracker 3-Hole Punch	No	> 1	Effort
 In Class 3 levers, the effort is applied between the fulcrum and the load. The load moves further than the effort, so this class always has a mechanical advantage of less than one. In this case, it is the *motion* of the load that is amplified rather than the force applied to it.	F<——>E<——>L effort anywhere between fulcrum and load	Catapult Tennis Racket Baseball Bat Tweezers Tongs Hammer Fishing Rod	No	< 1	Distance

We noted before that work is equal at the input and output of a lever. That also means that the *power* of effort and load are equal, since power is work per unit time, and the effort and load points of a lever move for the same duration. Relating the time of motion to the distance of motion brings us to the velocity of motion. And sure enough, the ratio of input velocity to output velocity is another measure of mechanical advantage. You push down fast and far on one end of a crowbar, and simultaneously the other end pries up a floorboard with a slow, short, more forceful pull. A crowbar is a class 1 lever and a great example of a force multiplier. Class 3 levers, on the other hand, are sometimes called *velocity multipliers*, because a relatively slow, short swing at the grip end becomes a fast, long swing at the business end of a hammer or baseball bat.