You, Me, and Math Makes Three:
Using SolidWorks as a Tool to Teach
Engineering Concepts to Botball Students
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1 What is this, and what does it do?

You finally got to go to your regional workshop and we spend two days showing you the ins and outs of IC and as a treat, revealed the new and exciting Botball game board. After all of that, we called your team forward and issued you a bin of LEGO® bricks and a SolidWorks DVD. In the shuffle back to your school the DVD probably got placed out of the way and forgotten. It is time to go dig out that DVD and take a look at it.

SolidWorks is design automation software [1], meaning that not only is this powerful CAD software, but it can also bring your designs to life. With SolidWorks not only can you talk about gears and show people gears, but you can animate the gears and show how they move and interact with each other. While there is nothing new about that, what is new is the ease in which it can be done. Throughout this paper I will show a few examples of what can be done with SolidWorks, but I strongly encourage you to check out the Education Edition Curriculum and Courseware for great lesson plans and activities for SolidWorks.

2 I've installed SolidWorks, now what?

The first thing to do is to become familiar with the SolidWorks software. SolidWorks has set up a very nice online tutorial that is easy to use and understand. Open SolidWorks by double clicking the desktop icon or by finding it in the start menu. SolidWorks will take a minute to load, so go grab a snack. After SolidWorks is open, the right pane of the window will be titled "SolidWorks Resources". In this pane there is a smaller window with a link titled "Online Tutorial". Click on this link. The SolidWorks window will resize and a new window will open next to the SolidWorks window. In this window there are 35 tutorials ranging in length from 15 minutes to an hour. If you have never used SolidWorks, or any other CAD software, I recommend that you at least complete lessons 1 and 2.
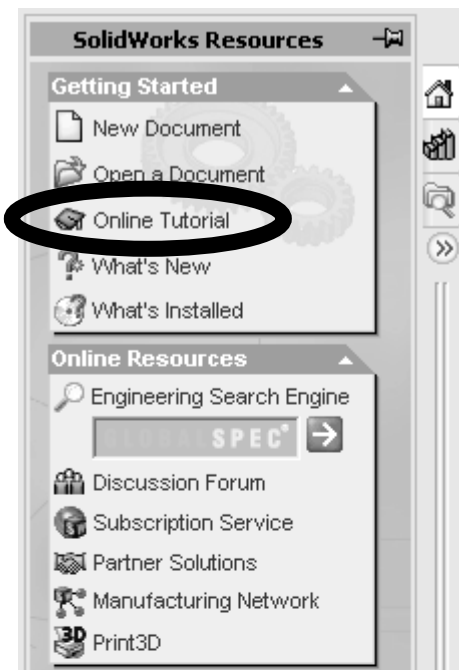
3 What's so great about SolidWorks?

SolidWorks is a powerful animation tool. It is very good for making models, but it excels at bringing them to life. SolidWorks can show interactions between parts, simulate forces and even make nice tidy movies to show off your creations. What I did was create two mini lessons. Each lesson has an example file and I walk you through what concepts each one demonstrates. Feel free to use these as a spring board to create lessons, or check the Education Edition Curriculum and Courseware DVD for complete lesson plans.

3.1 An example is worth 1,000,000 words

All of the examples that I talk about here are on the 2007 NCER Conference Proceedings CD in the SolidWorks folder. The first example is titled Triangle Study.SLDASM. You can run the simulation as is, or you can unsuppress the crossbeam, recalculate the simulation and run it to show triangles in action. The second example is titled Gearing Study.SLDASM. You can simulate this example to see all of the gears move, or you can hide and unhide gears to look at specific interactions.

3.2 Rigidity: Pythagoras makes things sturdy

The first mini lesson is on triangles and strength. Using LEGO pieces I modeled a four sided rectangle with the sides of three and four LEGO Units [2]. I secured the corners with pins. If you have ever played with LEGO bricks, you know that this can easily be built. An activity to add in could be having students build along as this is presented. Squares are not very strong if a lateral force is applied parallel to one of the sides, especially a square built out of LEGO Technic bricks. I simulated this instance with SolidWorks, showing that this square cannot even hold its own weight. Next I added in a diagonal cross brace. The structure instantly became rigid, and was able to hold its own weight plus additional forces put on it.

Now for a quick geometry lesson. To figure out how long the cross brace has to be, I am able to use the Pythagorean Theorem, which states $A^2 + B^2 = C^2$. A and B are the two shorter sides of a right triangle, and C is the hypotenuse. In our case we are trying to find C, the length of the cross beam. So:

$$A = 3, B = 4, C = ?$$
$$C^2 = A^2 + B^2 = (3)^2 + (4)^2$$
$$C^2 = 9 + 16 = 25$$
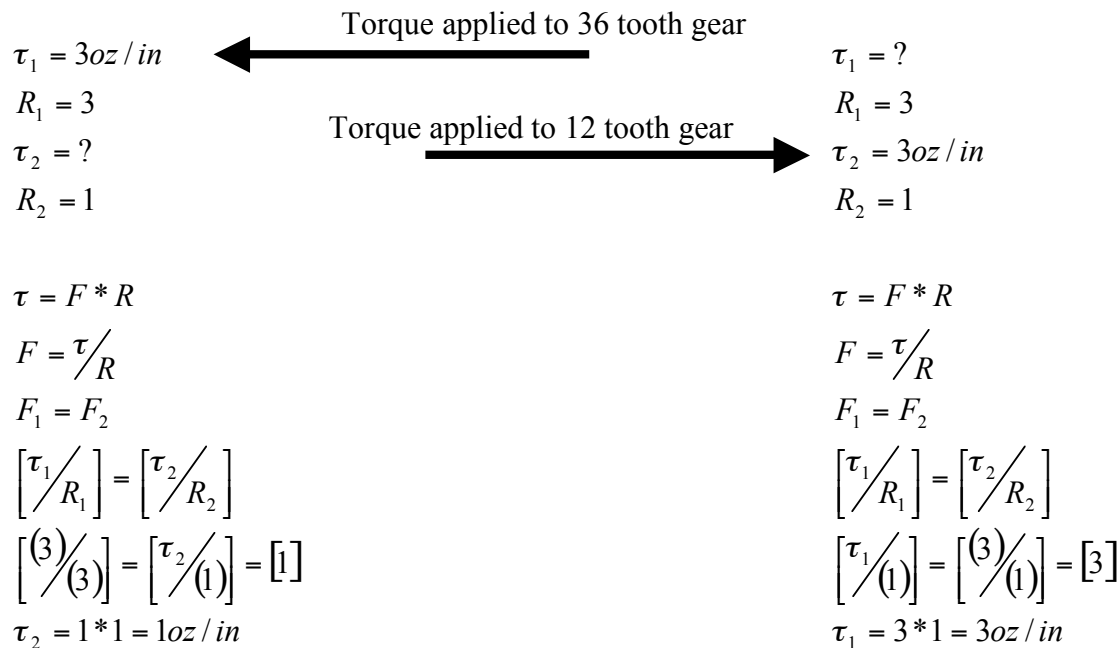$$C = \sqrt{25} = 5$$
$$C = 5$$

What I needed was a 5 LEGO unit long beam to attach two opposing corners and still keep the right angle corners. This is a simple way to teach geometry and the importance of triangles at the same time. This problem can be modified to suit your needs, some triangles that work out nicely are 3,4,5; 5,12,13; 7,24,25; 8,15,17; or any multiples of those numbers.

3.3 Gearing: The wheels on the bus have a 1:1 gear ratio

The second mini lesson is on gear ratios. In the Botball kit each team was issued gears with 12, 20, and 36 teeth. For two gears to fit together, their teeth have to mesh evenly. We are going to assume that the teeth on our gears are equally spaced and therefore the ratio of the diameter of the gears is equal to the ratio of the number of teeth. The gear ratio of a 12 tooth gear to a 36 tooth gear is 12:36 which reduces to 1:3. This means that for every 1 rotation of the 36 tooth gear, the 12 tooth gear will rotate 3 times. This also means that if the 36 tooth gear is rotated a set velocity, the 12 tooth gear will be rotating 3 times as fast. I made a gear chain in SolidWorks using the LEGO gears that were issued to Botball teams. I then applied a velocity to the first gear and I am able to show the speed of the last gear.

The downside to gearing so that the final gear turns faster is that torque decreases. Torque (τ) is the measurement of the ability to twist about an axis. Torque can be calculated by multiplying the force at the outside edge of the gear by the radius of the gear. Using our original example of a 1:3 gear ratio, what is the torque on the 12 tooth gear if we put 3 oz/in of torque on the 36 tooth gear? What is the torque on the 36 tooth gear if the 3 oz/in of torque is put on the 12 tooth gear? We will define system one as the 36 tooth gear and system two as the 12 tooth gear, therefore $R_1=3$ and $R_2=1$.

Torque applied to 36 tooth gear

$\tau_1 = 3oz/in$ $\tau_1 = ?$

$R_1 = 3$ $R_1 = 3$

Torque applied to 12 tooth gear

$\tau_2 = ?$ $\tau_2 = 3oz/in$

$R_2 = 1$ $R_2 = 1$

$\tau = F * R$ $\tau = F * R$

$F = \tau / R$ $F = \tau / R$

$F_1 = F_2$ $F_1 = F_2$

$\left[\dfrac{\tau_1}{R_1}\right] = \left[\dfrac{\tau_2}{R_2}\right]$ $\left[\dfrac{\tau_1}{R_1}\right] = \left[\dfrac{\tau_2}{R_2}\right]$

$\left[\dfrac{(3)}{(3)}\right] = \left[\dfrac{\tau_2}{(1)}\right] = [1]$ $\left[\dfrac{\tau_1}{(1)}\right] = \left[\dfrac{(3)}{(1)}\right] = [3]$

$\tau_2 = 1*1 = 1oz/in$ $\tau_1 = 3*1 = 3oz/in$

All of the interactions between gears are defined by the gear ratio, which can easily be expressed in SolidWorks as a visual example.

4 But when am I going to use this in real life?

Gearing, torque and strength through triangles are great concepts, but how do they fit into the real world? The answer is simple, Botball. As the students design their robot, they can simultaneously build their robot in SolidWorks. They may not initially use any of the concepts discussed here, but as they progress in their building and simulating with SolidWorks they will see the usefulness of these concepts.

4.1 Stop bringing me down, Gravity

As the students build their robot in SolidWorks, they can perform various simulations, including gravity. The students can fix their wheels in space as a good reference point, and use the gravity simulation. This is a quick way to check and see if everything is supported and braced, or if the robot is going to collapse on itself. This shows that triangles are important for structure and how do you find the length of a beam that will brace a square? You use the Pythagorean Theorem.

4.2 Gearing makes the world go around

While the students are building their robots, they can also examine their gearing. Do the gears fit together, will my gear ratio be too high, and that gear train does not fit in the space I have are all things that can be addressed while using SolidWorks.

5 Conclusion

SolidWorks is a powerful program that can be beneficial to students and teachers. SolidWorks can use simulations to mimic real world interactions, and with a little creativity teachers can use this tool as a resource for teaching engineering concepts to their students, especially students participating in the Botball Educational Robotics Program[3].

References

[1]   SolidWorks Corporation. SolidWorks Teacher Guide and Student Courseware.
        SolidWorks Curriculum and Courseware 2006-2007, 28.

[2]   Martin, Fred G. The Art of LEGO Design. *The Robotics Practitioner: The Journal for Robot Builders,*volume 1, number 2, (6), Spring 1995.

[3]   www.Botball.org