Combination Lock

❧ Learn how a combination lock works with this wooden mechanism kit modeled after Linus Yale's 1862 lock.

So what is a combination lock?

Everyone has seen a combination lock. They are found on lockers, bank safes, house front doors, realtor's lock box for keys, etc.

Compared to a lock with a physical key, the key to a combination lock is a set of numbers you have to memorize. It's easy to make a copy, where a lock with a physical key, usually needs a duplicator machine to cut from a blank another copy.

There are a number of different types of combination locks, some that go back thousands of years. This combination lock is modelled after Linus Yale's 1862 Patent of the first single knob combination lock. It is called a code wheel combination lock. This model has four code wheels, one for each number you dial.

As you turn the dial, a pusher underneath of the dial can engage the pin sticking up from the code wheel. When the dial turns and they meet, the dial then pushes the code wheel in the same direction. To push it in the opposite direction the dial has to turn all the way around until the pusher hits the other side of the pin to cause the code wheel to turn..

Just as the pin on the dial turns the first code wheel, each code wheel has a pin to turn the wheel underneath.

To get the top code wheel to move, you rotate the dial one full turn past zero. Two full turns of the dial gets the next wheel to move, and so on. The top code wheel is for the last or fourth number in the combination and the bottom code wheel is for the first number.

Let's say your combination is 12-4-11-10. Start by turning the dial clockwise four times past zero, then stop at 12. This moves the bottom code wheel into the unlocked position. The lock is still locked until all four code wheels have moved to the unlocked position.

Next go counter-clockwise three turns past 12, then stop at 4. This gets the third wheel into the unlocked position.

Now turn clockwise two turns past 4 and stop at 11, putting the second wheel into the unlocked position.

Finally, turn counter-clockwise once past 11 and stop at 10. This lets the fence drop into position and unlock the lock.

A simple way to change the combination is to move Code Wheels between levels. Another way to change a combination is to remove the "UP" pin from a Code Wheel and put it into a different position. If you glued your pins in place, simply assemble another code wheel. The kit includes some extra code wheels for this purpose.

Note: This kit does not require a finish, paint, stain or dye to be applied.

For those of you who enjoy finishing, painting, staining or dying models, the wooden parts of this model can be colored, stained, or dyed to your taste with a variety of different wood stains. Aniline dyes, or paints. You will need an adult to help and supervise the use and application of these chemical products which is outside the scope of this model. **DO NOT DO IT ON YOUR OWN** if you are not an adult. And _always read and follow the manufacturers instructions_.

Some general suggestions on finish parameters:

- Sanding - is not required for this kit. However some model builders who choose to apply a transparent coating such as lacquer, they do a light sanding with 320 grit sandpaper and a wooden block can clean up the surface. _If you choose to sand you do so at your own risk._ Use appropriate safety procedures and personal protective equipment for wood dust. If you are not an adult, seek the guidance of an adult.
- Any finish or coating to be applied should be very thin so as not to interfere with the mechanism. Spray lacquer or spray shellac have been used by some model builders.
- Be very careful not to get finish in the ¼ " diameter holes of the washers, dials, and wheels. Model builders usually mask these areas with 1" long piece from a drinking straw inserted into the holes before spraying. Once the finish is completely dry, wax will have to be applied to the moving joints and holes may have to be sanded back to the proper size.

Safety Instructions

When you assemble this model, you will use two different glues. You must read and follow the manufacturers instructions on the use of these products. The manufacturers of these products produce a MSDS (Material Safety Data Sheet) that contains safety information including First Aid measures. Always wear appropriate safety equipment including Safety Glasses when building and testing models to prevent eye injury.

Key Terms:
- **YW Glue** is yellow wood glue
- **CA Glue** is Cyanoacrylate glue

Step 1 — Assemble the Legs

Parts Used: 2 Narrow Legs, 2 Wide Legs

☐   Dry assemble the four Legs. A couple light taps with a hammer will ensure they are fully seated and flush on the top over the joint.

Step 2 — Assemble the Base

Parts Used: Leg Assembly, Base, 3 N Washers, 2 S Washers, 3 Posts, 3 Machine Screws

For the next few steps, here's what you are going to be putting together - This model is designed with tabs that fit in slots. If they are too tight, a quick sand with sandpaper will easily loosen them up, but most times you will not need sand paper.

The same is true for the holes, we try to get nice tight joints, but if they are too tight, coil the sandpaper into a cylinder and lightly sand the inside of the hole. A small 2-4 oz. hammer can be used to gently tap a joint together.

☐   Attach the 3 Posts to the Base Plate with the Machine Screws.
☐   Attach the Leg Assembly to the Base Assembly with YW Glue.
Use a damp cloth to wipe up any drips or spots.

☐   Apply YW Glue to one side of an "N" Washer and attach to the Dial Post of the Base Assembly. Press it firmly in place around the post.
☐   YW Glue together two "S" Washers.
☐   YW Glue to one face of the "S" Washer Assembly and attach to the Spring Post as shown.
☐   YW Glue together two "N" Washers, apply glue to one face and attach to the Fence Post as shown.
☐   Allow the glue to completely cure.
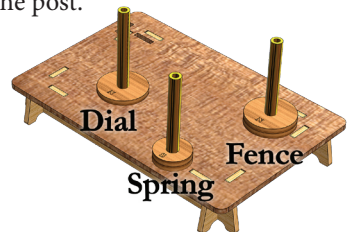
Step 3 — Assemble the Dial

Parts Used: Dial, "K" washer, "B" Disk, "F" washer, Pin, Base Assembly

☐   Glue a "K" Washer to a "B" Disk with YW Glue to make the KB Assembly. Check the outer edges for alignment. Allow the glue to set.

☐   Apply YW Glue to the hole 0 between location 19 and 1. It has no number. Insert a Pin from the back side into this hole. This Pin is called the pusher because it pushes the code wheel beneath it to cause it to turn. Each Pin pointing down is called a pusher.
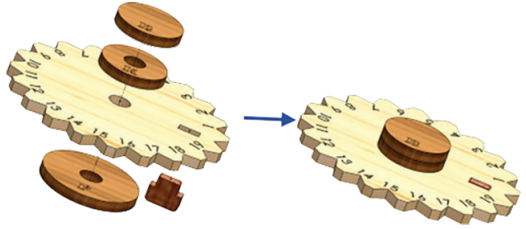
☐   Apply YW Glue to the washer side of the KB Assembly and attach to the front of the Dial. Check alignment using one of the posts on the Base Assembly. Allow the glue to set.

☐   Apply YW Glue to an "F" Washer and attach to the bottom side of the Dial. Check alignment using one of the posts on the base. Allow the glue to set.

Step 4 — Assemble the Code Wheels

Parts Used: 4 Code Wheels, 8 Pins, 8 "F" Washers
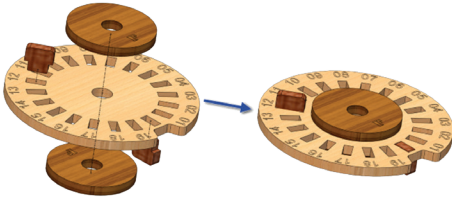
☐　Apply YW Glue to hole "0", the position next to the notch (it has no number) on the Code Wheel and to one of the Pins. Put the Pin into this hole from the _back_ (non-numbered) side. This is the Pusher.
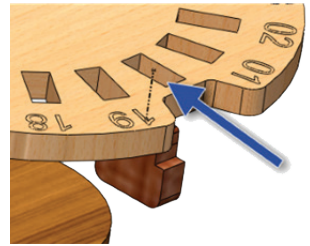
☐　Put a second Pin in a different hole (your choice) using glue as before. This is the code pin and it is inserted from the _top_ (numbered side) of the code wheel (this example shows it is placed at position 12).

☐　Apply YW Glue to one side of two "F" Washers and attach one to each side of the Code Wheel. Wipe any squeeze-out with a damp cloth and immediately place the assembly on the Dial Post on the base, press it down firmly. This will force the wheel assembly to sit flat and true on the shaft and against the base.

☐　Repeat for all four Code Wheels. On wheels 2, 3, and 4 put the code pin in a different hole (your choice). Remove the Code Wheels from the post after the glue has cured.

Note: your package contains 2 Extra Code Wheels, 4 Pins and 4 "F" Washers that will be used later. You may assemble these as above but do not insert the Pin on these extra Code Wheels at this time.

Step 5 — Assemble the Fence

Parts Used: Curley Latch, Fence, Bottom Latch, Fence Support
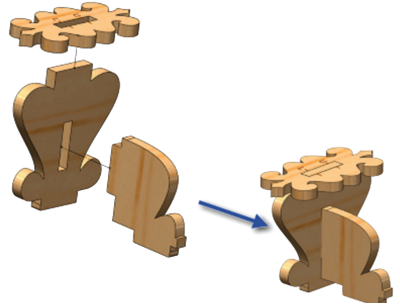
☐   Make the Fence Assembly from the four fence parts as shown ensuring joints are fully seated. Apply CA Glue to the joints from the underside.
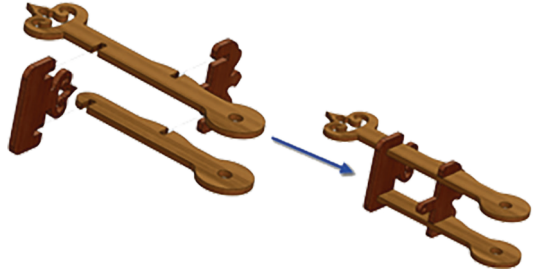
Step 6 — Assemble the Indicator

Parts Used: Indicator Scale, Support, Brace, Base Assembly

☐   Apply YW Glue to the holes in the Scale, Brace, and Support and assemble as shown. Make sure the Scale shows the "U" (Unlocked) and "L" (Locked) face up.

☐   Apply YW Glue to the two open holes in the Base Assembly and the foot of the Indicator Assembly and attach to the base assembly as shown. Use a damp cloth to remove any squeeze-out glue.
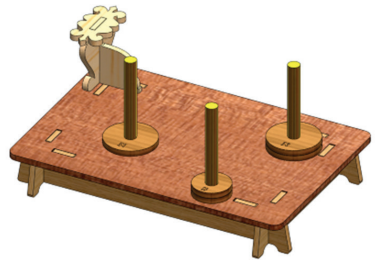
Step 7 — Mount the Fence Assembly

Parts Used: Fence Assembly, 6 "C" Washers, 2 "L" Washers, Base Assembly
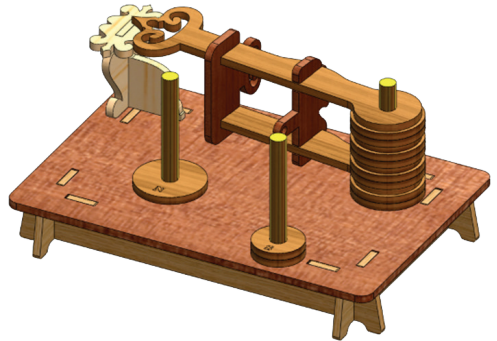
☐ Assemble the washer stack by placing washers in the following sequence "C-C-L-C-C-L-C-C". DO NOT USE GLUE.

☐ Assemble the washers inside the Fence Assembly as shown. DO NOT USE GLUE.

☐ Slip the combined Fence and Washer stack over the Fence Post on the Base Assembly—DO NOT USE GLUE.

Step 8 — Pressure Spring Assembly

Parts Used: 4 Pressure Springs, 4 Gap Spacers

☐ Apply YW Glue to the rectangular hole in the Pressure Spring and to the Gap Spacer. Insert the Gap Spacer from the bottom side.
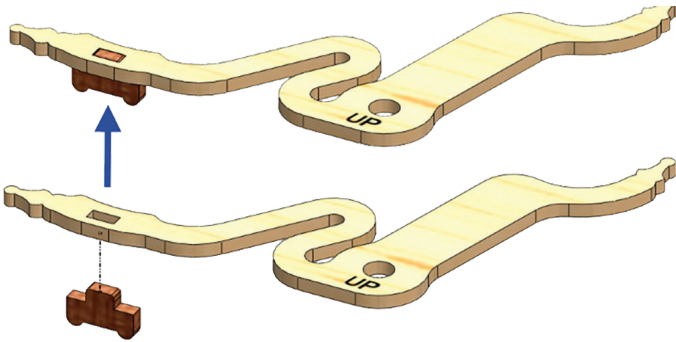
Step 9 — Lubricate the Components

Parts Used: 4 Code Wheel Assemblies, 4 Pressure Spring Assemblies, Base Assembly

This is a good point to stop for the day or night and allow the glue in all of the parts to fully harden. If you have to continue, make sure everything with glue has cured at least one hour before proceeding.

☐ Apply a light coating of candle wax (paraffin) to the inside curved surface of the Pressure Spring Assemblies. Just rub a used candle on these surfaces for a few seconds and it will apply sufficient wax for lubrication. Brush off the candle wax particles from the rest of the assembly. DO NOT apply wax to the hole for the spring post.
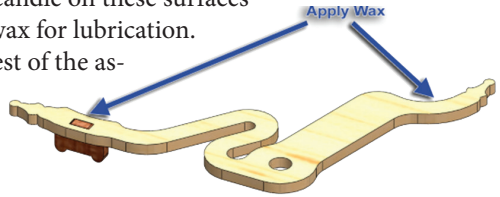
☐ Apply wax to the faces of the two washers on the Code Wheel Assembly (note: you cannot see the bottom washer in this image). Also, apply wax to the rim or circumference of the Code Wheel using the same process as above.
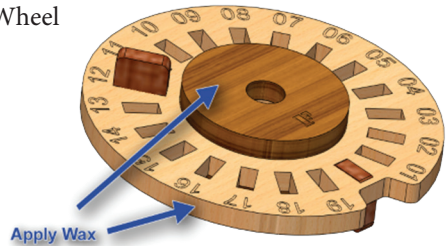
☐ Apply wax to the faces of the two washers on the base assembly. One is on the Dial Post and one is on the Spring Post. Also, rub some wax on the edge of the Fence. Do not apply wax to the Spring Post.
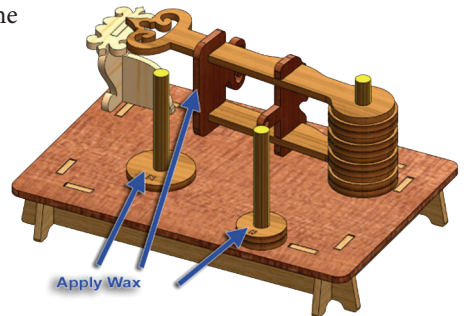
Step 10 — Load Code Wheels and Springs

**Parts Used: Base Assembly, 4 Code Wheel Assemblies, Pressure Spring assemblies, 6 "S" Washers**

☐ Slip a Pressure Spring Assembly over the Spring Post.
☐ Slip the Code Wheel Assembly over the Dial Post.
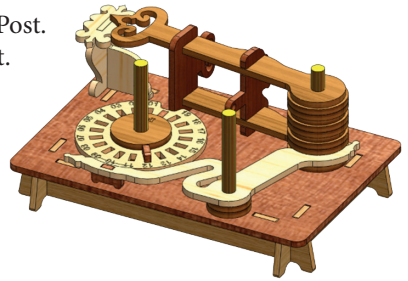
☐ The Pressure Spring must fit in the groove on the Fence Post and you will have to slightly pull the Pressure Spring out so it sits on the circumference of the Code Wheel. USE NO GLUE.
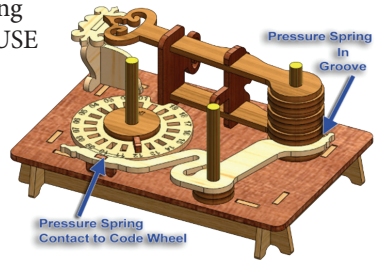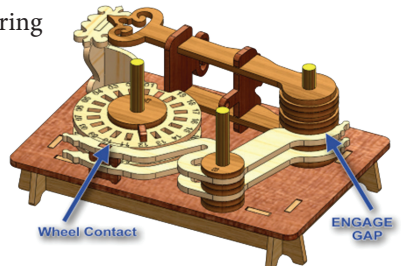
☐ Add *two* "S" Washers over the Pressure Spring. USE NO GLUE.
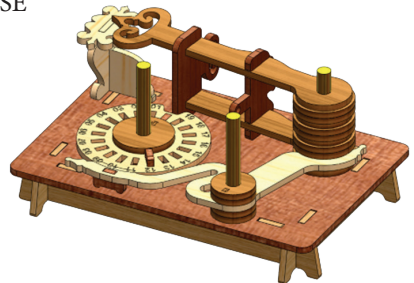
☐ Add a second Pressure Spring Assembly to the Spring Post and a second Code Wheel Assembly to the Dial Post. Fit the Pressure Spring into the groove on the Fence Post as before. Fit the Pressure Spring on the Code Wheel rim as before.

☐ Add *one* "S" Washer to the Spring Post. USE NO GLUE.

Step 11 — Rubber Band Spring

Parts Used: Rubber Band, Latch Support, Spring Loop Washer, Base Assembly

☐ Cut a Rubber Band open. Tie an overhand knot in one end.

☐ Cut a tapered point on the other end. Thread it through the Latch Support hole on the Fence Assembly and the Spring Loop Washer.

☐ Tie a second overhand knot so the two parts are almost touching. You need about 1/8" to 1/4" gap between the Latch Support and Loop Washer.
☐ Trim away the excess rubber band material.

Rubber Band

☐ Stretch the Rubber Band and put the Spring Loop Washer onto the Spring Post. (Note: rubber band not shown). The Fence Assembly should now be held against the Code Wheel by the force exerted by the Rubber Band.

Spring Loop Washer

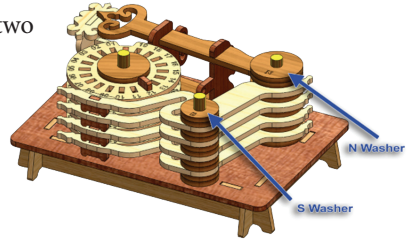☐ Repeat the process adding a 3rd Code Wheel Assembly, Pressure Spring Assembly, two "S" Washers, followed by the 4th Code Wheel, and Pressure Spring Assemblies.
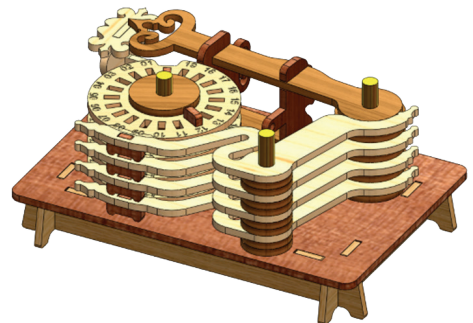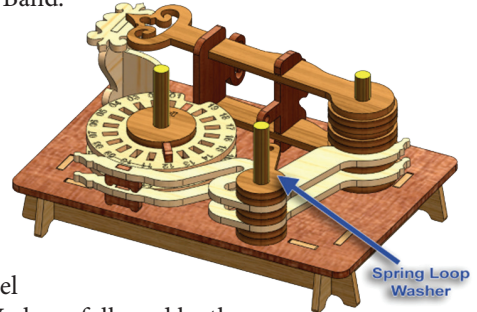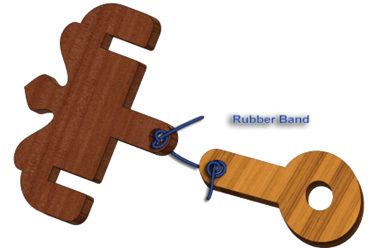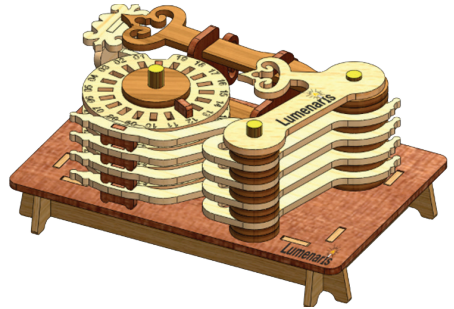
Step 12 — Top Supports

Parts Used: Base Assembly, 2 "S" Washers, 2 "N" Washers, Pointer

☐   Add two "S" Washers to the Spring Post and two "N" Washers to the Fence Post. USE NO GLUE.
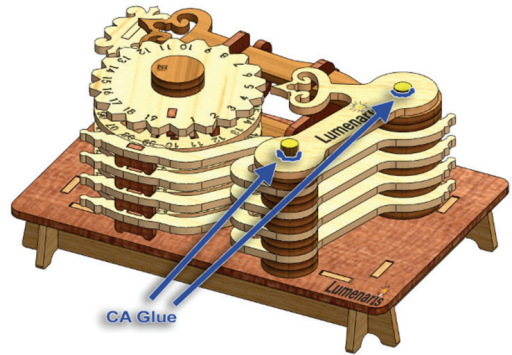
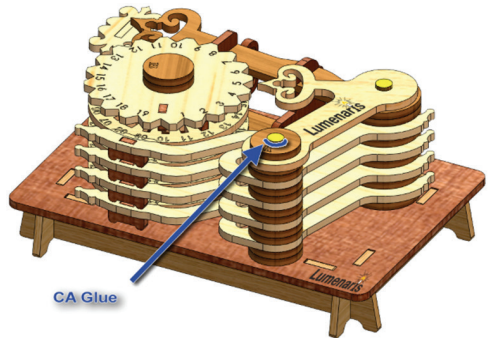☐   Add the Pointer as shown (Lumenaris Logo is up).

Step 13 — Dial

Parts Used: Base Assembly, Dial Assembly

☐ Slide the Dial Assembly over the Dial Post.
☐ Apply CA Glue to the Spring Post and Fence Post as shown. Wipe off all excess glue.

☐ Add a "K" Washer to the top of the Spring Post and apply CA Glue to it. Wipe off all excess glue.

☐ Final Check—If you have sanded the code wheels and spacer washers, you may have altered the alignment of the code wheel top surface to the top of top pressure spring. If these are not in the same plane, it makes the lock harder to operate and can cause the dial to touch the fence. To bring the code wheels back into alignment with the pressure spring, take the single thin washer and insert it under the bottom code wheel. This raises the code wheel stack into alignment.

Here is why it happens: The code wheels and washers have a total of 24 sides. Each layer is approximately 0.120" thick. If you sand 0.0025" or 2½ thousandths of an inch off of the wood when you sand (roughly the thickness of one sheet of copy paper), you will lose 24 x 0.0025" or 0.060" which is half of the thickness of one layer. Adding the thin washer of about half the layer thickness raises the stack back into alignment. If you apply lacquer to the sanded parts, it adds about 0.0025" per side which generally offsets the material lost in sanding. So, just check the alignment and add the washer only if it is needed.

Congratulations

You have just completed building your Combination Lock Model. Now the fun starts with seeing how it works

Observation

☐ Can you figure out how to unlock the combination lock?
☐ How does the code pin position relate to the combination?
☐ Make a chart of Code Wheel number, code pin position, Combination digit.
☐ Swap two Code Wheels—what happens to the combination?
☐ Experiment with other Code Wheels that have pins in different positions. What happens to the combination?
☐ Design—what works in the design, what does not?
☐ From what time period is this code wheel design?
☐ Are there different types of combination locks?
☐ How far back in time combination locks exist?
☐ Can you generate a time-line of the different types of combination locks?
☐ What are the personal safety items that one should be aware of when working on a model and what protection should be used? Did you use it?

Environment

☐ Describe the environmental impact of the product and its packaging. What materials were used? How can it be properly disposed of? How could the product be made better from an environmental point of view?
☐ Speculate on how you would figure out how much wood is lost in the kerf produced during the cutting of the product? From the sheet the parts are cut out of?

Questions to Think About

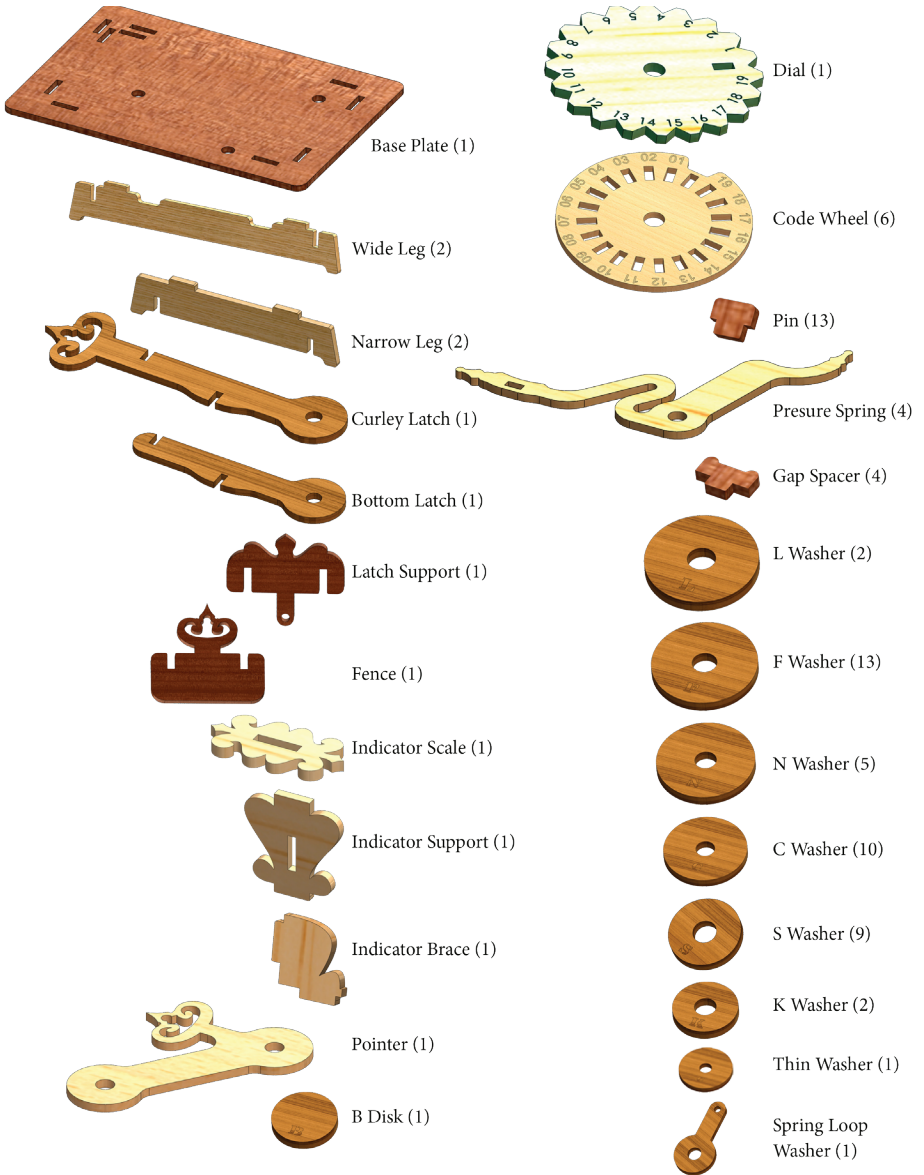☐ How can the US compete in a world with low cost labor?

Analysis

☐ Explain what happens to the combination when two Code Wheels are swapped.

☐ Explain what happens to the combination when the Code Pin of a Code Wheel is moved to another position on the same Code Wheel. Repeat for a different Code Wheel.

☐ Generate a table for a digit of the combination vs. Code Wheel - Code Pin position.

☐ Graph the data from the table of combination = f(Code Pin position), Is the relationship linear? Are their discontinuities?

☐ Write a mathematical expression that relates the Code Wheel number and it's Code Pin location to the combination digits?

☐ The Pointer is offset from the Fence, the Code Pin on a wheel is offset by the width of the pusher from a higher wheel or dial. When calculating a combination from the Code Pin position on a Code Wheel and the level the Code Wheel is on. What math function returns the remainder after one or more full or partial turns is needed. Do you know what that function is? How is it used?

☐ What could be improved in the design ? Why?

☐ How could we add a time clock to the lock which would not allow it to be unlocked except at specific times?

Results

Write a technical report describing the construction project, your observations, analysis, environmental impact, conclusions and recommendations.

Parts List

Base Plate (1)

Wide Leg (2)

Narrow Leg (2)

Curley Latch (1)

Bottom Latch (1)

Latch Support (1)

Fence (1)

Indicator Scale (1)

Indicator Support (1)

Indicator Brace (1)

Pointer (1)

B Disk (1)

Dial (1)

Code Wheel (6)

Pin (13)

Presure Spring (4)

Gap Spacer (4)

L Washer (2)

F Washer (13)

N Washer (5)

C Washer (10)

S Washer (9)

K Washer (2)

Thin Washer (1)

Spring Loop
Washer (1)

Other Parts

- 3 Metal Posts
- 3 - 8/32x1/2" Machine Screws
- 2 - Rubber Bands
- This Instruction Manual

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Lumenaris® Combination Lock

Learning Objectives:

1. Demonstrate how a code wheel combination lock works
2. Learn the terminology of locks
3. Hands on construction of a lock
4. Explain the concepts of setting a combination
5. Calculate the number of unique combinations possible
6. Calculate the time to try all possible combinations
7. Explain the mathematical relationship between the pin location on the code wheel to the dial position
8. Measure the environmental impact of building, using, and disposing of this product

Assembly Time - 3-5 hours

Tools and Supplies Needed:

* Yellow wood glue
* Cyanoacrylate glue (Instant glue)
* Candle or paraffin wax
* Optional: 320 grit sand paper
* Safety Glasses
* 1 Bamboo wood skewer or tooth pick to use as a glue applicator
* Hammer - small 2 to 4 ounce - wood, metal, or plastic

Lesson Plan:

A lesson plan covering the history, science, and math is available pn the website. It contains additional experiement, educational material, questions, and an answer sheet.

Made in the USA

Of European Birch from ecologically managed forests
Suitable for Age 13+

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