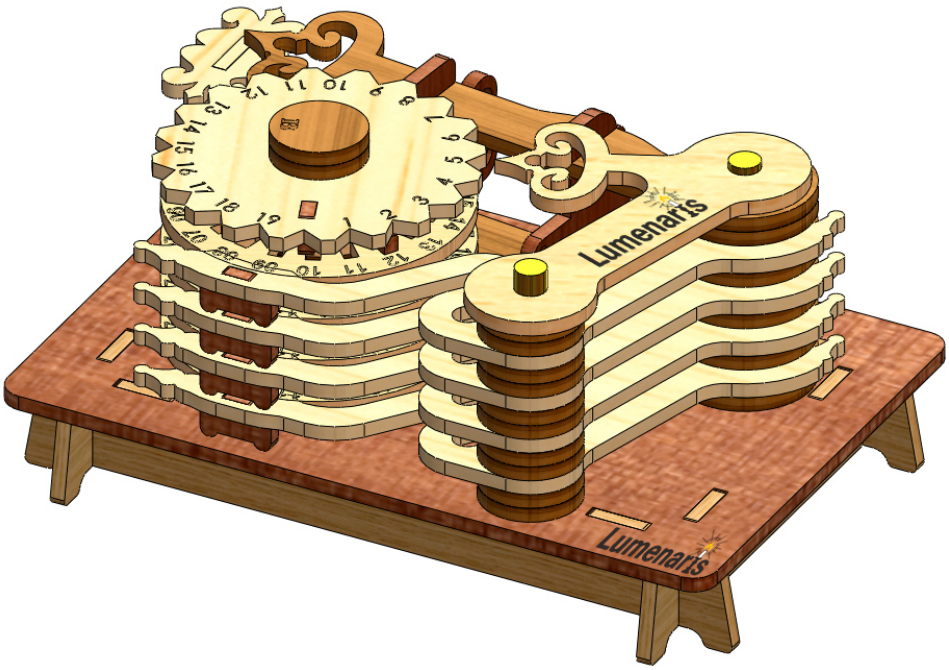
Lesson Plan and Suggestions for:

The Lumenaris Combination Lock™



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Section I. The Combination Lock

A. What is a Combination Lock?

A Combination Lock is a lock that has a dial or set of dials that are used by rotating through a specific sequence to unlock the lock. The dials are usually marked with letters or numbers.

B. Brief History

The first mechanical locks show up sometime around 2000 BC[1, 2] in Egypt. They have gone through many changes over time to that which is used today.

Locks are basically divided into two branches; key based and combination based.

The earliest known key based locks started during the Assyrian Empire in Khorsabad near Nineveh about 704 BC. Nineveh is located near the modern city of Mosul, Iraq. These locks were constructed out of wood.

The earliest known combination lock was excavated from a Roman tomb at Kerameikos, in Athens, Greece. It is a multi-dial lock where each number is dialed on a separate dial. The exact date is unknown, but Roman tombs at Kerameikos date from 800 BC to 150 BC.

Al-Jazari in his book, Compendium of the Theory and Practice of Mechanical Arts from 1198AD, describes a four dial combination lock[3].

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[1] http://www.locks.ru/germ/informat/schlagehistory.htm .

[2] The World of Wonders: a record of things wonderful in nature, science and art, p.300, Cassell & Company, Ltd. 1883

[3] http://www.christies.com/lotfinder/lot_details.aspx?intObjectID=5358612

Muhammad al-Baghdadi of Northern Mesopotamia, in the 13th Century made a 4 dial Combination Lock Box which was sold at Christies[4] in London for $758,894 in October of 2010.

The four dial knobs are shown on the top surface of the box.

Gerolamo Cardano, 1501-1576 AD, also described a combination lock. Hans Bullman and Hans Ehemann in the mid 1500's developed combination locks as did Girolamo Cardano and Johannes Bueto.

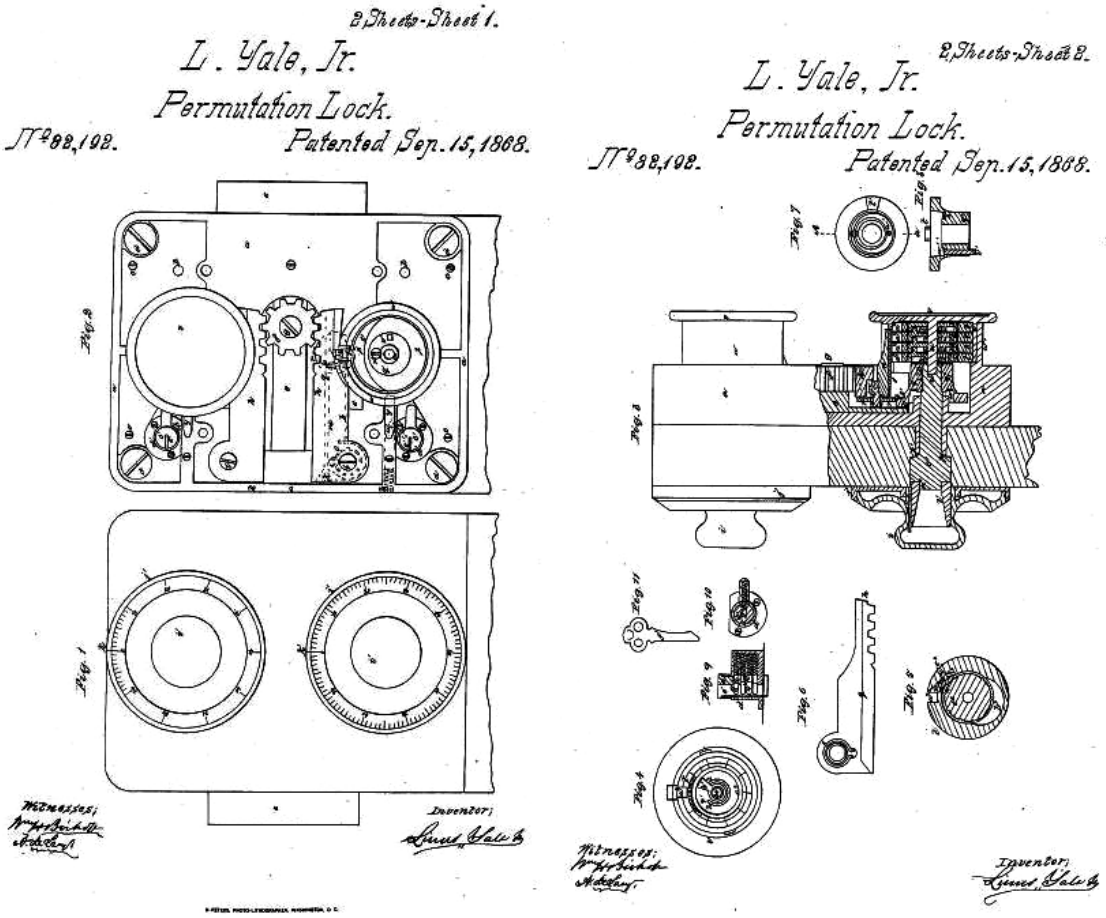
In the 1600's, Gustavus Selenus also described a combination lock.

The Eureka Lock patented in 1862, has five tumblers or code wheels and was used by the US Treasury. It has 1,073,741,824 combinations which would take more than 2000 years to try them all.

Joseph Loch invented a lock for Tiffany's Jewelers in 1878 to protect their merchandise.

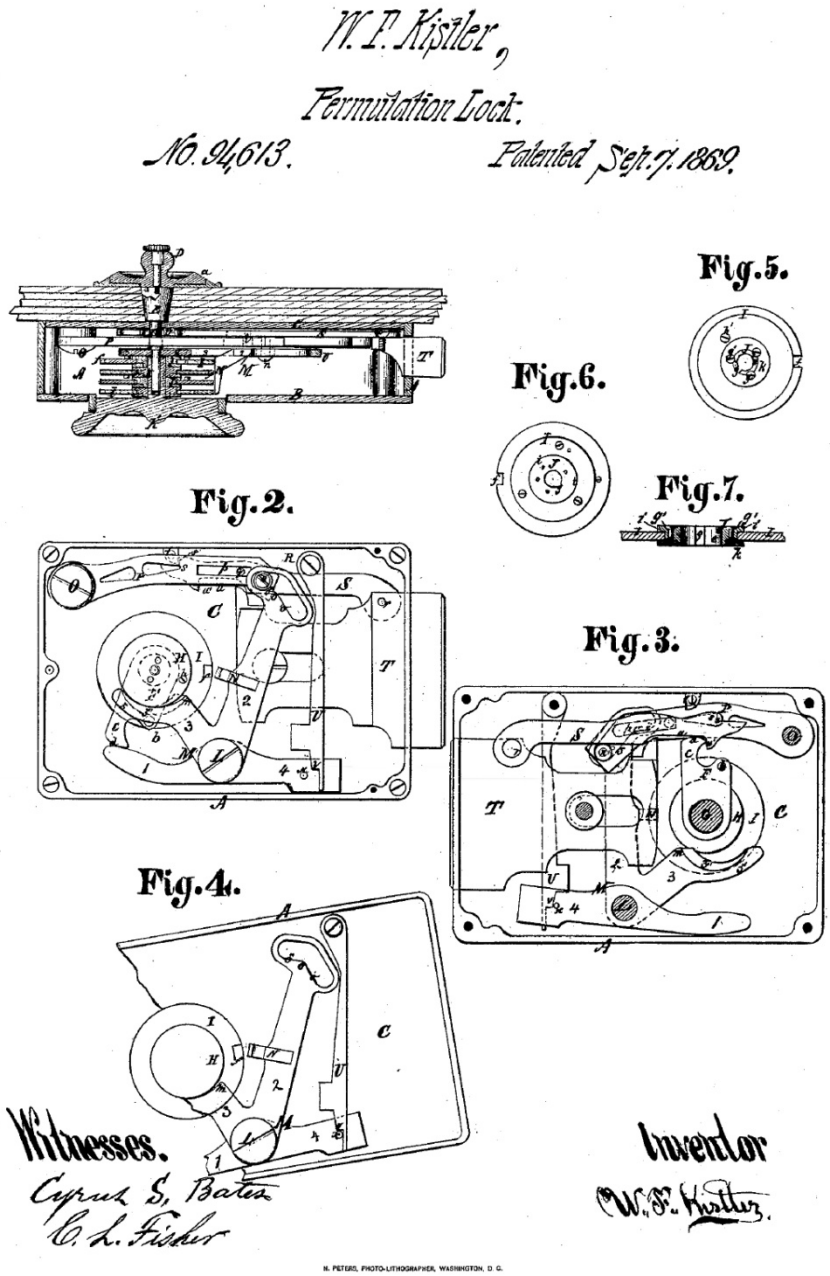
[4] Ibid, Lot Notes

Linus Yale, Jr. patents a cylinder pin-tumbler lock in 1862 followed by the modern combination lock in 1862-1868[5]. Yale's dial combination lock was historically significant because it became the banking standard and replaced older locks which used keys.



[5] http://patft1.uspto.gov/netahtml/PTO/search-bool.html

W. F. Kistler, in September 7, 1869, correctly named the combination lock a "Permutation Lock" in his patent US 94,614.



Section II. Lesson Suggestions

A. Shop

In assembling your Lumenaris Combination Lock™ kit, you can sand the surfaces lightly, stain the wood, and apply a clear coating of lacquer or paint to finish the lock before assembly. (Note: Do not sand the washers, code wheels or pressure springs).

Q1: *What process step above takes the longest time for you to perform?*
Q2: *What process step above takes the longest overall time?*

B. Math

Everyone calls this style of lock a combination lock, but is it?

A combination is defined as an arrangement of a specific group of numbers where the order doesn't matter. For example, if the combination was 10-15-02-07, and if any arrangement of these would unlock the lock (e.g. 15-10-02-07, 02-15-10-07, etc.), then it's a Combination lock. In a Permutation, the order of these numbers matters, so that makes our lock, and almost every other combination lock, a Permutation Lock.

Q3: *How many possible combinations would the Lumenaris Combination Lock™ have if there were only 1 code wheel? 2 code wheels? 3 code wheels? Or 4 code wheels?*
Q4: *If it takes 1 minute to try a combination, how many minutes would it take to try all possible combinations for the lock? What is that in hours and days?*
Q5: *What does the fence do in mathematical terms (Hint: it's a Boolean function)?*

C. Computational Science

Did you know that combination lock has a place where information is stored? It has a place where information is input by a person and it has a method of combining these two items to allow the lock to change states (locked <-> unlocked).

Q6: *How is information stored in the combination lock?*
Q7: *How is information input into the combination lock?*
Q8: *How does the mechanism convert the stored information and the input information into a single output (locked or unlocked)?*
Q9: *Using the basic mechanism of this combination lock, how would you integrate it into a door vault?*
Q10: *How could you use X-rays to help you unlock the lock? What could prevent X-rays from working?*

D. Environment

You are the manufacturer of this lock and need to make a choice between cutting the components with a saw vs. using a laser. Your objective is to use a process that minimizes energy consumption.

Definitions and Facts:

What is Energy?

$$Energy\ [watt - minutes] = Power\ [watts] * Time\ [minutes]$$

If you know the power that a piece of equipment uses in watts and you know how long you run it for in minutes, multiplying these together yields the Energy that is consumed e.g. Watt-Minutes. The electric meter in your home measures energy in Kilowatt-Hours. A Kilowatt-Hour is simply 60,000 Watt-Minutes. Typically a Kilowatt-Hour costs about 15¢.

The fret saw or scroll saw uses about 150 watts of power when it runs, while the laser uses about 100 watts. The saw is guided by an operator and the operator can cut at an average of 10 inches per minute. The laser is computer controlled and can cut at an average of 20 inches per minute. Assuming that the energy consumed by the person is not included:

Q11: *How many watt-minutes of energy are used by the saw and by the laser to cut the dial of lock?*
Q12: *Which method uses less energy (fret saw or laser)?*
Q13: *Which method is faster (fret saw or laser)?*

Did you ever hear of the term "kerf". When a saw or laser cuts a piece of wood, the cut it creates is called the kerf. In a wood saw, this can be about 20 thousandths of an inch wide. The laser's kerf is about 2 thousandths of an inch wide. How big is 2 thousandths of an inch? A typical sheet of printer paper is about 3 thousandths of an inch thick, so the laser's kerf or cut is smaller than the thickness of a sheet of paper. Wow!

When the laser vaporizes the wood, the waste product is primarily CO_2 (carbon dioxide) and water vapor. When a saw cuts the wood, it produces saw dust, which when placed in a land fill or your compost pile, eventually converts to CO_2 and water vapor.

If the wood is ⅛" thick:

Q14: *How much less waste is produced by the laser when making the dial for this lock?*

E. Language Arts

Technical Writing – explaining how things work and how they are different is an important step in communicating information from one person to another, particularly if they are not close enough to talk.

Q15: *Write a descriptive paragraph in which you describe the way this lock is different compared to a locker or bicycle combination lock.*

Writing about how you feel – explaining how you feel about things that have happened to you or could happen to you are important to communicate.

Q16: *Write a story about being "locked in or locked out."*
Q17: *Write a story about locking in your feelings.*

F. History - Social Studies

Study the history of inventions that "keep things in" or "keep things out."

Q18: *Write a one page summary of these inventions. Don't limit yourself to combination locks. You can include other inventions such as fences, doors, walls, river locks, etc.*

Learn about Al-Jazari, Joseph Loch, and Linus Yale, Jr.

Q19: *Pick one of these people and summarize their work. Did they work on inventions other than locks?*

Research the importance that locks had to their users.

Q20: *Describe in one page how locks were used as an alternative to hiding or constantly guarding your possessions.*
Q21: *How did gold miners protect their finds while in the gold fields of California during the gold rush of the 1840's?*

Look-up and read Linus Yale, Jr.'s patent #82,192 on US Patent Office Web Site. Go to:

- www.uspto.gov
- Patents
- Search
- Quick Search
- Term 1 (82192)
- Field 1(Patent Number)
- Select Years (1790 to Present)

- View Images (you may need to download a viewer for the images).[6]

Q22: *Read through U.S. Patent 82,192 and summarize the invention? What does Yale claim is unique about his invention?*

G. Rubric

This detailed rubric contains suggestions for scoring each piece of work that your student delivers. The four columns describe the quality of the work from excellent to poor.

[6] http://www.uspto.gov/faq/plugins/tiff.jsp

Lumenaris Combination Lock™

	Excellent	Very Good	Good	Poor
QUESTIONS	Consistent use of multiple facts, perspectives, observation, and evidence	Relies on multiple facts, observation, and evidence	Uses one fact/item of observation or evidence	States facts w/no support
	Uses variety of methods for supporting evidence	Use of supporting evidence	Limited support	Little or no use of context
	Relies on identification, evaluation, and comparison/contrast	Use of differentiation between and among statements	Limited use of context	
EVIDENCE	Relies heavily on primary and secondary sources from a variety of resources	Uses some primary/secondary sources	Limited secondary sources used - two	One or no secondary sources used e.g. Wikipedia
	Uses deftly research skills in documenting authorities	Uses limited number of other resources	Very Limited primary sources used	No primary source used
	Uses analysis, evaluation, synthesis throughout	Uses research skills with limited assessment of evaluation of source	No attention to research skills in evaluating authorities	No evaluation of credibility of sources
	Efficient, clear, effective and complete use of direct observation	Complete and effective use of direct observation	limited direct observation	No direct observation
UNDERSTANDING	The solution shows a deep understanding of the problem and includes the ability to identify the appropriate concepts and information necessary	The solution shows a broad understanding of the problem and major concepts necessary	The solution is not complete indicating that parts of the problem are not understood	There is no solution or the solution has no relationship to the problem
	The solution completely addresses all components	The solution addresses all of the components presented in the task	The solution addresses some but not all of the components presented in the task	Inappropriate procedures are used
	The solution puts to use the underlying concepts upon with the task is designed			Inappropriate concepts are applied
				The solution addresses none of the components presented

	Excellent	Very Good	Good	Poor
STRATEGIES	Very efficient and sophisticated strategy leading directly to the solution	Uses a strategy that leads to the solution	Uses a strategy that is partially useful, leading part way toward a solution	No evidence of a strategy or procedure
REASONING	Employs refined and complex reasoning	Uses effective reasoning	Some evidence of reasoning	Uses a strategy that does not help solve the problem
	Makes relevant observations and connections	All parts are correct and the solution is achieved	Some parts may be correct, but the task is not accomplished	There were so many errors that the problem could not be solved
	Verifies the results and evaluates the reasonableness of the solution			
PROCEDURES	Applies procedures accurately and correctly to solve the problem	Effectively uses procedures	Could not completely carry out the procedures	No evidence of reasoning
COMMUNICATION	Clear, effective explanation with details on how the problem is solved and all steps included so reader inferences are not required to determine how and why decisions were made	Clear explanation	Incomplete or unclear explanation	No explanation of the solution, or the explanation cannot be understood, or the explanation is unrelated to the problem
	Representation is actively used as means of communicating the ideas related to the solution	Accurate representation (tables, figures, graphs, drawings)	Some use of appropriate representations (tables, figures, graphs, drawings)	No use or incorrect use of representations (tables, figures, graphs, drawings)
	Precise and appropriate use of terminology and notation	Effective use of terminology or notation appropriate to the problem	Some use of terminology or notation appropriate to the problem	No use of terminology or notation appropriate to the problem

Section III. Answer Sheet:

A. Shop

In assembling your Lumenaris Combination Lock™ kit, you can sand the surfaces lightly, stain the wood, and apply a clear coating of lacquer or paint to finish the lock before assembly.

A1: What process step above takes the longest time for you to perform?

Sanding the wood takes the longest time for a person to perform.

A2: What process step above takes the longest overall time?

The longest amount of time is spent waiting for the stain to dry.

B. Math

Everyone calls this style of lock a combination lock, but is it?

A combination is defined as an arrangement of a specific group of numbers where the order doesn't matter. For example, if the combination was 10-15-02-07, and if any arrangement of these would unlock the lock (e.g. 15-10-02-07, 02-15-10-07, etc.), then it's a Combination lock. In a Permutation, the order of these numbers matters, so that makes our lock a Permutation Lock.

A3: How many possible combinations would the Lumenaris Combination Lock™ have if there were only 1 code wheel? 2 code wheels? 3 code wheels? Or 4 code wheels?

The code wheel has positions 0 through 19 or 20 possible positions. The notch in the code wheel is only 1 position wide, meaning that all 20 possible positions are valid to lock or unlock the lock. Some locks have a notch that is several numbers wide giving you the impression that there are lots more possible combinations than what actually exists.

A single code wheel lock would have 20 possible positions to unlock the lock.

$$20^n = 20^1 = 20\ combinations$$

$$where\ n = number\ of\ code\ wheels$$

A double code wheel lock has:

$$20^n = 20^2 = 400\ combinations$$

A three code wheel lock has:

$$20^n = 20^3 = 8000\ combinations$$

Finally, the Lumenaris Combination Lock which is a four code wheel lock has:

$$20^n = 20^4 = 160{,}000\ combinations$$

Note: The last digit can be dialed until the fence drops into the notch without knowing the number therefore one could open the lock by trying only the 8000 combinations of the three code wheel lock and rotating the dial until the lock unlocks.

A4: If it takes 1 minute to try a combination, how many minutes would it take to try all possible combinations for the lock? What is that in hours and days?

If one were to try all possible combinations of the lock (160,000) at 1 try per minute it would take:

- $160{,}000\ combinations * \frac{1\ minute}{combination} = 160{,}000\ minutes$
- $160{,}000\ minutes * \frac{1\ hour}{60\ minutes} = 2{,}666.7\ hours$
- $160{,}000\ minutes * \frac{1\ hour}{60\ minutes} * \frac{1\ day}{24\ hours} = 111.1\ days$

A5: What does the fence do in mathematical terms (Hint: it's a Boolean function)?

The fence performs the Boolean function called a Logical AND between the code wheels. For example, on a two code wheel lock, the notch from wheel 1 and the notch from wheel 2 must be present under the fence to unlock the lock. If the presence of the notch under the fence is a "1" and the absence of a notch under the fence is a "0" then the truth table for unlocking the lock, the Boolean AND function is as follows:

Code Wheel 1	Code Wheel 2	Fence Position
0	0	Locked
0	1	Locked
1	0	Locked
1	1	Unlocked

C. Computational Science

A6: How is information stored in the combination lock?

The code pin position on a code wheel is used to store the combination information in the lock.

A7: How is information input into the combination lock?

The dial is the human input device for the lock and the sequence that is inputs through it transfers information into the code wheel positions which act as a temporary memory to store that information.

A8: How does the mechanism convert the stored information and the input information into a single output (locked or unlocked)?

The position of the notches in each code wheel as governed by the input information and as modified by the stored information is mathematically "ANDed" by the fence to produce a binary output of Locked or Unlocked.

A9: Using the basic mechanism of this combination lock, how would you integrate it into a door vault?

It would need to use the fence to enable or disable the extension or retraction of a bolt or other blocking device that prevents a vault door from opening.

A10: How could you use X-rays to help you unlock the lock? What could prevent X-rays from working?

If X-rays could be sent through the vault door and detected on the opposite side of the safe, the position of the code wheel notches could be observed. X-rays could be prevented from working by making the code wheels transparent to X-rays or by blocking the X-rays with something that is X-ray opaque such as a Lead sheet.

D. Environment

You are the manufacturer of this lock and need to make a choice between cutting the components with a saw vs. using a laser to cut out the pieces. Your objective is to use a process that minimizes energy consumption.

Definitions and Facts:

What is Energy?

$$Energy\ [watt - minutes] = Power\ [watts] * Time\ [minutes]$$

If you know the power that a piece of equipment uses in watts and you know how long you run it for in minutes, multiplying these together yields the Energy that is consumed e.g. Watt-Minutes. The electric meter in your home measures energy in Kilowatt-Hours. A Kilowatt-Hour is simply 60,000 Watt-Minutes. Typically a Kilowatt-Hour costs about 15¢.

The saw uses about 150 watts of power when it runs, while the laser uses about 100 watts. The saw is guided by an operator and the operator can cut at an average of 10 inches per minute. The laser is computer controlled and can cut at an average of 20 inches per minute.

A11: How many watt-minutes of energy are used by the saw and by the laser to cut the dial of lock?

To figure this out, you need to know the length of the cut that either the saw or laser would have to make. Then multiplying it by the power and dividing it by the speed will produce the energy required.

To compute the length of the cut there are three components – the perimeter of the dial, the circumference of the inside hole, and the perimeter of the pusher pin rectangular hole.

- The dial perimeter consists of 20 "V" shaped notches with 2 sides of length 0.22"and 20 flats between "V notches which are 0.11" long. These sums up to 8.80" of perimeter.
- The ¼" diameter hole has a circumference of 0.79" and the rectangular pusher pin hole that is 0.125" x 0.280" or 0.81" in perimeter
- In total, the three components add up to 12.6" of perimeter that must be cut by either the saw or the laser.

	Length		Quantity	Perimeter	Units
V Notch	0.22		40.00	8.80	Inches
Flat Notch	0.11		20.00	2.20	Inches
1/4" Hole in Dial	0.25	3.14	1.00	0.79	Inches
Pusher Pin Hole	0.25	0.56	1.00	0.81	Inches
			Total	**12.60**	**Inches**

To compute the energy, take the perimeter in inches divided by the speed in inches per minute which yields the time to cut in minutes. Multiply these minutes by the power in watts and the result is the Watt-Minutes of Energy needed to perform the operation. The ratio of Saw to Laser is about 3:1 times worse for the saw vs. the laser, making the laser a clear winner in the energy battle.

	Power	Units	Speed	Units	Peri-meter	Units	Energy	Units
Saw	150	Watts	10	Inch/Minute	12.60	Inches	188.93	Watt-Minutes
Laser	100	Watts	20	Inch/Minute	12.60	Inches	62.98	Watt-Minutes
						Ratio	**3.00**	

A12: Which method uses less energy (fret saw or laser)?

The laser uses 3x less energy than the fret saw because its power is lower and its speed is higher.

A13: Which method is faster (fret saw or laser)?

The Laser is faster as it cuts at 2x higher speed than the fret saw.

A14: How much less waste is produced by the laser when making the lock?

The volume of wood which is vaporized by the laser is the length of the cut times the width of the cut times the thickness of the material.

	Length [inches]	Width or Kerf [inches]	Thickness [inches]	Volume [cubic inches]
Saw	12.60	0.020	0.125	0.031
Laser	12.60	0.002	0.125	0.0031
			Ratio	**10**

E. Language Arts

Technical Writing – explaining how things work and how they are different is an important step in communicating information from one person to another, particularly if they are not close enough to talk.

A15: Write a descriptive paragraph in which you describe the way this lock is different compared to a locker or bicycle combination lock.

Key points for the student to address:

- Construction materials
- Visibility of the mechanism
- Incorporation of a hasp or bolt

Writing about how you feel – explaining how you feel about things that have happened to you or could happen to you are important to communicate.

A16: Write a story about being "locked in or locked out."
A17: Write a story about locking in your feelings.

F. History - Social Studies

Study the history of inventions that "keep things in" or "keep things out."

A18: Write a one page summary of these inventions. Don't limit yourself to combination locks. You can include other inventions such as fences, doors, walls, river locks, etc.

Learn about Al-Jazari, Joseph Loch, and Linus Yale, Jr.

A19: Pick one of these people and summarize their work. Did they work on inventions other than locks?

Research the importance that locks had to their users.

A20: Describe in one page how locks were used as an alternative to hiding or constantly guarding your possessions.

Key points for the student to address:

- Locks did not require a person to be present at all times which many times was not practical or cost effective
- Locks eliminated the risk of someone finding the hiding place either intentionally or accidentally
- Locks raised the awareness of where the wealth was concentrated
- Locks eliminated the risk of a dishonest guard

A21: How did gold miners protect their finds while in the gold fields of California during the gold rush of the 1840's?

Some of the ways they would protect their findings were to carry them on their person or burying them in a leather pouch in a hiding place to prevent theft. The hiding method carried the risk of the miner being observed while hiding the pouch, of accidental discovery, and of the miner forgetting the location. To prevent the latter, miners would sometimes draw the location on a map raising the risk of the location being discovered.

Look-up and read Linus Yale, Jr.'s patent #82,192 on US Patent Office Web Site. Go to:

- www.uspto.gov
- Patents
- Search
- Quick Search
- Term 1 (82192)
- Field 1(Patent Number)
- Select Years (1790 to Present)
- View Images (you may need to download a viewer for the images).[7]

A22: Read through U.S. Patent 82,192 and summarize the invention? What does Yale claim is unique about his invention?

[7] http://www.uspto.gov/faq/plugins/tiff.jsp

Section IV. Feedback

We are always looking for ways to improve our products including this lesson plan.

Our company's focus is on providing Products that are "Fun with a Purpose" to help young people grow in the world around them and your ideas are always welcome.

If you have ideas, suggestions, corrections, questions, photos of a completed lock, critiques, or reviews on this lesson plan or for the combination lock that you would like to share with us, you can send an email with any of these to:

combination.lock@lumenaris.com