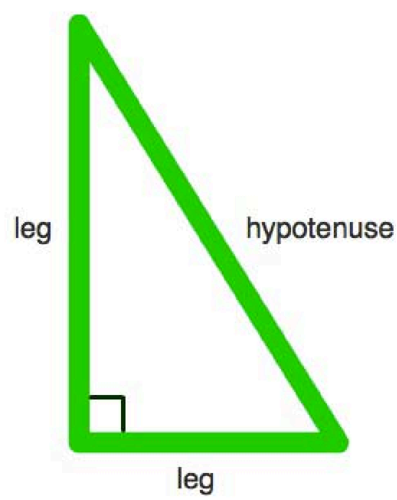
Hi. My name is Irv Kalb, and I am a mentor for the VEX Robotics Team 3129A, the Green MacHHHHine.

I would like to explain how we are using the Pythagorean Theorem to make perfect right angles in our robot. Right angles have allowed us to build a very strong and stable robot for the VEX Round Up competition.

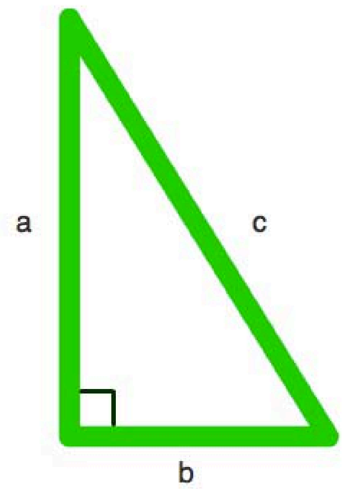
QuickTime™ and a
decompressor
are needed to see this picture.

As you may know, Pythagoras was a Greek philosopher and mathematician. He is most well known for what is called the Pythagorean Theorem.

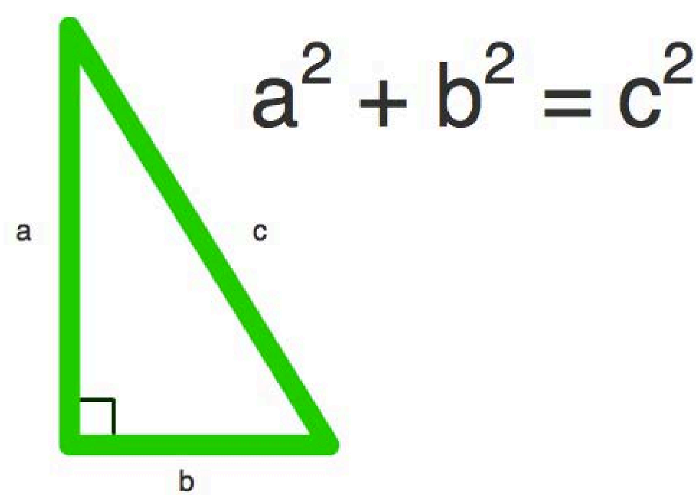
Stated simply, the Pythagorean Theorem says that in a right triangle, the sums of the squares of the two shortest sides (called the legs) will equal the square of the longest side (called the hypotenuse).



Here we have a right triangle, with legs of length a and b and a hypotenuse of length c.



This shows a right triangle with the Pythagorean Theorem formula stated in mathematical terms: a squared plus b squared equals c squared:



It turns out that the converse of this theorem is also true. That is, if you have a triangle where the length of the longest side squared, equals the sum of the lengths of the other two sides squared, then the triangle must be a right triangle.

Converse of Pythagorean Theorem

if

$$a^2 + b^2 = c^2$$

then

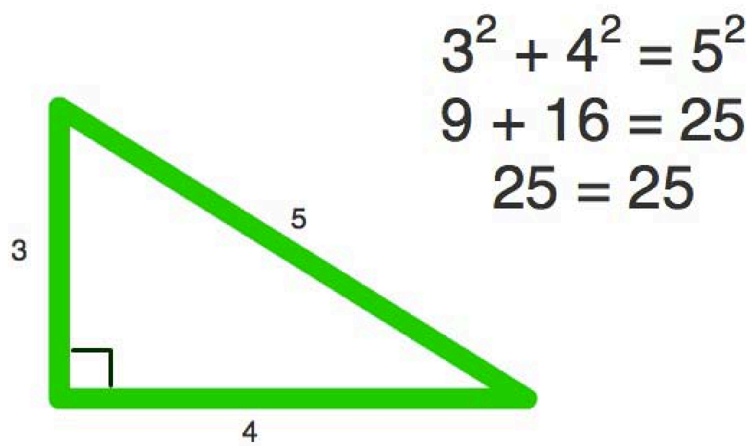
triangle is a right triangle

The point of all this is, if you create a Pythagorean triangle, then you will create a perfect right angle – which is very useful when building robots.

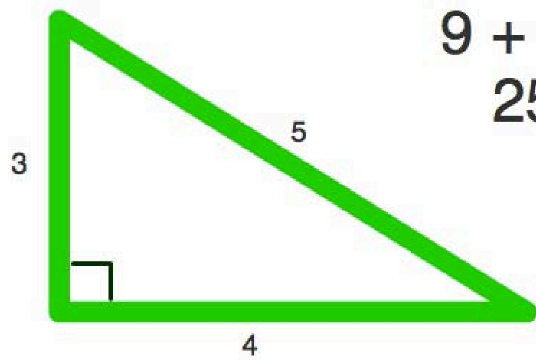
Now, I want to show how we use this in the design of our robot. In the robot that our team built to play the Vex Round Up game, we decided to build a two-stage elevator, which raises and lowers a claw to grab and place tubes.

There are a number of places on our robot where we wanted, or needed to have right angles. While certain Vex parts can give you basic right angles …

There are an infinite number of Pythagorean right triangles. However, when building Vex robots, you want to work with ones that have integers, or counting numbers, in them. The simplest example is the 3, 4, 5 right triangle



This works because 3 three squared plus 4 squared equals 5 squared. Or working through the math, 9 + 16 = 25. The angle opposite the side whose length is 5 is a right angle.



$$3^2 + 4^2 = 5^2$$
$$9 + 16 = 25$$
$$25 = 25$$

All Vex structural parts have holes that are ½ inch apart. However, the exact distance is not important. What *is* important, is that the holes are all the same distance on all pieces. So we can just think of "holes" as the units constant.

QuickTime™ and a
decompressor
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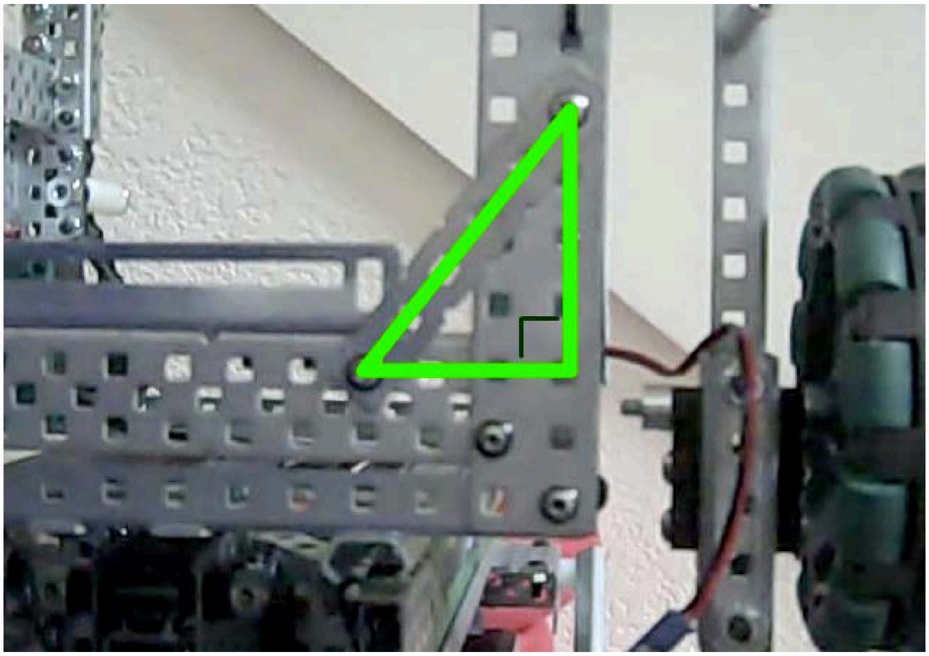
Here’s a simple example of how we apply the Pythagorean triangle, and Vex distances, in our robot. To surround the Round Up tubes on three sides we wanted our claw to have two ninety-degree angles. To accomplish this went into each corner, and constructed a simple 3, 4, 5 right triangle.

QuickTime™ and a decompressor are needed to see this picture.

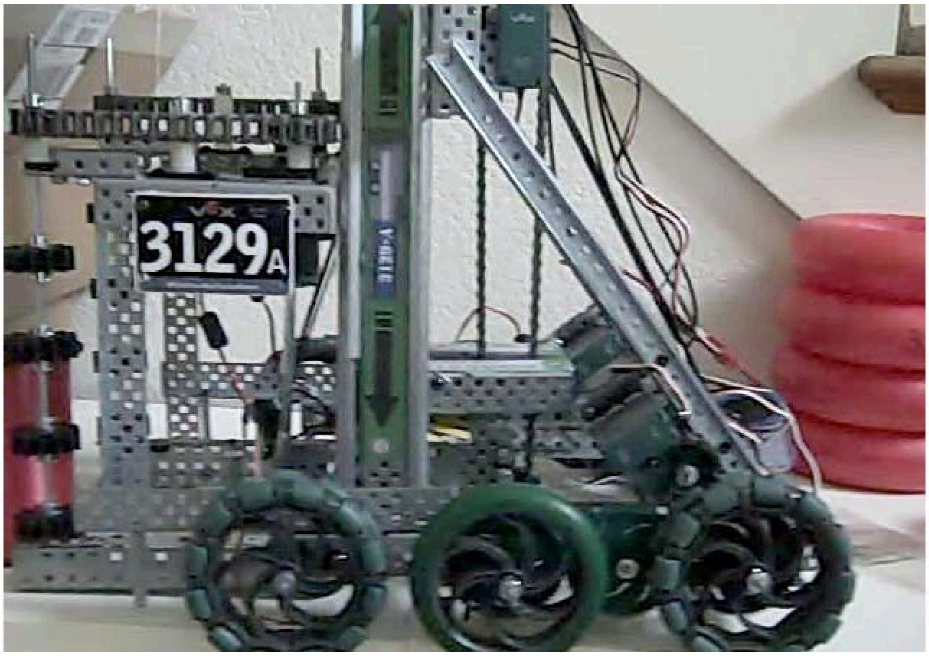
To keep exact right angles in our claw, we went from the corner and we counted starting from zero, out 3 holes in one direction, and counted 4 holes in the other direction. Then we cut a strut that is 5 units in length (actually 6 holes total), and bolted that in as the hypotenuse.

[Video of counting holes]

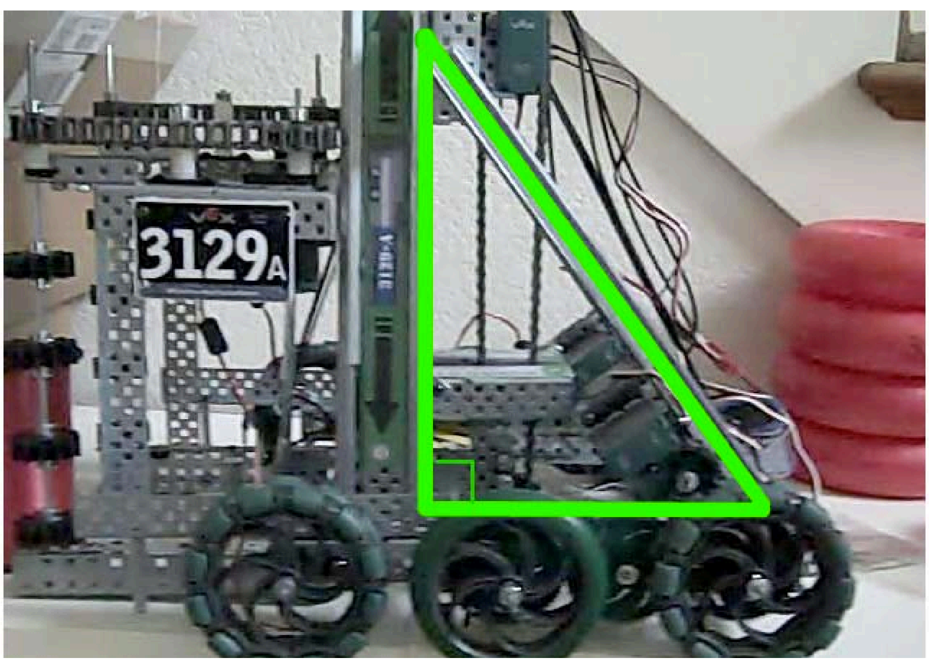
This results in a very strong structure, and gives us a perfect ninety-degree angle.



Our elevator provides another example where we needed a right triangle. In order for the elevator to be efficient, we wanted it to go straight up and down. Or thinking of it another way, our elevator had to be perpendicular to our drive base.

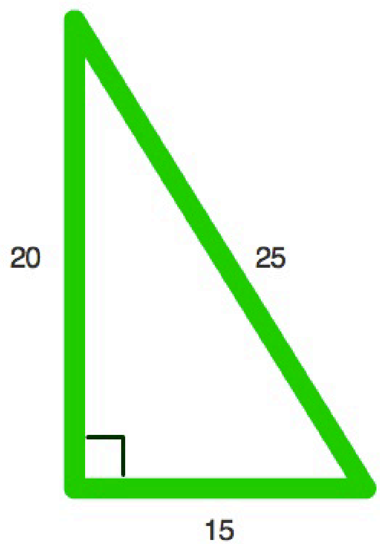


Our elevator is quite tall, and we wanted to support it as much as possible. While the distance here is much greater, we again used the converse of the Pythagorean theorem to ensure that we had our elevator aligned just right.



We wound up building another integer Pythagorean right triangle, but this time, 15 by 20 by 25 units. This is exactly the same as a 3, 4, 5 right triangle, but each distance is multiplied by five.

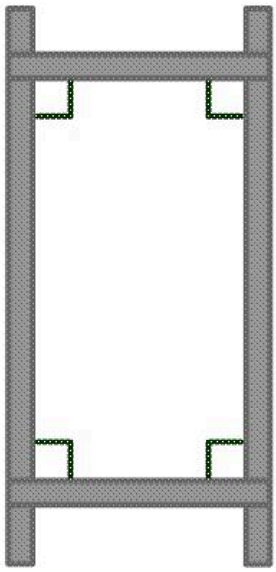
$$15^2 + 20^2 = 25^2$$
$$225 + 400 = 625$$
$$625 = 625$$



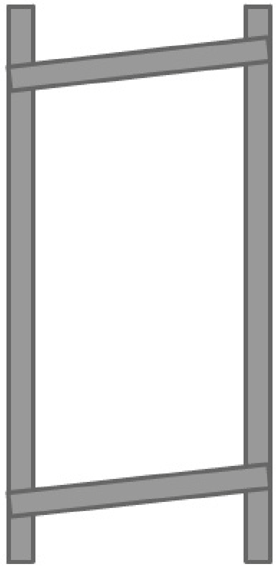
These supports are so strong that grabbing them is our preferred way to pick up our robot.

Once we figured out how to make the elevator perpendicular to our drive base, we also had to make our elevator move up and down. Our elevator is designed to travel on two linear slides. But in order for these slides to work together, they must be perfectly parallel. We faced a tough challenge trying to figure out how to make these pieces be, and stay parallel. Here was our thought process.

We know that a rectangle is made up of a two sets of two parallel lines. If we just added equal length cross pieces, we could build a perfect rectangle, and our linear slides would be parallel.

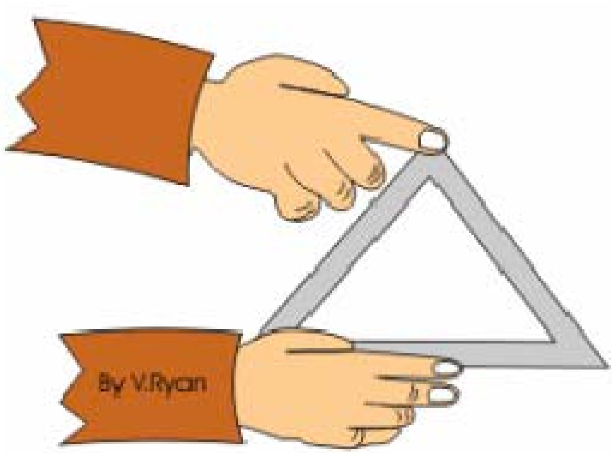


However, rectangles are not very strong and the angles can change easily.   This is called “parallelogramming”, and you can see why.

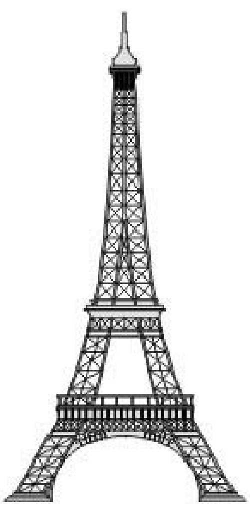


This misalignment would cause the elevator to bind badly, and it would not be able to move.

While rectangles are not very strong, triangles are extremely strong. They cannot be pushed out of shape in any direction.



In fact, this concept is called "triangulation" and because of their strength, triangles have been used by engineers in construction for centuries. Here are some examples:



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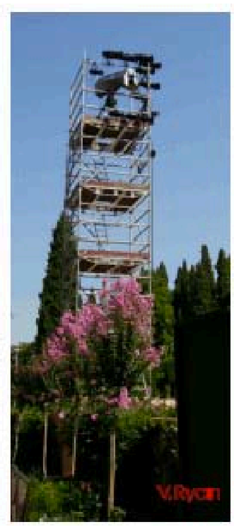
SCAFFOLDING FOR A BUILDING



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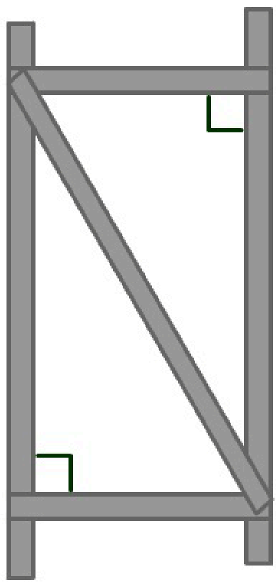
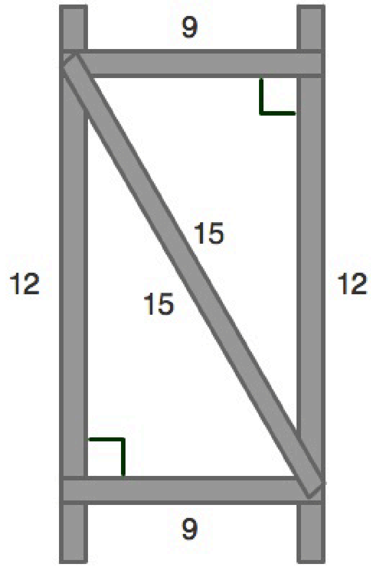
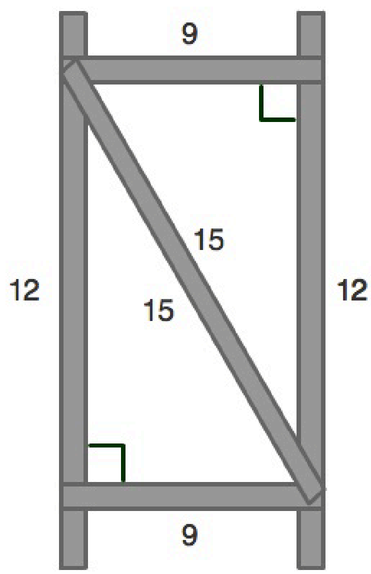
So, to solve our elevator design problem, we built our rectangle, but to get the strength of triangles, we added a diagonal. This diagonal divides the rectangle into two right triangles.



But not just any triangles, we chose dimensions so that our diagonal forms two congruent Pythagorean triangles. In our case, we decided to put our slides 9 units apart, and have our rectangle be 12 units high. Using the Pythagorean Theorem, we needed a diagonal that was 15 units long.



This is just another variant of the 3, 4, 5 right triangle.



$$9^2 + 12^2 = 15^2$$
$$81 + 144 = 225$$
$$225 = 225$$

We do have one more application on our robot, but it very difficult to see. The part of our robot that undergoes the most stress is what we call the “arms”.

QuickTime™ and a
decompressor
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These are two horizontal pieces with a sprocket between them that are used to lift the first stage of the elevator. It was imperative that these arms be perpendicular to the elevator. If the arms moved to more or less than 90 degrees, then that would increase or decrease the amount of slack in our chain.

Not surprisingly, we wound up building another set of 3,4,5 right triangles to support the arms. Our elevator now moves up and down gracefully, and the amount of slack in the chain never changes.

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In summary, Pythagorean triangles can and should be used in the construction of VEX robots, wherever you need strength and/or exact ninety degree angles.

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There is an old saying that you should beware of Greeks bearing gifts. But Mr. Pythagoras and has given us a gift of his theorem about right triangles, that is essential to the construction and proper operation of our robot. And for that gift, we say, “Thank you Mr. Pythagoras”.