



Hydraulics – fun in a piston!

This booklet is part two of the teachers manual for the class pack designed to help teachers and students understand and explore how hydraulics systems work, and present some ideas for making hydraulic mechanisms using simple tools and the materials from a hydraulics class pack. Whenever possible we link to websites that provide further information.

Three Sections:

1. Background Information about hydraulics
2. Ideas, and samples of types of models that can be made.
3. Tips for assembling parts - photocopy and enlarge!

History of hydraulics

The word hydraulics comes from the Greek word Hudraulikos - hudor- meaning water and aulos – meaning pipe. In a dictionary you will find a description such as **the science of conveyance of liquids through pipes, especially as motive (motion) power.** Modern uses of hydraulics reflect this well, we push hydraulic fluid through pistons and pipes to help us do work.

Early evidence of the understanding of the use of hydraulics was demonstrated by **Leonardo de Vinci** (1452- 1519) when he made sketches of simple hydraulic pumps, perhaps for printing presses.

The French scientist **Blaise Pascal** (1623-1662) however discovered the principles that govern the action of pressure on a surface. Pascal's experiments in the mid 1600's explained both hydraulics and pneumatics (which is somewhat similar to hydraulics, but uses air instead). What he found was: "the pressure put upon an enclosed fluid is transmitted equally in all directions without loss and acts with an equal intensity upon equal surfaces." It meant that the pressure you put on one piston, would be transferred equally to another one. **Joseph Bramah**, a later scientist (1748-1814), put this theory into practical use, when he found that force applied in a small piston produced a greater force in a larger piston, but with less movement.



Force on the fluid in a small cylinder is greatly increased in the "slave" (larger) cylinder since the diameter is larger. The only drawback is that the distance the small cylinder must go is greater and the slave cylinder moves only a short distance. The small syringe is easier to push, but it doesn't make much movement in the larger one!

A great way to experience this is to fill and put two different sized syringes together and press one at a time. It is easy to push the water from a small syringe into a larger one, but much harder the other way! That's because **force equals pressure times the area, $F = P \times A$** . Since the area of the big syringe is larger, the force is multiplied – (the pressure of the water is the same between the two syringes). Take out some syringes and try it! The larger syringe doesn't move much though, so while the force is stronger, the movement is less. This is similar in levers, where a large weight on one side of a lever close to a fulcrum, can be easily moved by a light weight on the other side of the fulcrum, as long as it is further away from the fulcrum.

Here is a great website to learn more about Pascal and the physics behind hydraulics.

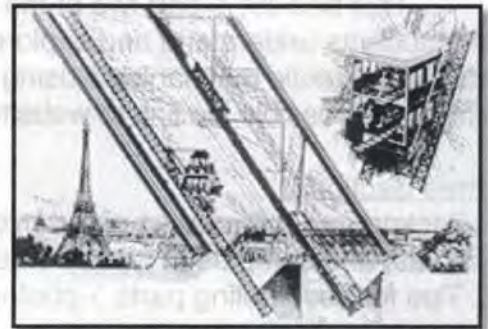
<http://hyperphysics.phy-astr.gsu.edu/hbase/pasc.html>

As time went on, hydraulic mechanisms were used in many places, from raising bridges, (the Tower Bridge in London used hydraulics), raising people, (the Eiffel Tower in Paris was first outfitted with a hydraulic elevator!) to opening large doors – such as the ones that open the huge lock doors in canals and waterways around the world, and of course in the myriad of machines we see all around us, from dentist chairs to excavators and robotic assembly lines.

Want more? Check out the Thames Barrier in London – where huge hydraulic machines move a swinging barrier to stop flooding during storm surges!

<http://www.environment-agency.gov.uk/homeandleisure/floods/105361.aspx>

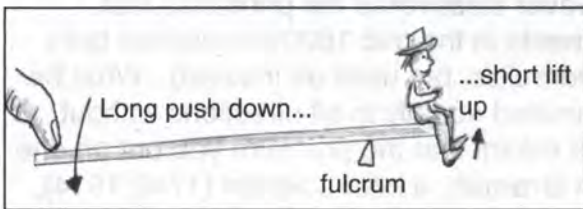
Also of interest is the **Peterborough Lift Lock** in Ontario, the largest in the world!



The Eiffel Tower used hydraulic elevators!

Hydraulic machines usually work with levers of some sort. If you have a short distance on the load side of the fulcrum and a long distance on the other side, you push a long way down, but you only lift the object up a little. So while you could lift a person with a finger, it would likely be a small distance!

Hydraulics machines, however, have hydraulic fluid under tremendous pressure in the tubes connecting them. The fluid is very similar to engine oil. These big machines will have pressures in the tubes up to 10,000 pounds per square inch (psi) (hydraulic brakes in a car may have a pressure of only 800 to 1,000 psi). Since they are so strong, the piston is usually on the **short side of the lever and close to the fulcrum**, so when it makes a small movement in or out, it creates a much larger movement on the other end. You will see that in the drawings of the machines in this booklet.



For more information about hydraulic machines, have a look at the **how stuff works** web site: <http://science.howstuffworks.com/hydraulic.htm>

What is the difference between hydraulics and pneumatics?

Hydraulics uses water and pneumatics uses air. As an experiment, connect two syringes that are mostly full of water, but leave a small air bubble in one. Notice that if you hold one plunger tight and press the other you can compress the air bubble in the syringe. If you pull on the plunger while holding the other one the bubble becomes larger since the air inside expands. When you make your machines try to get all the air out of the syringe and tube so this doesn't happen.

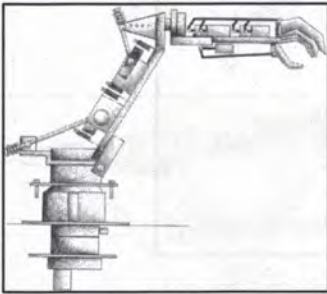
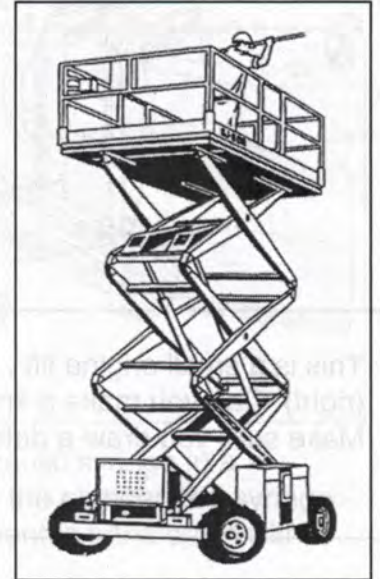
You cannot compress water, nor stretch it since the molecules are already tightly packed and held together much more tightly than air. This is the same for all liquids, including hydraulic fluid, which is used in real machines, since it can withstand the heat that is generated during use and not break down (remember water expands, and might rust the parts inside the machine). Hydraulic fluid doesn't expand, and it lubricates the parts inside - nice!

Have a look at the illustrations on the next few pages and then put on your thinking caps. How can you make one of them with the materials you have? After these examples of where hydraulic machines are used, there are some ideas for making your own hydraulic machine models. Good luck and enjoy!

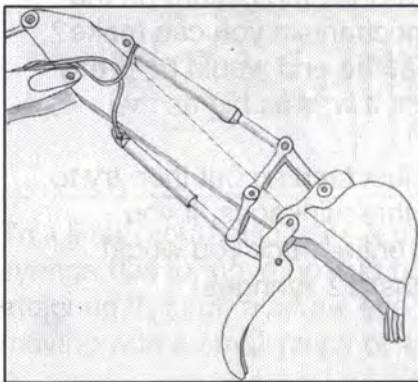
Hydraulics in everyday use

These drawings represent a small fraction of the places where hydraulic machines are used, an internet image search will find a lot more! Go to the Pathfinders web site to see pictures of models that have been made by people.

A scissor lift is used as a movable, elevating platform (right). The pistons can be attached in a number of ways.

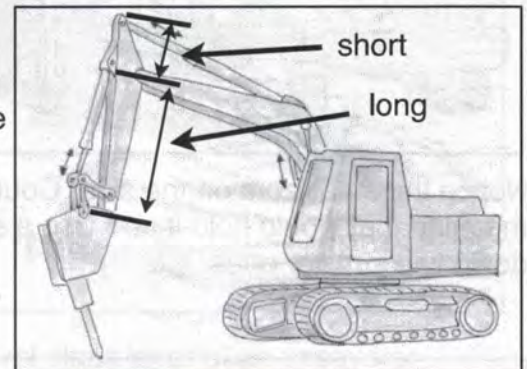


Robotic arms use hydraulics and small motors to make the same movements over and over.

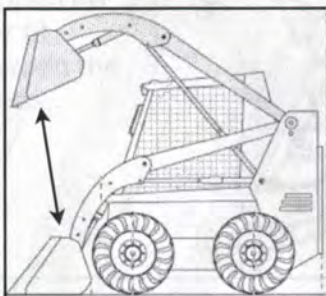
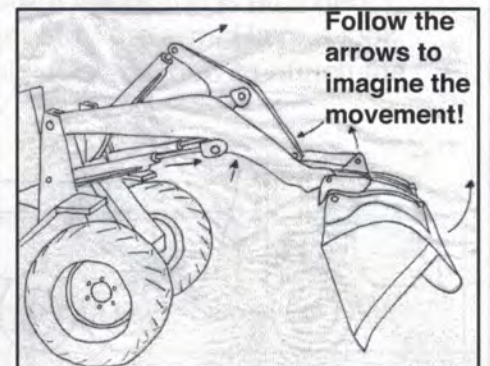
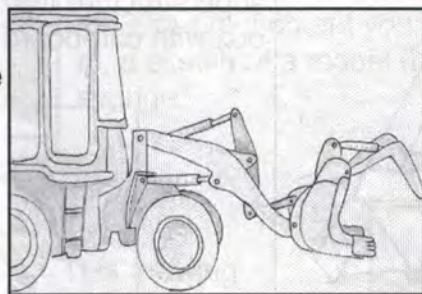


An excavator (left) uses 3rd class levers to dig and grab. Notice how the piston is attached close to the fulcrum. This way a small movement of the piston creates a larger movement in the arm and shovel

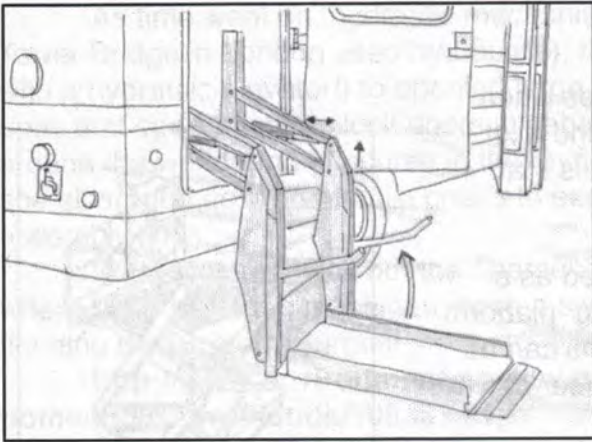
Excavators, this one fitted with a pneumatic jackhammer, enhance movement with the push on the short lever on one end (right). The straight movement of the piston results in curved movement of the arm.



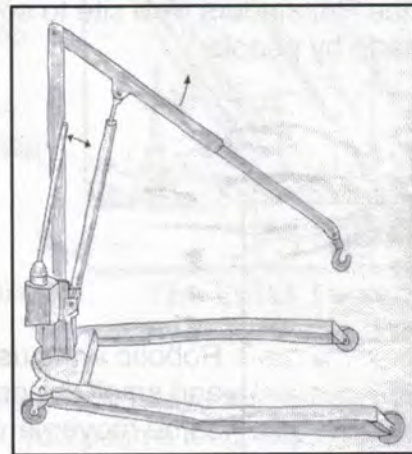
Some front-end loaders have a **reverse linkage** so when the piston pushes the linkage, the action on the other end is a pull (right). Can you tell what happens when these pistons move?



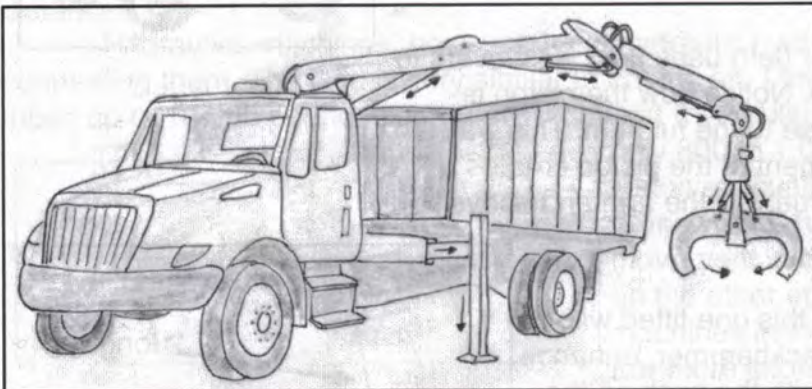
This skid steer loader is very cool. You will need to use cardboard to make the scoop and the cab.



Wheel-trans busses use a parallel linkage to move the platforms horizontally. You could use the linkage plates to make something like this.

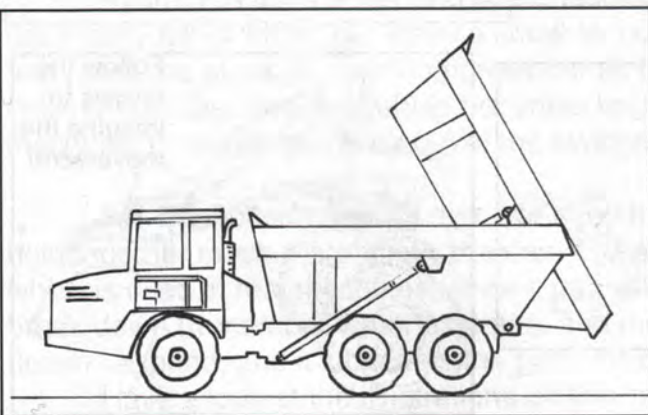


This is a small engine lift, widely used in auto shops (right). Can you make a small machine that does this? Make sure you draw a detailed diagram first!

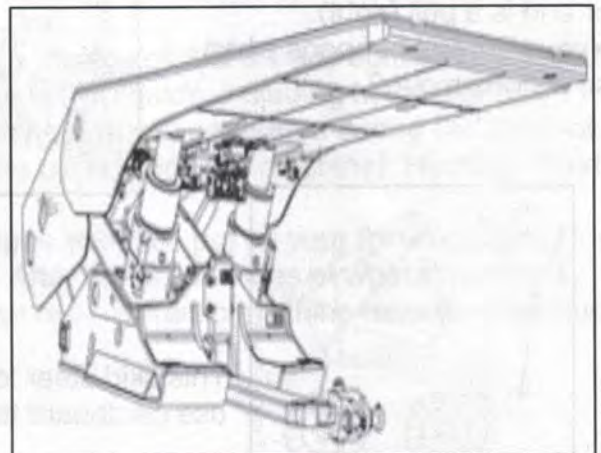


Can you re-draw the picture on the left as a mechanism you can make? The claw at the end would be pretty hard unless it was as big as the syringe. If you are just starting out then try to do two or three linkages. If you made this entire truck you would need at least 12 syringes!

Notice the stabilizers on the side. Could you make a simple stabilizer for a machine that would hold it up? Use a splitter and one large syringe to push down two smaller ones.



A simple dump truck isn't too hard. Make the superstructure from the wood, and then make the box with cardboard!

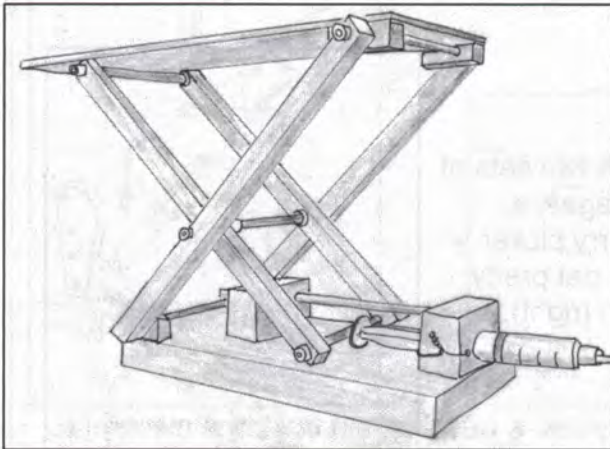
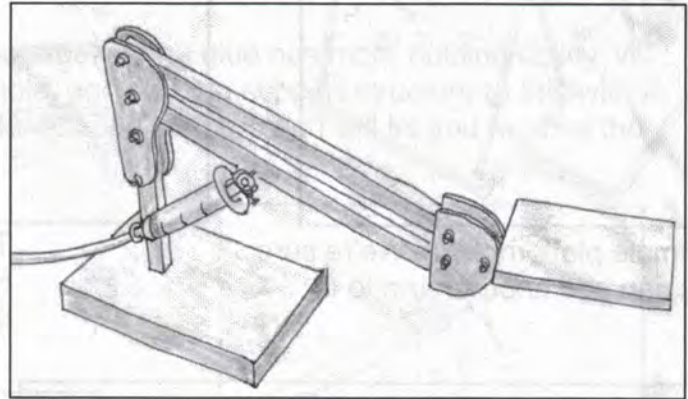


This mine roof holder (right), supports the roof of mines so they don't collapse.

Some examples of mechanisms you can make!

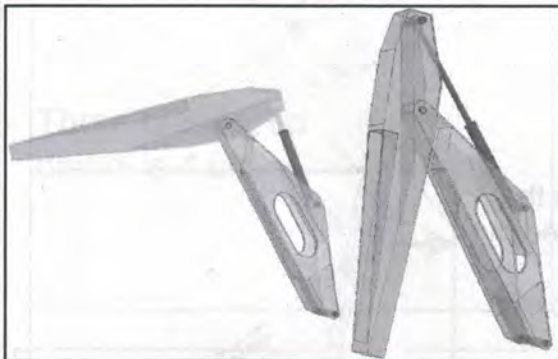
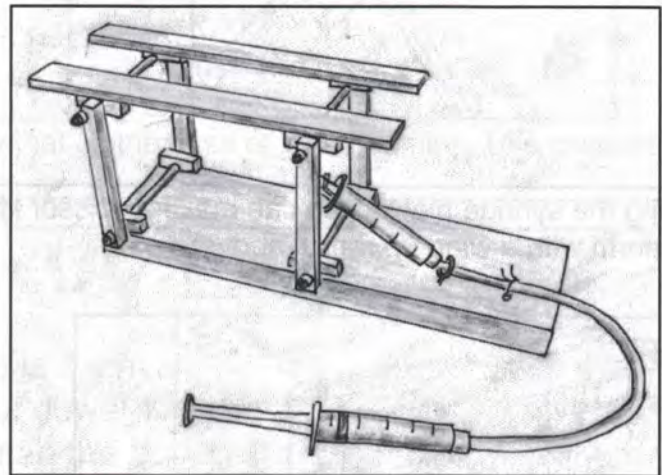
When you look at the following mechanisms, look carefully at how pieces are attached to each other. The easiest way to attach a syringe is to use a screw eye and wire the plunger to it with some of the twist tie. These can be removed and changed if they are not in the perfect spot.

This simple parallel lifter (right) lifts the platform horizontally. It uses a third class lever, attached with some screw eyes to the pieces.



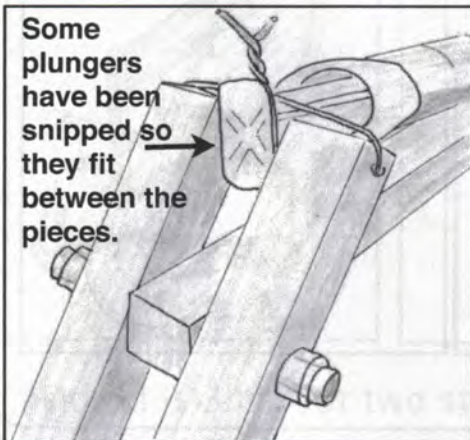
A scissor lift (left) uses a hydraulic syringe in a different direction. By pushing the plunger, the syringe pushes sideways, this movement is transferred with a lever to an upward motion.

This lifter (right) also uses a parallel linkage, but the syringe has to move up and down, so needs to be attached through a screw eye and then held from moving with a small piece of wire.

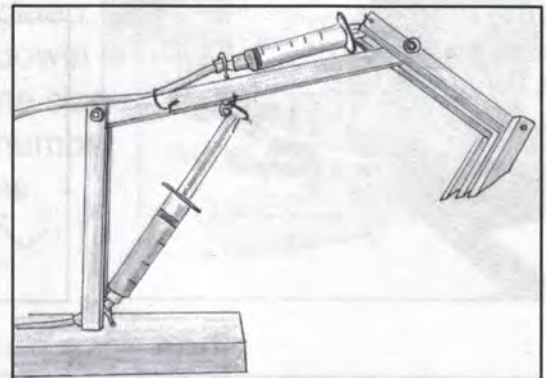


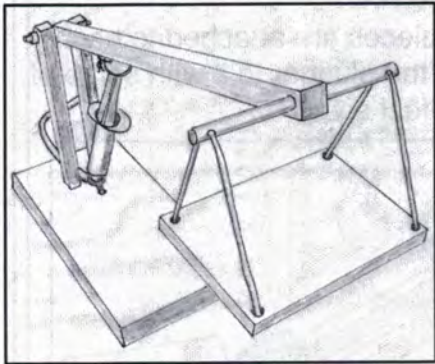
This is a sketch of the first class lever of an excavator (left). The closer to the fulcrum the piston is attached, the more movement you get from the arm. Have a look at a sketch of a model (below) to see how to attach the syringe.

Some plungers have been snipped so they fit between the pieces.

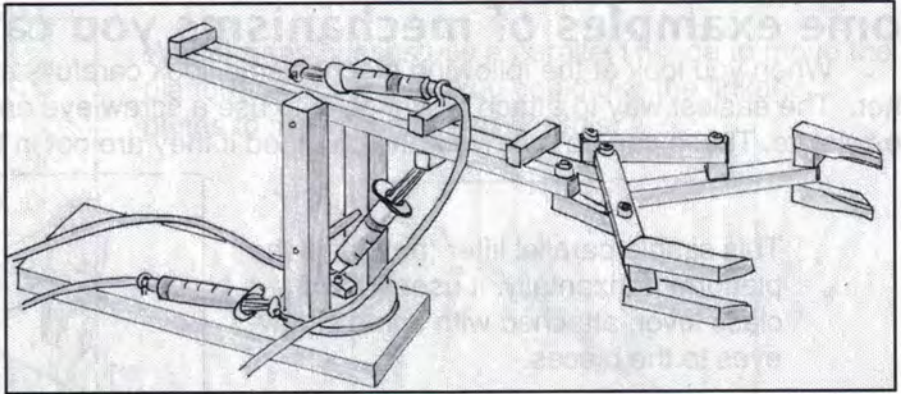


This drawing (right) shows how that excavator might be assembled (close-up left and overall drawing on the right).

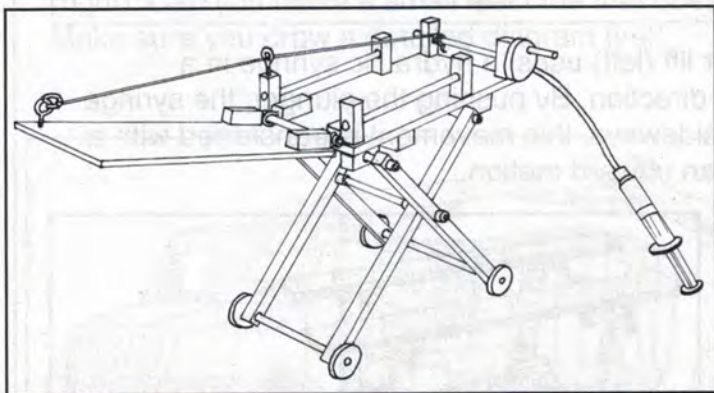




A simple platform lifter. We're sure you can add another arm to it!

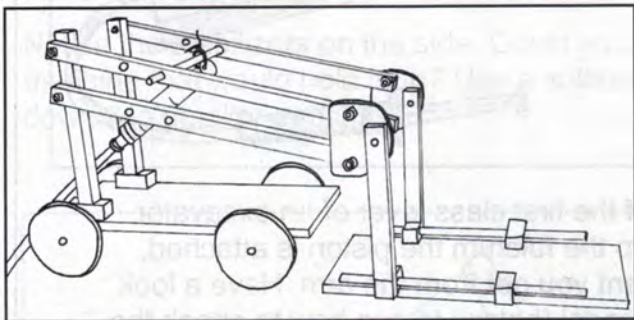
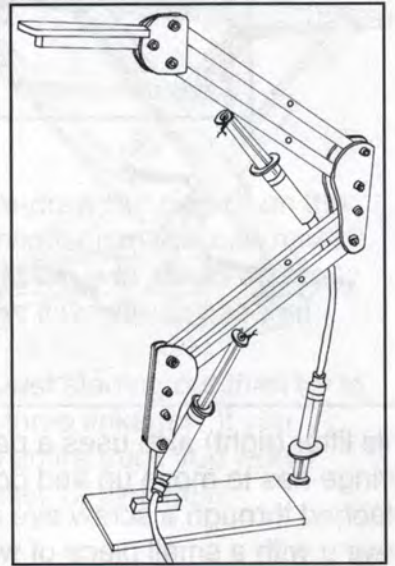


This robotic arm has plans on the Pathfinders web site, but make up your own!



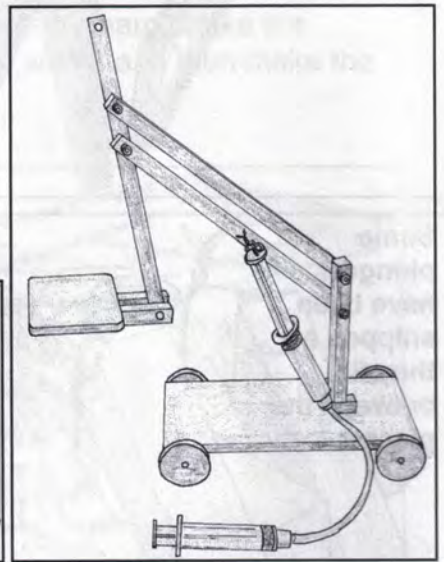
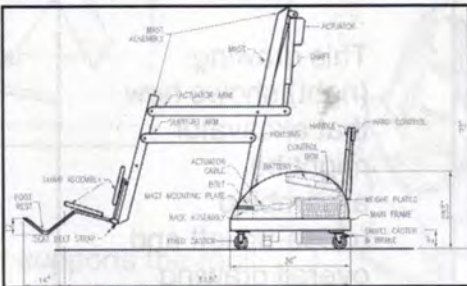
Using the syringe blocks you can make a scissor lift platform with a wind up ramp (above).

With two sets of linkages, a cherry picker can get pretty high (right).



The Platform lifter above was inspired by a wheel-trans bus (below).

The pool lift on the right was inspired by one seen at an accessibility web site (below).



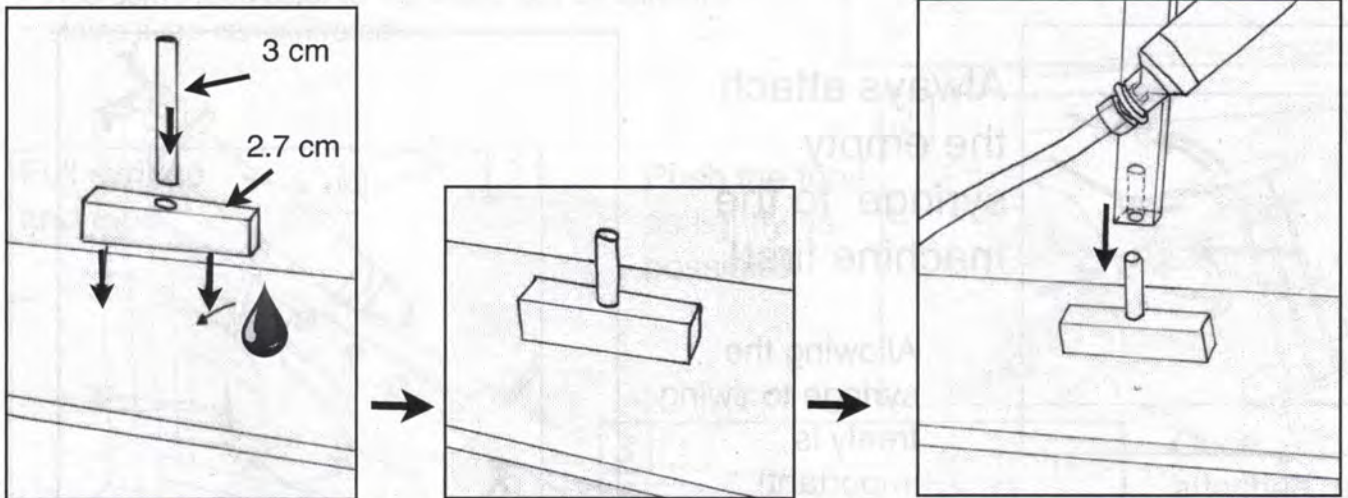
Tips for making machines

There are a few areas to consider:

1. Making a strong base
2. Connecting pieces with dowels
3. Attaching the syringes
4. Attaching wheels

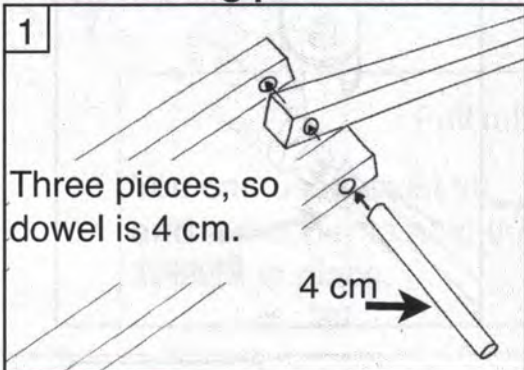
1. Making a strong base

Holding a structure to a base needs a larger surface area, so the glue has more holding ability. We suggest that you glue down a 2.7 cm piece with a hole, and add the support structure to this with a piece that has a hole in the end. The dowels provide a strong support, and will let you remove the piece, or rotate it if needed.



Glue down a 2.7 cm piece, insert a dowel, then use that as the base of your machine. Use scissors to cut the dowel if needed.

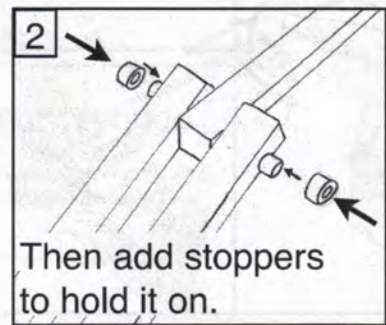
2. Connecting pieces with dowels



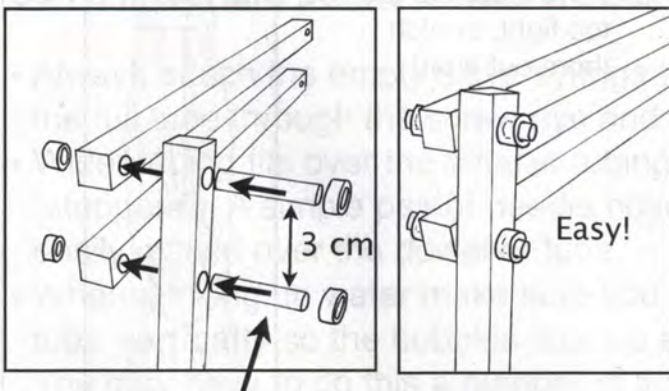
Three pieces, so dowel is 4 cm.

4 cm

Each piece is 1 cm wide, so cut dowel 1 cm wider than the number of pieces. Easy!

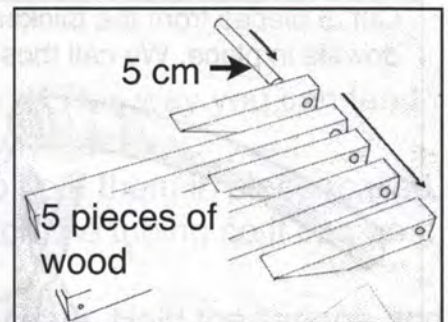


Then add stoppers to hold it on.



Easy!

This excavator shovel (right) will be glued, so the dowel is the same size as the number of pieces.



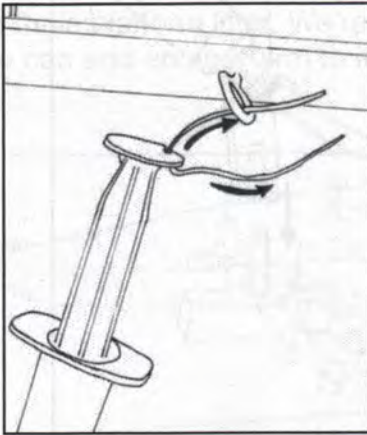
5 cm

5 pieces of wood

Dowel is 3 cm for two sticks (.5 cm pokes out on each end).

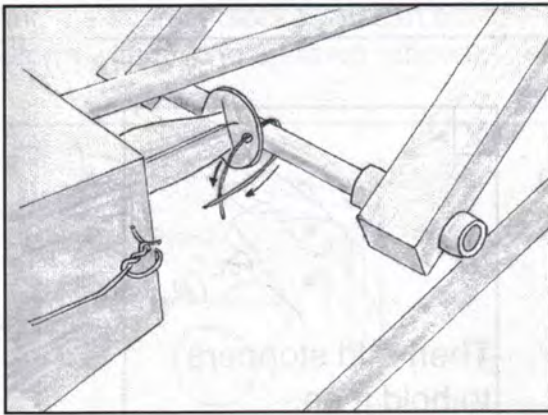
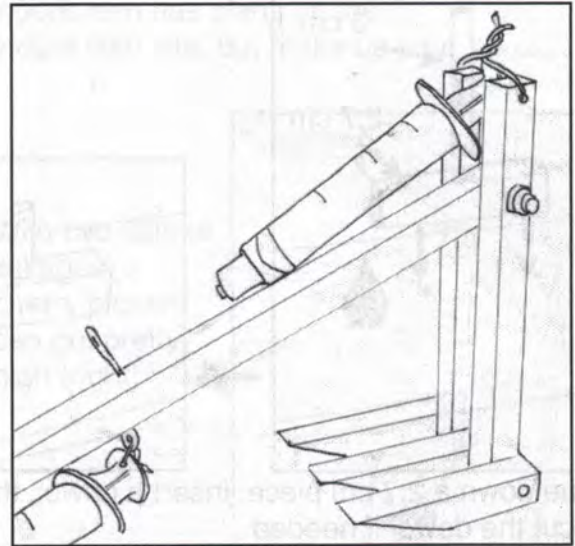
3. Attaching syringes

1. Once you have the basic structure made, take a syringe and hold it to the base support (where it will be attached through the screw eye) and mark the position on the arm when it is fully shut. Open the syringe fully and see where the arm would move to. Re-adjust until you have it where you want, this will take a few tries!
2. Attach an empty syringe to the structure with a screw eye. Open it up and test it to make sure it has the movement you want.

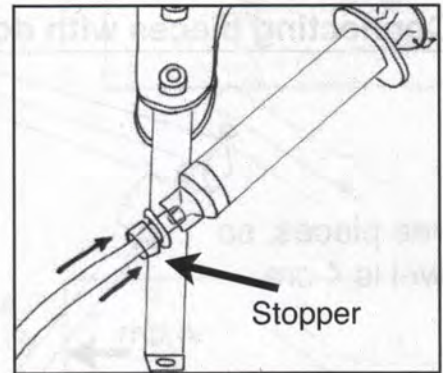


Always attach the empty syringe to the machine first!

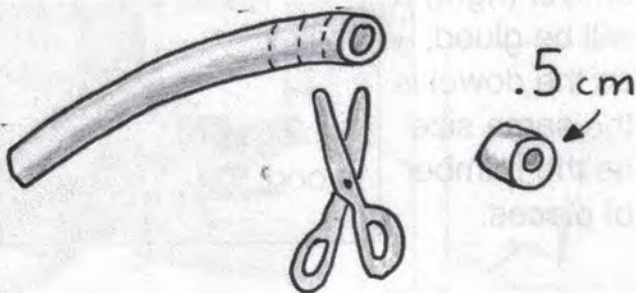
Allowing the syringe to swing freely is important!



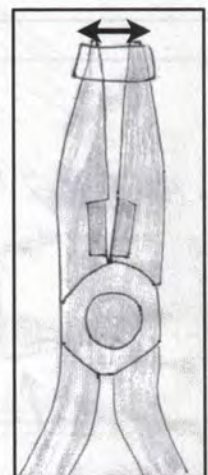
A plastic stopper holds the syringe in place (right).



Cut .5 pieces from the thicker tube to hold dowels in place. We call these **stoppers**.

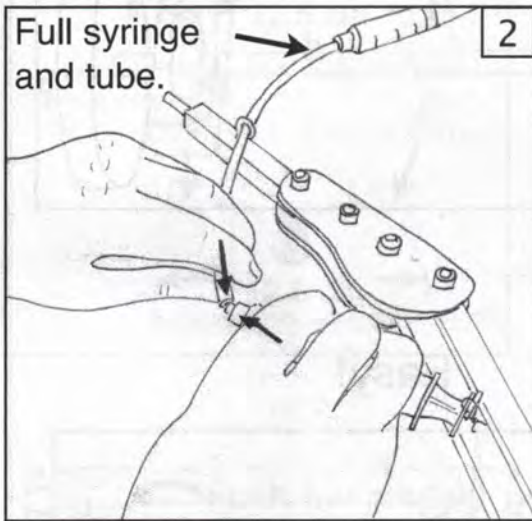
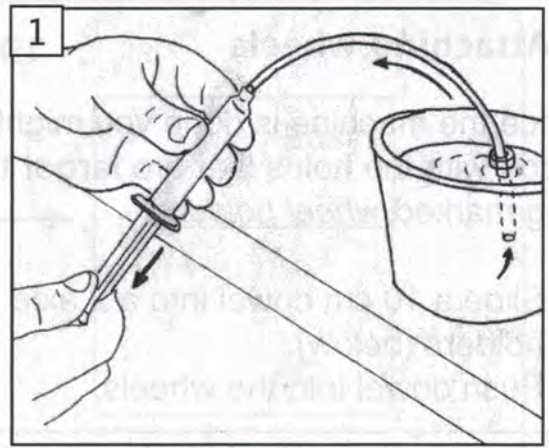


If the stoppers are too tight, stretch them out a bit!

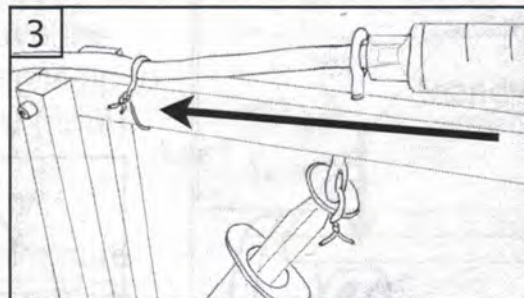
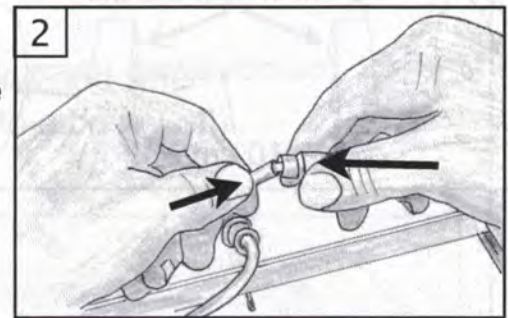


Filling and attaching the master cylinder

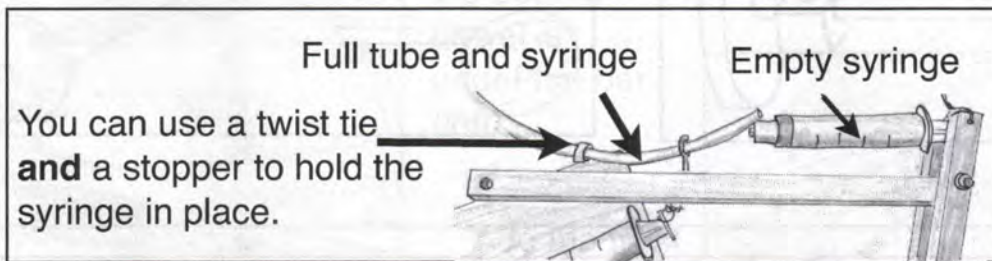
- The longer **thinner** pre-cut tubing pieces are used between the two syringes.
- The master syringe (the one you hold) has no hole in the plunger!
- Suck water from a small bowl or cup. Push and pull the plunger to get all the air out. Tip the tube up so the air bubbles rise to the top, then push them out!
- Add some food color to the water, but be careful it stains if too concentrated!



Push the tube as tightly as possible!



Once attached, use some twist tie to hold the tube in place.



Some important points (noted in pictures above)

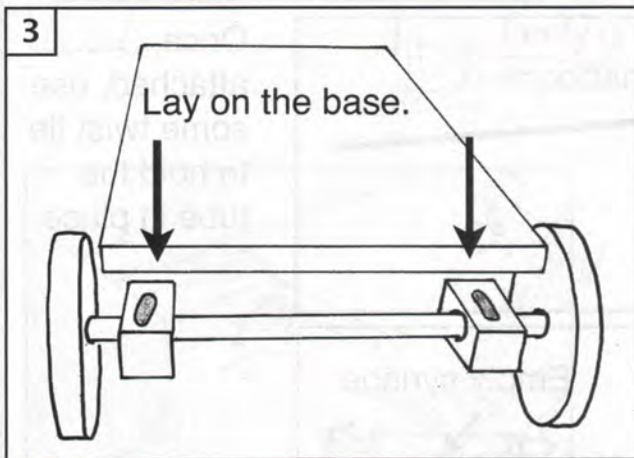
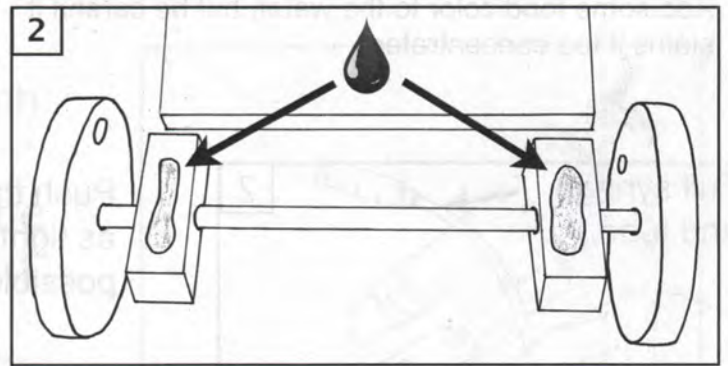
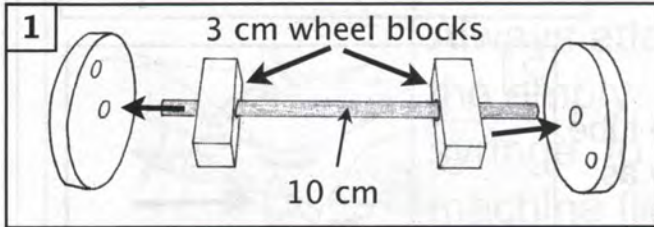
- Always attach the empty slave syringe to the mechanism first! This way you can feed the full tube through the screw eye and then to the empty syringe.
- Wider tubing fits over the smaller tubing and over dowels to hold them in place (called "stoppers"). A simple pair of needle nosed pliers helps stretch the tubing so it can be easily placed over the dowel or tube.
- When sucking up water make sure you have **all** the bubbles out! Hold the syringe and tube **vertically** so the bubbles float up and tap the side of the syringe and tube to help. You may have to do this a number of times!
- If the tube comes off, or the plunger is pulled out, just refill and away you go!

4. Attaching wheels

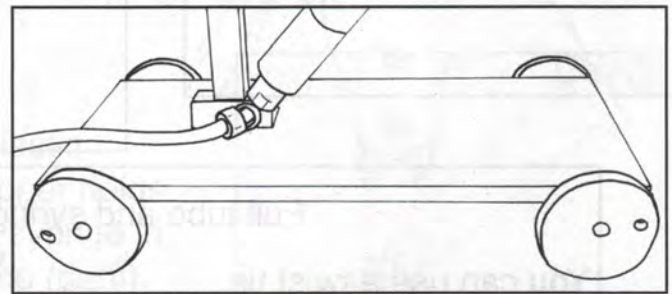
Once the machine is done you might want to add wheels. Use the **3 cm** pieces of wood with the holes that are **larger** than the dowel (7/32). These are in a separate bag marked *wheel holders*.

Slide a 10 cm dowel into a 2 axle holders (below).
Push dowel into the wheels.

Add a glob of glue.



Easy!

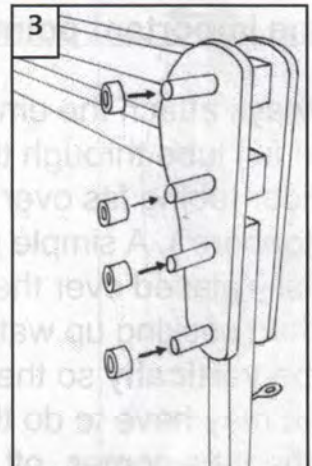
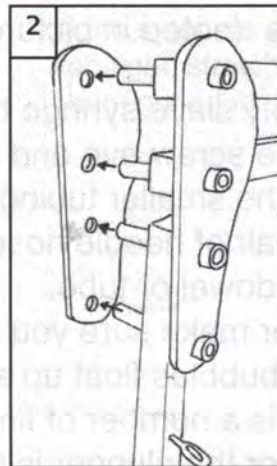
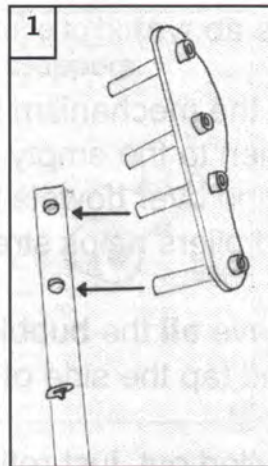


Using linkage plates

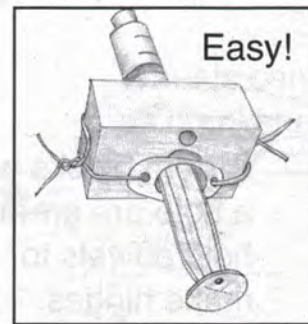
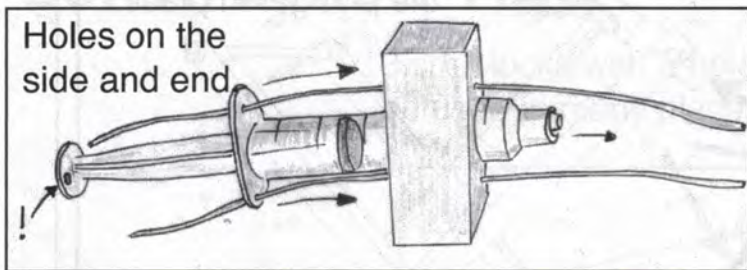
Cut the dowels at 2.5 cm, (or use the 3 cm ones), add stoppers, and slide into plate (1).

Insert them into the pieces and slide on other side (2).

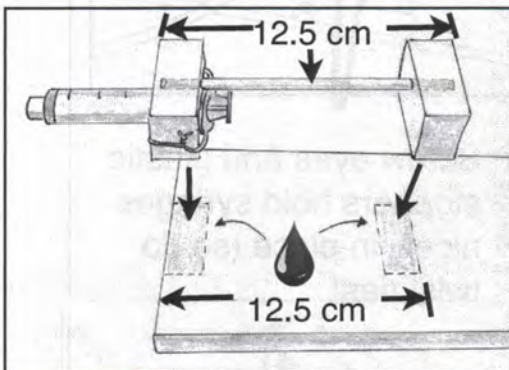
Add stoppers, to the other side (3). Easy!



Using the scissor lift syringe holder

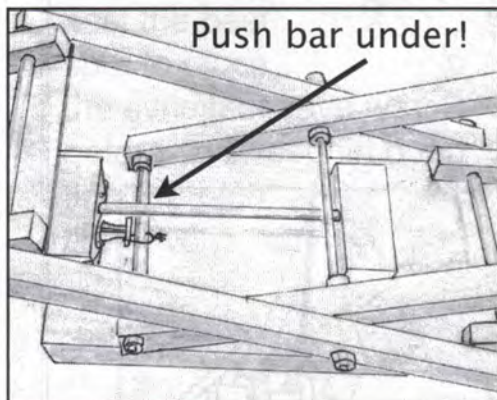
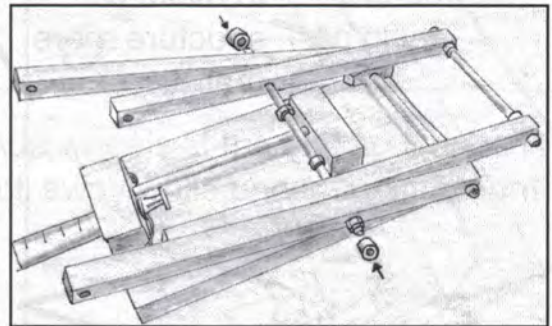


Insert an empty syringe with holes on the side and end. Add twist ties, and twist them tight! (above).



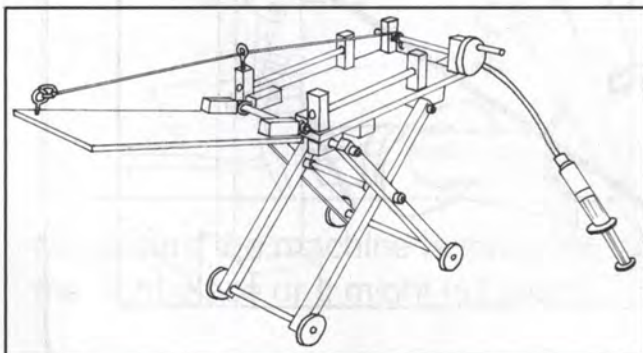
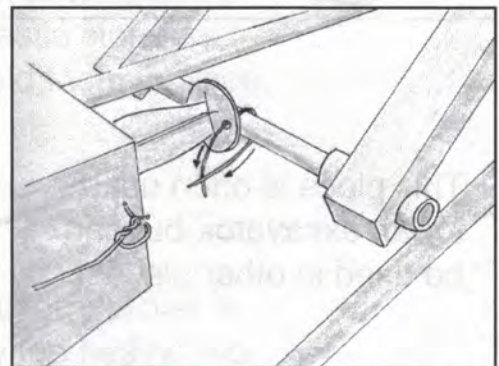
Plan out your machine and when ready, glue the unit to a base (left).

Assemble the pieces - we'll leave the details up to you (right).



Make sure the bottom dowel is under the bar (left).

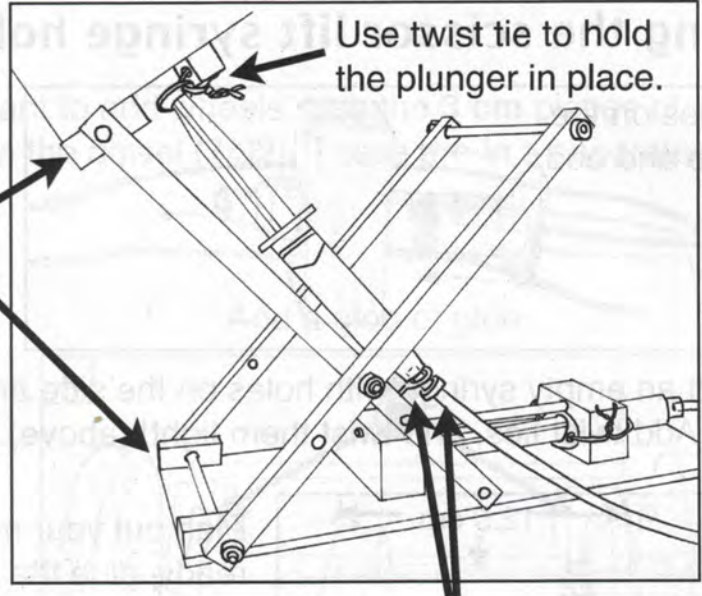
Add the twist tie and away you go!



This is an upside down scissor lift (with wheels and other things).

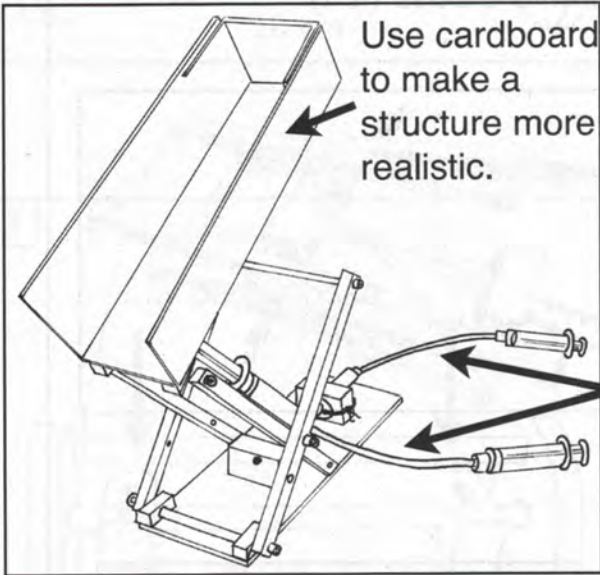
Construction Tips

2.7 cm blocks with a hole are great to hold dowels to make hinges.



Use twist tie to hold the plunger in place.

Use cardboard to make a structure more realistic.

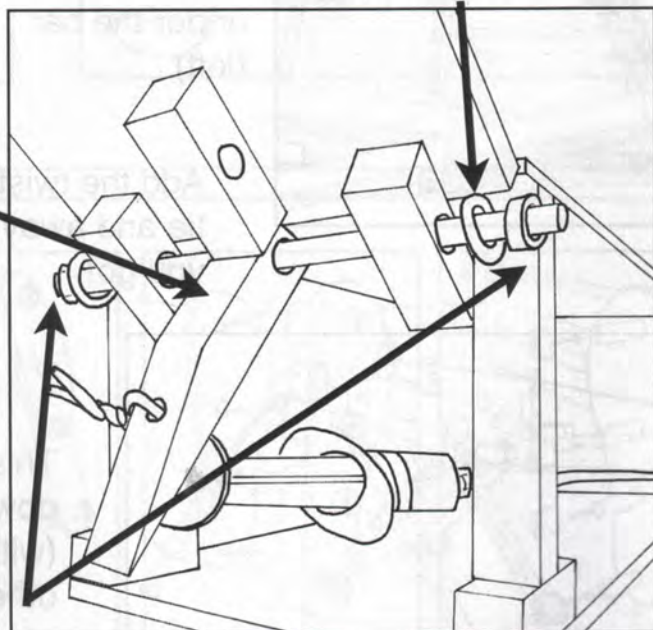


Screw eyes and plastic stoppers hold syringes nicely in place (so do twist ties!)

The tubing is short so it doesn't hang all over the place.

Screw eyes make good hinges!

This piece is often used for an excavator, but can be used in other places!

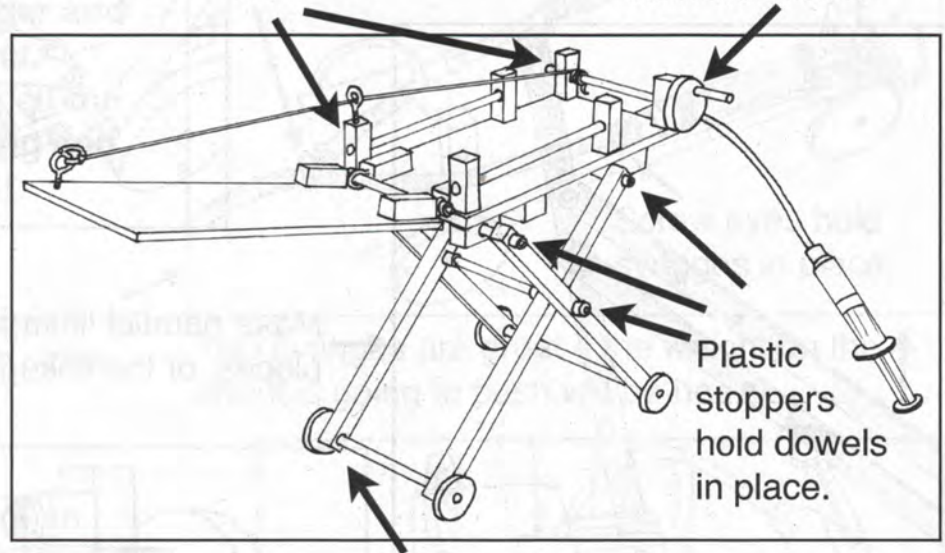


Plastic stoppers hold dowels in place. Use the **thick** tubing for this!

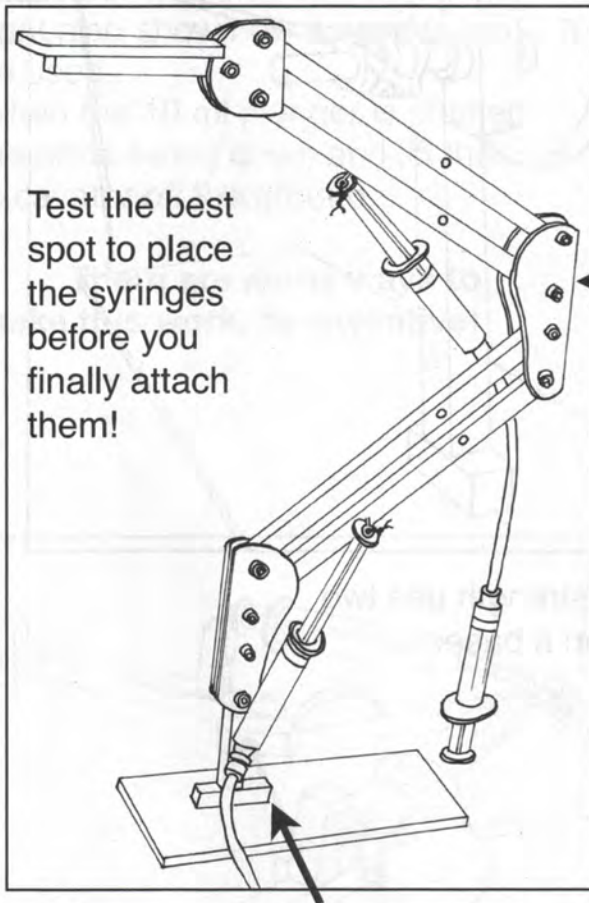
Construction Tips

3 cm blocks with a hole can be used in many places.

Wheels can be used as cranks.



Add wheels at the end so it doesn't roll away while under construction!



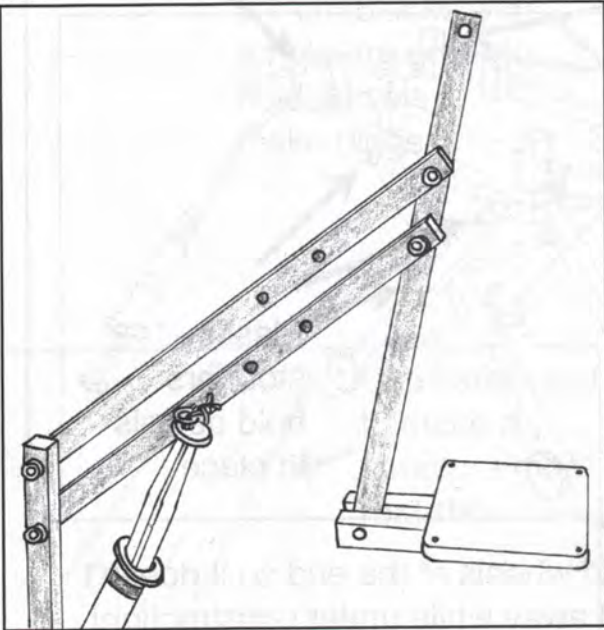
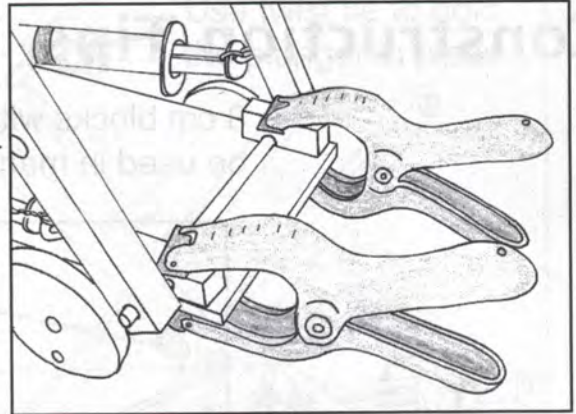
Each linkage plate needs 4 - 2.5 to 3 cm dowels and 8 plastic stoppers to hold them in place.

This cherry picker is pretty top heavy, two main support uprights might have been better!

Make sure the machine is mounted in the right place or it might fall over!

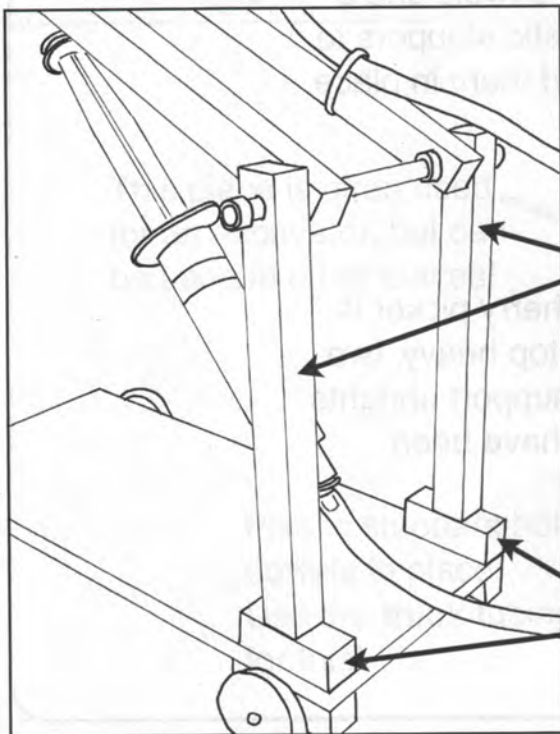
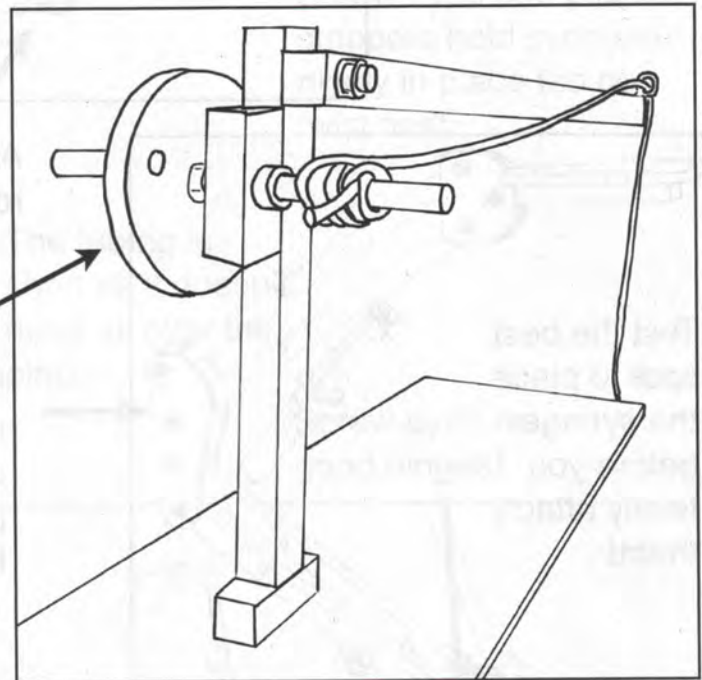
Construction Tips

Small clamps help hold pieces while you test to see if they work correctly. →



← Make parallel linkages with the 20 cm pieces, or the linkage plates.

Use the wheels as a pulley.
Insert a dowel as the crankshaft.

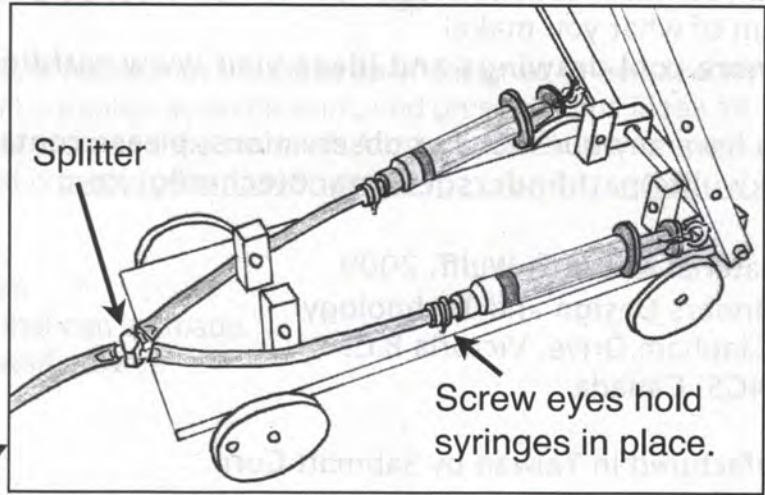


← For extra strength use two uprights on a base.

← Always use the 2.7 cm blocks to hold your uprights!

Using Splitters

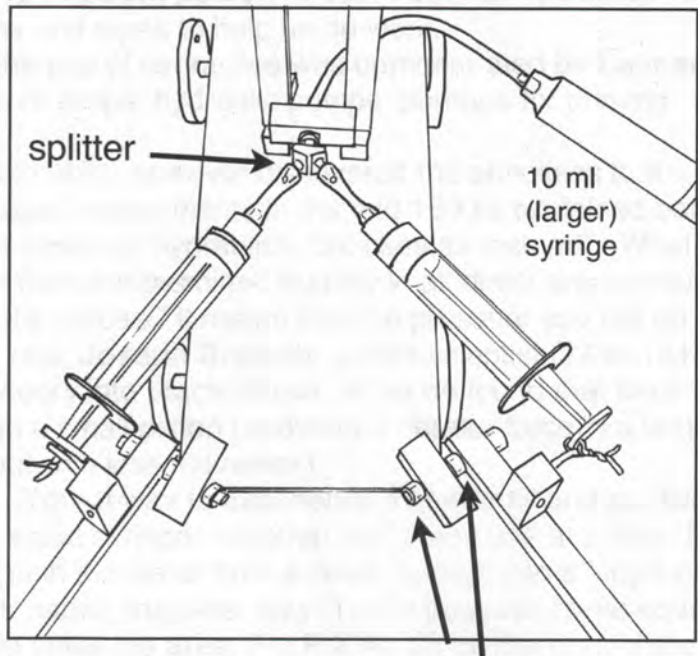
Use a 10 ml syringe and two smaller syringes with a splitter to make stronger and double lift mechanisms. It is a challenge to get all the bubbles out when filling and attaching the syringes!



Use a 10 ml syringe and a splitter to push both sides.

Two syringes are great if the weight on the arm it is going to push will be heavy. ↑

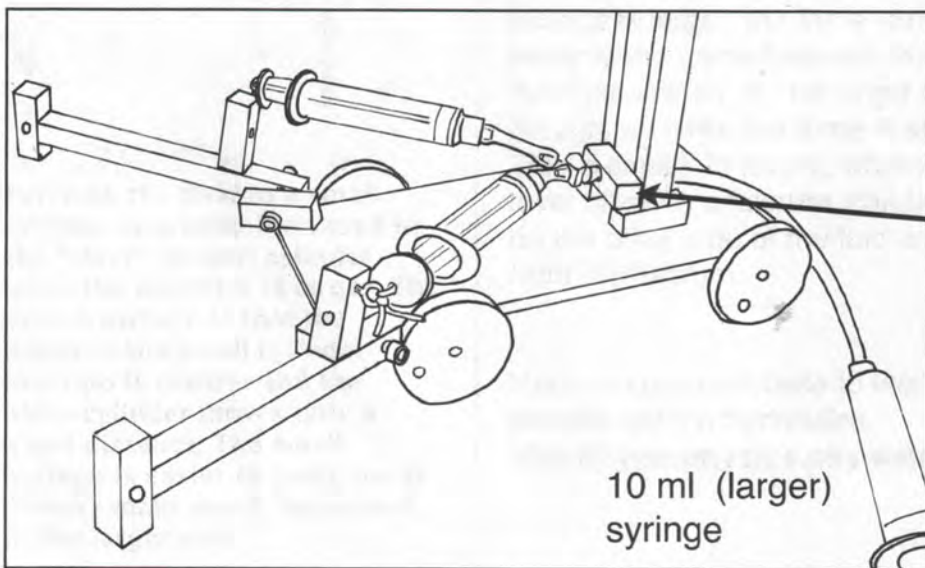
These two views of an excavator with a double lift on the front also show how a splitter can be used. When the 10 ml plunger is pushed, the arms swing down and lift the excavator off the ground.



There are many ways to make this work, be inventive!

Use plastic stoppers as spacers and dowel holders.

Feed tubing through the hole in a 2.7 cm block.



When you make something cool, take a picture and email it to us, we always like to share in the fun of what you make!

For more cool drawings and ideas visit www.pathfindersdesign.com

If you have any questions or observations, please contact us at:

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