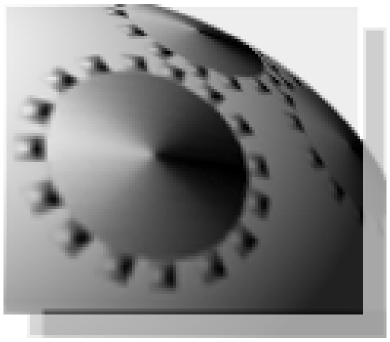


SIMPLE MACHINES

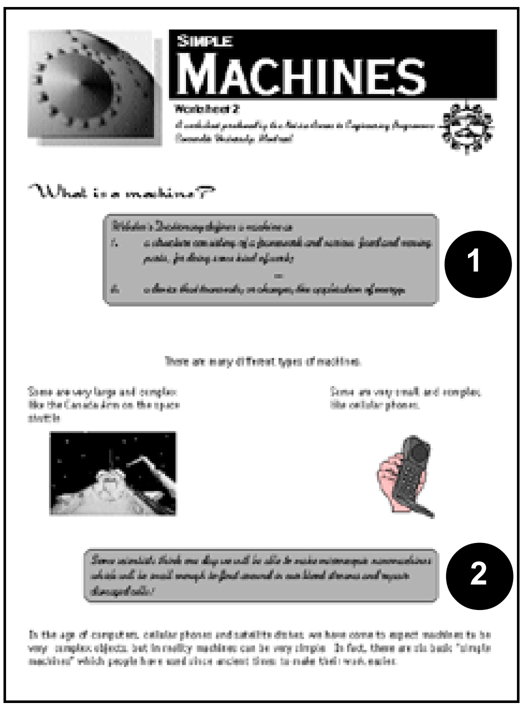
Worksheet 2

A worksheet produced by the Native Access to Engineering Programme
Concordia University, Montreal

Teacher`s Guide

Here are some suggestions for how you can work with this worksheet.

1. Definition
   Ask the students if the definition is clear. Do they understand the terms? Can they name or identify machines based on the definition?



You might want to list a number of items and ask the students whether or not each is a machine and if it is, how it fits into the definition. For example,

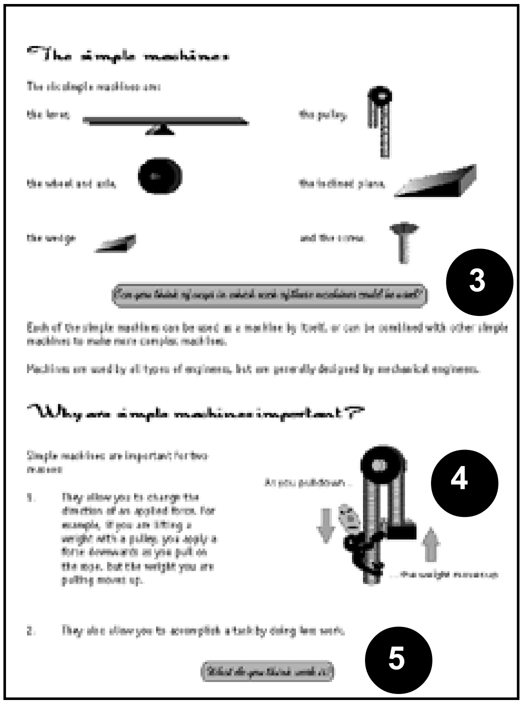
- the human body is a machine. It is a structure consisting of a framework (bones, skin, muscles) and various fixed (heart, liver, kidneys) and moving parts (arms, legs, lungs) for doing some kind of work (pumping blood, walking, lifting objects etc...)

- a paddle is a machine. It is a device that transmits or changes the application of energy. It takes the physical energy put into it by the rower and transmits it into the water, which is how a canoe moves forward.

- a drumstick is also a machine that transmits and changes energy. It converts the physical energy of a swinging arm into acoustical energy of sound coming from a drum. There are many other possible examples.

2. Nanomachines are usually found in science fiction stories. The term “nanomachines” is based on the decimal system. The prefix “nano” indicates something on the order of 10^{-9} meters - very, very small. In the decimal system the following prefixes indicate powers of ten.

exa-	10^{18}	1 000 000 000 000 000 000	0.000 000 000 000 000 001	10^{-18}	atto-
peta-	10^{15}	1 000 000 000 000 000	0.000 000 000 000 001	10^{-15}	femto-
tera-	10^{12}	1 000 000 000 000	0.000 000 000 001	10^{-12}	pico-
giga-	10^{9}	1 000 000 000	0.000 000 001	10^{-9}	nano-
mega-	10^{6}	1 000 000	0.000 001	10^{-6}	micro-
kilo-	10^{3}	1 000	0.001	10^{-3}	milli-
hecto-	10^{2}	100	0.01	10^{-2}	centi-
deka-	10^{1}	10	0.1	10^{-1}	deci-
	10^{0}	1			



3. Ask the students if they can identify where each of the simple machines is used in the home, at school and in other places they frequent.

Lever: see saws, wrenches, scissors, scales, hockey sticks, fishing rods, paddles, lacrosse sticks, hammers
Pulley: fishing boats (pulleys are often used to haul in nets), fishing reels, laundry lines, exercise machines likes rowers, bicycle gears and chains, fire drills
Wheel & axle: cars, bikes, motorcycles, roller blades, rolling pins, baby push chairs, wheel chairs
Inclined plane: any kind of ramp
Wedge : fleshers, carving tools, arrow heads, axe heads, plows
Screw: screws, jar lids, twist-off bottle tops

4. Not all the applications of simple machines change the direction of an applied force but many do. The change in direction can be demonstrated in class fairly easily. Here is a an example.

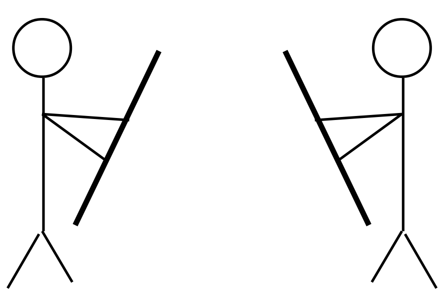
Lever: You can construct a simple lever by placing a meter stick on a box or book. As long as the fulcrum (pivot point) is between the load and the applied force, the load and force will move in opposite directions. I.E. If you push down on the lever, the load will move up and if you pull up on the lever the load will move down.

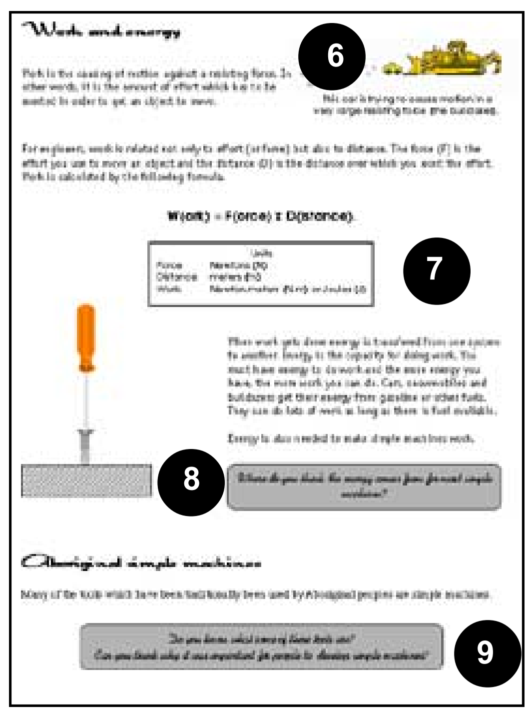
5. Before moving on to the discussion on page 3 of the worksheet, it might be helpful to find out what your students think work is.

6. The following activity demonstrates causing motion against a resisting force.
<u>You need:</u> 3 students
two broom handles or hockey sticks
a fairly long length of rope, 3-4m

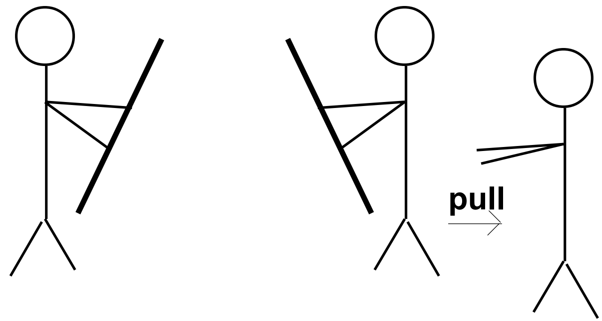
<u>Demonstration:</u>

- Get two of the students to stand facing each other about 1m apart.
- Ask the third student to get them to stand close enough so that their noses can touch without using excessive force.
- Have each of the standing students hold a broom stick as shown.

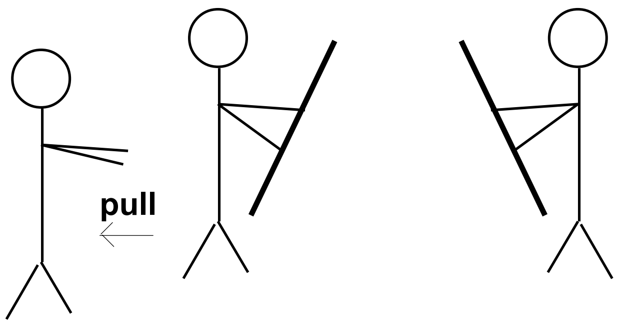




- Tie the rope firmly to one of the broom sticks, and wrap it around the other broom stick. Give the end to the third student and ask him or her to pull on the rope.



- Now wrap the rope around the first broom stick again (as shown) and get the third student to pull the rope again.



- Repeat the wrapping process one last time, and again have the student pull.

Each time the rope is wrapped around a broom handle it should become easier to pull the two students together. The broom handles are acting like pulleys. The more pulleys there are in a system, the easier it is to move a load. The pulling student is the one doing the work, he or she is the one trying to cause motion against a resisting force (the other two students).

7. Even though we often don't write down the units we are using in calculations, it is important to know what the units are and what they are measuring.

   The names of units used in science are often taken from the names of scientists who were prominent in the field. **Sir Isaac <u>Newton</u>** was a 17th century British mathematician, scientist, inventor and statesman. He is the person who "discovered" gravity when an apple fell on his head as he was sitting under a tree reading. He also developed a number of basic scientific laws about motion and the way the universe can be studied mathematically. **James <u>Joule</u>** was also British. he lived in the 19th century and was a scientist and inventor. Joule was the first person to develop accurate, reliable thermometers. He also stated the Theory of Conservation of Energy.

8. People supply the energy for most simple machines.

9. Tools: fire drill (pulley), fleshers (wedge), drum sticks (lever) , carving tools (wedge), axes (wedge), arrows(wedge)
   The development of tools was important for survival, especially during the winter when food could be scarce.

10. This photo comes from the Yukon archives and the flesher seen in it is specific to that area. There are different types of fleshers used by different Aboriginal groups. Bringing in different tools which have traditionally been used in the community might provide an interesting demonstration for the students, particularly if you can get an elder or skilled craftsperson to come in and show them how to use the tools.

11. Stone is harder than bone and so lasts longer and breaks less easily.

12. Paddles are designed to help you travel through the water quickly without tiring you out too much. They are very wide at the bottom so that they can push a lot of water. The more of the wide part you can put in the water, the faster you will be able to travel.

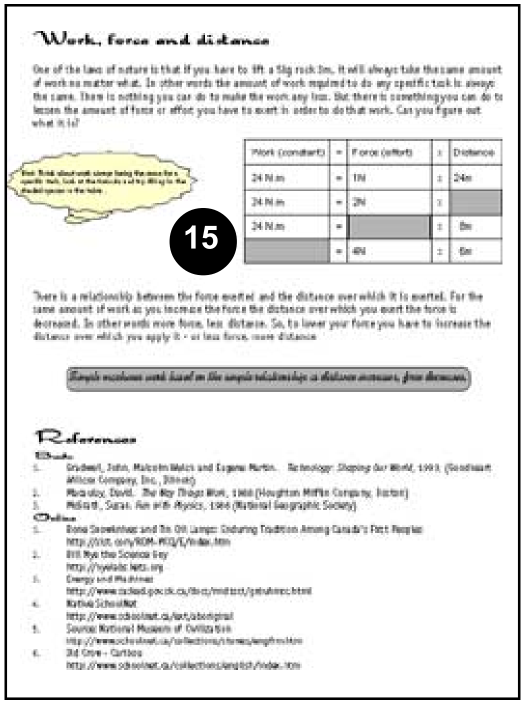
The handle of the paddle is much narrower. There is no need to use a lot of material in the handle for two reasons:

a. The handle doesn't enter the water to help push the boat forward, so making the it wider would just waste material (a thing which engineers try not to do);

b. If the handle were wider the extra material would make the paddle quite a bit heavier and tire out the person paddling the boat much sooner.

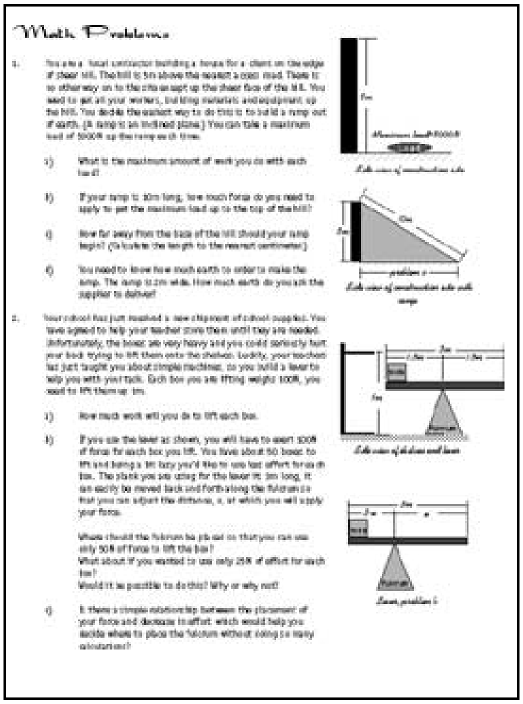
13. On the West Coast of Canada Aboriginal people built large community buildings using the huge cedar trees which grow in the forests there. They started construction by erecting the building frame, beginning with the centre beam in the roof. The cedar logs used for this purpose could be very long and very heavy, lifting them 10m or more above the ground was not easy, so what the people did was use ramps made out of dirt and sand. They would build a ramp that was as high as they wanted the building, and roll the large centre beam up to the top of it. Then they would insert the supporting log columns underneath the beam so that they no longer needed the earth to support it. Each time they put a beam in place, they removed enough earth to allow them to place beams which were lower on the roof.

14. There are many answers to this question. The idea here is to get students thinking about simple machines and how they might be helpful in a context they understand. For instance throwing a rope over or around a tree trunk to help lift something heavy is a variation on the pulley. Do they use carts with wheels and axles to carry kill out of the bush? Has anyone ever carried fish or birds attached to a stick over their shoulders? This is a lever.



15.

Work (constant)	=	Force (effort)	x	Distance
24 N.m	=	1N	x	24m
24 N.m	=	2N	x	**12m**
24 N.m	=	**3N**	x	8m
24N.m	=	4N	x	6m



Solutions

Problem 1a.

I. What do you know?

- Height (distance) over which force needs to be applied is 5m
- The maximum load which can be lifted at a time is 5000N

II. Determining the force.

Because we have a shear hill, the load has to be either pushed or pulled straight up, moving against the force of gravity. Newton's first law of motion says that for every action there is an equal and opposite reaction. This means that in order to get the load to move, the amount of force we need to apply to it will be equal to its weight. (In reality we would probably have to exert a little more force than the weight of the load in order to overcome inertia.) Since we are looking for the maximum amount of work which will be done on any one trip up the hill, we will use the weight of the maximum load as the amount of force which needs to be exerted.

III. Maximum work

Maximum work	=	Maximum force	x	Distance
	=	5000N	x	5m
	=	25,000N.m or 25,000J		

Answer = 25,000 Joules

Problem 1b.

I. What do you know?

- Ramp is lOm long, this is the distance over which the force will be exerted
- Work is constant, so we will still do 25,000N.m of work pushing the maximum load up the ramp

II. Force required

Use the formula for determining the amount of work and plug in the values that you already know.

Work = Force x Distance

25,000N.m = Force x 10m

$\frac{25,000N.m}{10m}$ = Force

2,500N = Force

Answer = 2,500N

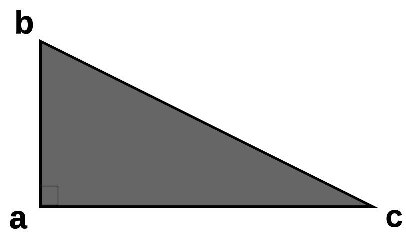
Problem 1c.

I. What do you know?

- The cliff is shear, which means we can assume it makes a right angle to the ground.
- Height of cliff is 5m
- The ramp must reach the top of the cliff, so the height of the ramp is 5m.
- Length of ramp is 10m

II. Distance from the base of the hill at which the ramp should begin

Essentially we have a right angled triangle, Δabc, in which we know the lengths of two of the sides. The length of the third side can be determined using Pythagorean theorum.



$\overline{bc}^2 = \overline{ac}^2 + \overline{ab}^2$

$(10)^2 = \overline{ac}^2 + (5)^2$

$100 = \overline{ac}^2 + 25$

$100 - 25 = \overline{ac}^2$

$75 = \overline{ac}^2$

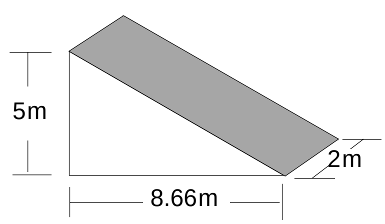
$\overline{ac} = 8.66\text{m}$

Answer = 8.66m from the base of the hill

Problem 1d.

I. What do you know?

- Height of cliff (and ramp) is 5m
- Base of ramp is 8.66m
- Width of ramp is 2m



II. Amount of earth needed for ramp

This is a problem in calculating the volume of a geometric solid. The ramp is triangular, which means its volume is half that of a rectangular solid of the same dimensions.

$$\text{Volume} = \frac{\text{Base x Height x Width}}{2}$$

$$= \frac{8.66\text{m} \times 5\text{m} \times 2\text{m}}{2}$$

$$= \frac{86.60\text{m}^3}{2}$$

$$= 43.3\text{m}^3$$

Answer = 43.3m^3

Problem 2a.

I. What do you know?

- height to lift each box lm
- each box is a load of l00N

II. Determining the force to be exerted

Again, as in problem 1a, the load has to be pushed straight up, moving against the force of gravity. Following Newton's first law of motion, this means that in order to get the load to move, the amount of force we need to apply to it will be equal to its weight, 100N.

III. Work to lift a box.

Work = Force x Distance
= 100N x 1m
= 100N.m or 100 J

Answer = 100 Joules

Problem 2b.

Note: The problem is quite challenging.

I. What do you know.

- Work is constant and equal to 100J for each box lifted.
- The plank being used for the lever is 3m long.

II. Determining the required distances through which the force must be exerted in order to get the specified forces.

There are several ways to do this but, the easiest way is to create a table like the one found on page five of the worksheet. The first line is filled in with what is already known from 2a. We

Work (constant)	=	Force (effort)	x	Distance
100 N.m	=	100N	x	1m
100 N.m	=	50N	x	2m *
100 N.m	=	25N	x	4m *

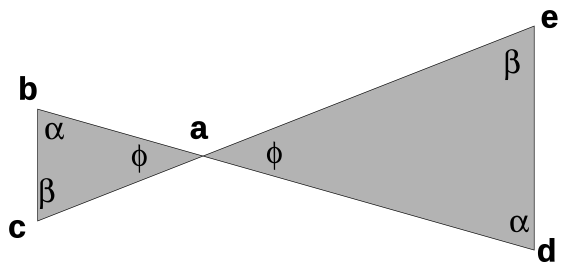
* **Students need to calculate values for these two boxes. All other values are known or given.**

also know that work is constant, so each entry under Work is the same. Finally, we are given the values of 50N and 25N as forces, so the only thing left for the students to fill in is two boxes under distance.

In order to exert only 50N of force lifting each box, we would have to push the lever down 2m. And, in order to exert only 25m of force lifting each box, we would have to be able to push down the lever a total of 4m.

III. Where to place the fulcrum in order to get the specified forces.

Geometrically, when a lever pivots on its fulcrum, the two sides of the plank describe similar triangles. Similar triangles are triangles in which corresponding interior angles are equal and corresponding sides are proportional in length. In the diagram below Δabc and Δade are similar triangles.



$\overline{ae} = x\overline{ac}$
$\overline{ad} = x\overline{ab}$
$\overline{de} = x\overline{ed}$

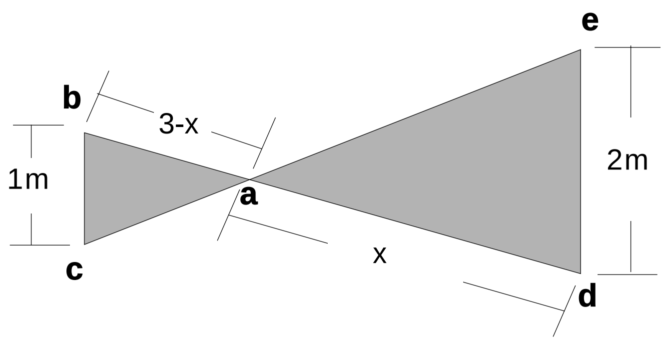
So, when a fulcrum is placed exactly in the middle of a lever, the force required to lift a load is equal to the weight of the load, because for every centimeter you push down on one end of the beam the other end of the beam moves up by exactly one centimeter. However, if the fulcrum is not at the centre point in the lever, things change: for every centimeter you push down on one end, the loaded end may move more or less than one centimeter depending on whether the fulcrum has been placed closer to the load or farther away from the load.

For 50N force

We know

- the load moves up lm
- the other end of the lever is pushed down 2m
- the lever is 3m long
- x is the distance from where the force is applied to the fulcrum
- 3-x is the distance from the loaded end of the lever to the fulcrum
- Triangle Δabc and Δade are similar triangles

By superimposing the above diagrams we get the below figure.



Triangle Δabc and Δade are similar triangles. This means that all the corresponding interior angles in each triangle are the same, and that each element of one triangle is proportional to the corresponding elements in the other triangle. Because the triangles are similar, this means that the ratio of any two sides in one triangle is equal to the ratio of the corresponding sides in the other triangle.

In our problem this means that

$$\frac{bc}{ac} = \frac{de}{ad}$$

Filling in the known quantities we get

$$\frac{x}{2} = \frac{3 - x}{1}$$

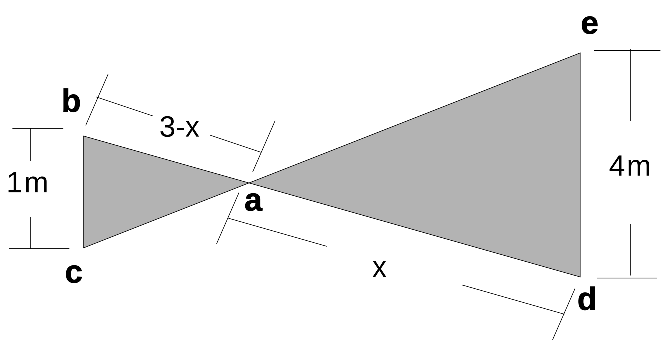
$$x = 2\,(3 - x)$$
$$= 6 - 2x$$
$$x + 2x = 6$$
$$3x = 6$$
$$x = 2m$$

For the 50N force the distance from the fulcrum to the force is 2m.

For the 25N force the problem is solved in the same way.

We know

- the load moves up lm
- the other end of the lever is pushed down 4m
- the lever is 3m long
- x is the distance from where the force is applied to the fulcrum
- 3-x is the distance from the loaded end of the lever to the fulcrum
- Triangle Δabc and Δade are similar triangles



Again,

$$\frac{bc}{ac} = \frac{de}{ad}$$

Filling in the known quantities we get

$$\frac{x}{4} = \frac{3 - x}{1}$$

$$\begin{aligned} x &= 4(3 - x) \\ &= 12 - 4x \\ x + 4x &= 12 \\ 5x &= 12 \\ x &= 2.4\text{m} \end{aligned}$$

For the 25N force the distance from the fulcrum to the force is 2.4 m.

Answer = Place fulcrum 2m from force to exert 50N of force.
Place fulcrum 2.4m from force to exert 25N of force.

Problem 2c.

While it maybe theoretically possible to lift each of the boxes by exerting only 50N, it probably wouldn't be practical. The problem is that in order to use less force you have to be able to push the lever down further, in the case of the 50N force, 2m. This means that the end of the lever where you will apply your force has to be at least 2m (or 2.4m) above the floor when you load the boxes onto the other end. Reaching up 2m or higher to pull on a lever is simply impractical for most people. A good engineer keeps the user in mind at all times during the design process, he or she would not suggest any design which was impractical.

It would be almost impossible in real life to exert only 25N force lifting each box. Even if you had a room which was 4m high, no one can reach up that high to grab the end of the lever. Also, the lever would be so steep the boxes would probably fall off.

Notes