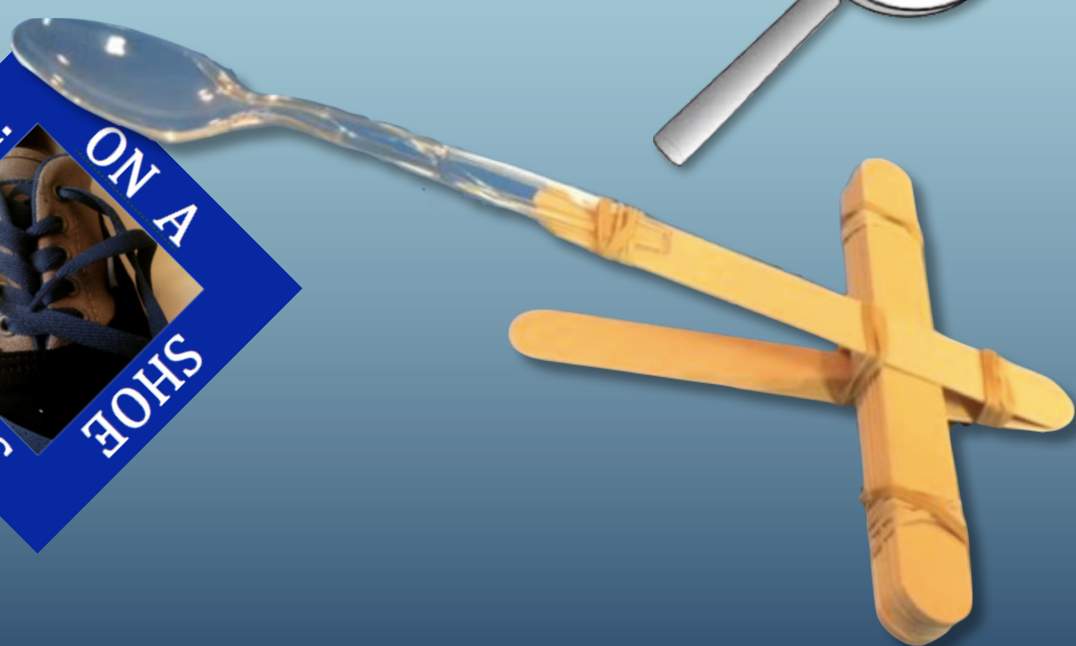
3-2-1 Launch! Designing Catapults

A STEM on a Shoestring Lab



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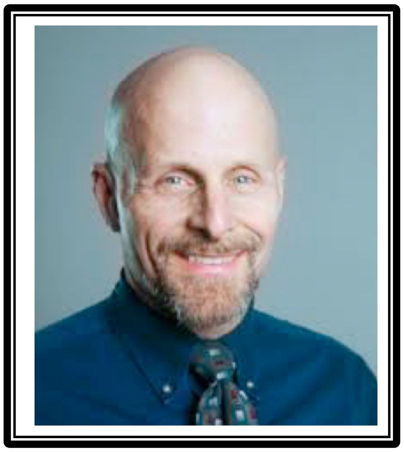

Brad Fulton
Educator of the Year

- ♦ Consultant
- ♦ Educator
- ♦ Author
- ♦ Keynote presenter
- ♦ Teacher trainer
- ♦ Conference speaker

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Known throughout the country for motivating and engaging teachers and students, Brad has co-authored over a dozen books that provide easy-to-teach yet mathematically rich activities for busy teachers while teaching full time for over 30 years. In addition, he has co-authored over 40 teacher training manuals full of activities and ideas that help teachers who believe mathematics must be both meaningful and powerful.

Seminar leader and trainer of mathematics teachers

- ♦ 2005 California League of Middle Schools Educator of the Year
- ♦ California Math Council and NCTM national featured presenter
- ♦ Lead trainer for summer teacher training institutes
- ♦ Trainer/consultant for district, county, regional, and national workshops

Author and co-author of mathematics curriculum

- ♦ Simply Great Math Activities series: six books covering all major strands
- ♦ Angle On Geometry Program: over 400 pages of research-based geometry instruction
- ♦ Math Discoveries series: bringing math alive for students in middle schools
- ♦ Teacher training seminar materials handbooks for elementary, middle, and secondary school

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All workshops provide participants with complete, ready-to-use activities that require minimal preparation and give clear and specific directions. Participants also receive journal prompts, homework suggestions, and ideas for extensions and assessment.

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"Absolutely engaging. I can teach algebra to second graders!"
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References available upon request

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Thanks and happy teaching,

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3 – 2 – 1 Launch!
Designing Catapults

Overview:

Students will love the challenge of engineering the most formidable catapult from the simple and inexpensive materials you provide. Adaptations allow for integrating science, technology, and math across a wide spectrum of grade levels and abilities so this can be used with students from primary grades through high school.

Required Materials per team of two students:

- ☒ Tongue depressors or craft sticks (10)
- ☒ Rubber bands (5 or 6)
- ☒ Plastic spoon
- ☒ Binder clip
- ☒ Bottle cap
- ☒ Miniature Marshmallow
- ☒ Pom pom

Optional Materials:

- ☐ Target

Procedure:

1. Set up the catapult kits ahead of time. Glue a bottle cap onto the end of one craft stick as shown. You can then put it and 9 more craft sticks, 5 or 6 rubber bands, a plastic spoon, and a binder clip in a zip lock plastic bag. Students should work in pairs on this activity. Each bag should also contain one marshmallow and/or one pom-pom to use as the projectile. You can of course use other objects, but I chose these because they aren't likely to hurt a child during a misfire. However, they are so light that the students will not get maximum distances. Play dough is also a possibility.

I left a small finger hold here to aid in launching.

2. Tell the students that they will need to design a catapult that will shoot the farthest (or most accurately) using the materials that you provide. If necessary, you can show

them pictures of catapults, but you should refrain if possible from giving them help in their design. The process of trial, error, and retrial is vital in STEM instruction and project-based learning.

3. Here is the basic catapult kit. Students may use some or all of the materials as needed. If you wish, you can allow them to use other materials. There is one tongue depressor with the attached cap and nine more for a total of ten.

4. I begin by teaching my students about what I call the STEM Instructional Cycle. We begin with **research**. Give students time to discuss their knowledge and ideas about catapults. Then ask them to research the subject online or in reference materials.

5. The second stage is **design**. Here students can draw a sketch or plan of their catapult. With younger students, this may be very simple. With my middle school students however, I require drawings that have the parts labeled and dimensions given using metric measurements. Then I ask them to exchange plans with another team. Since someone else will be building their design, they to attend to greater detail and precision. It also teaches them that any engineering process is a team effort. The people who design a rocket aren't the ones who build it or fly it.

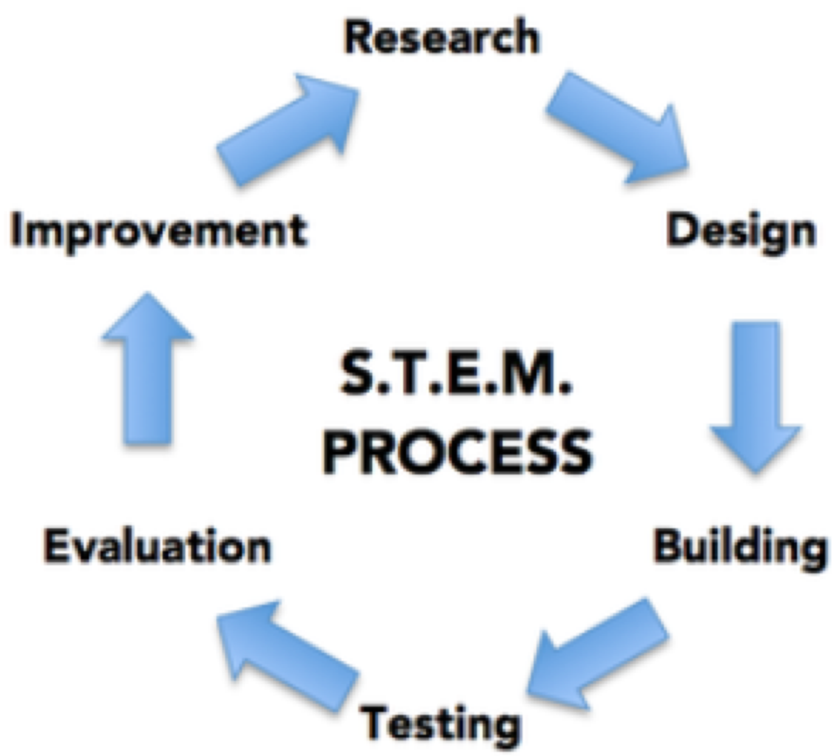
6. Next, students **build** their catapults. This is one of the parts they look forward to the most, but make sure they don't skip the previous crucial steps in the process.

7. Now they get to **test** their designs. Initially they may be pleased with the performance. However, when other students' designs outperform theirs, they may reconsider. One of the greatest advantages of STEM instruction is that it redefines failure. In typical instruction, failure is the end of the road. Our clocks, our calendars, and our pacing guides mandate that we typically must move on. But when

students fail to create a catapult that meets their standards, they are eager to try again. Failure becomes a natural and positive part of the learning process. Just as when a child learns to walk, they fall, they laugh, the learn from their mistakes, and they get back up.

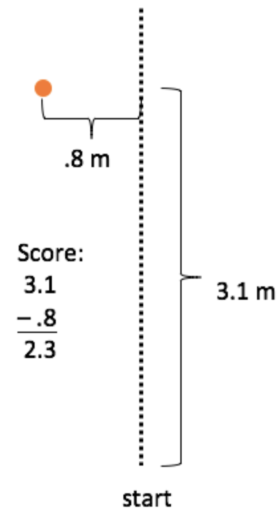
8. Failure steers students toward the next phase of the STEM Instruction Cycle: **evaluation**. Now students appraise the success of their design. Notice that they are not appraising themselves: failure is an event, not a person. If they are satisfied with the performance of their model, they are ready to compete in the challenge.
9. If not, they move to the sixth phase: **improve**. This takes them back through the loop to the research stage. They can cycle through this as many times as they want until they are satisfied with the results. Thus failure becomes a positive step in the process. And in this STEM-based instructional process students begin to lose their fear of failure and their risk aversion. These are two of the leading inhibitors of learning in our classrooms.

The STEM Instructional Cycle:



Here are some catapult challenges sorted by grade levels.

10. Primary: Grades K-2:
    a. Have students measure linear distance. This can be done using feet or inches or using metric measures. You can also use non-standard units, such as linoleum floor tiles or paper clip chains.
    b. Have students try to hit a target on the floor.
    c. Have students try to make a shot into a basket. You can have them keep score.
    d. Primary students may need assistance building their designs.
11. Elementary: Grades 3-5:
    a. Students can measure linear distance using more precise standardized measurements.
    b. Fractions can be incorporated into distances such as 7½ feet.
    c. Feet and inches can be combined for precision: 8 feet, 4¼ inches.
    d. Decimals can be used with metric measurements: 3.27 meters.
    e. Incorporate subtraction by measuring how far away they landed from the straight line and subtracting it as shown.



    f. Students can take ten shots and find the range, median, and mean of the data. These can be graphed on a line plot.
    g. Students can analyze the effects of variables in the exploration as part of the scientific process. What launch angle is best? Does a long armature perform better than a shorter one? How do models that use plastic spoons perform compared to models with a wooden armature? They can evaluate the different types of catapults and classify them by design and effectiveness.
12. Middle grades: 6-8:
    a. Students should be using metric measurements in all STEM related explorations as it is the international system used by scientists.
    b. Advanced scoring systems can be incorporated involving decimals or common fractions.
    c. You can also incorporate area into the competition. For example, a target can be used in which the concentric rings have values that increase toward the bull's eye. These can be based on the areas of the regions. In the example at right, the areas of the regions were calculated using the area formula for a circle: $A=\pi r^2$. The outermost red ring has an area

five times that of the blue circle, and the yellow ring's area is three times that of the blue region. Thus you could make the blue circle worth 5 points, the yellow three, and the red worth one point by reversing their areas.

d. Students should be encouraged to experiment with variables. What effect does the angle of the catapult's arm have on the outcome? What is the ideal angle that maximizes distance? A coordinate graph can be used with the angle on the x-axis and launch distance on the y-axis. This allows students to work with independent and dependent variables and to look for association in bivariate data.

e. What effect does the length of the armature make?

f. The models can be sorted by design: Wooden vs. spoon armatures; binder clips vs. no binder clips. Then the variables can be evaluated.

g. Students can take twenty shots with their catapults and gather the data. Then they can find the range, median, and mean. They can represent their data on a line plot or as a box and whisker plot. The graphical representations of different designs can be compared and analyzed.

h. Students will likely build more successful designs in middle school than in younger grades. Often they also will be more willing to improve and redesign their models.

13. High school:

a. Students can use the middle grades challenges, and they can also take it even further using the adaptations below.

b. Students can study the parabolic arc of the ammunition. This can be done using the camera on a phone. Place an easily read vertical scale on the wall behind the launch area. One team member films the launch in slow motion. Then the distance from launch to landing is measured. As the video is replayed, the students watch for the vertical height. They now know the x-intercepts (launch and landing points) and the vertex (maximum height). These can be plotted on a coordinate graph and the parabola can be sketched.

c. For greater rigor, students can find the quadratic equation given the three points: the two x-intercepts and the vertex. There are online calculators that can do this, but it can also be done with a system of equations. For example, let's assume that the ammunition travels 6 meters and has a maximum height of 4 meters. We will let (0, 0) represent the launch position, and (6, 0) the landing position. These then are the x-intercepts. The axis of symmetry will be halfway between them at $x=3$. The vertex is on the axis of symmetry; it can be located at (3, 4). Now we have our three points.

   The general form for a quadratic equation is $y=ax^2+bx+c$. The y-intercept is c and is at (0, 0). Thus $c=0$.

   We also know that when $x=3$, $y=4$. Thus $4=a(3)^2+b(3)$, or $4=9a+3b$.

   Our other point at (6, 0) gives $0=a(6)^2+b(6)$, or $0=36a+6b$

We now solve our system of equations:

$$0 = 36a + 6b \; and \; 4 = 9a + 3b$$

Multiplying the second equation gives:

$$0 = 36a + 6b \; and \; 8 = 18a + 6b$$

Subtraction gives us:

$$-8 = 18a$$

Dividing gives:

$$a = \frac{-8}{18} = \frac{-4}{9}$$

Solving for *b* gives:

$$0 = 36\left(\frac{-4}{9}\right) + 6b$$

$$0 = -16 + 6b$$

$$16 = 6b$$

$$b = \frac{16}{6} = \frac{8}{3}$$

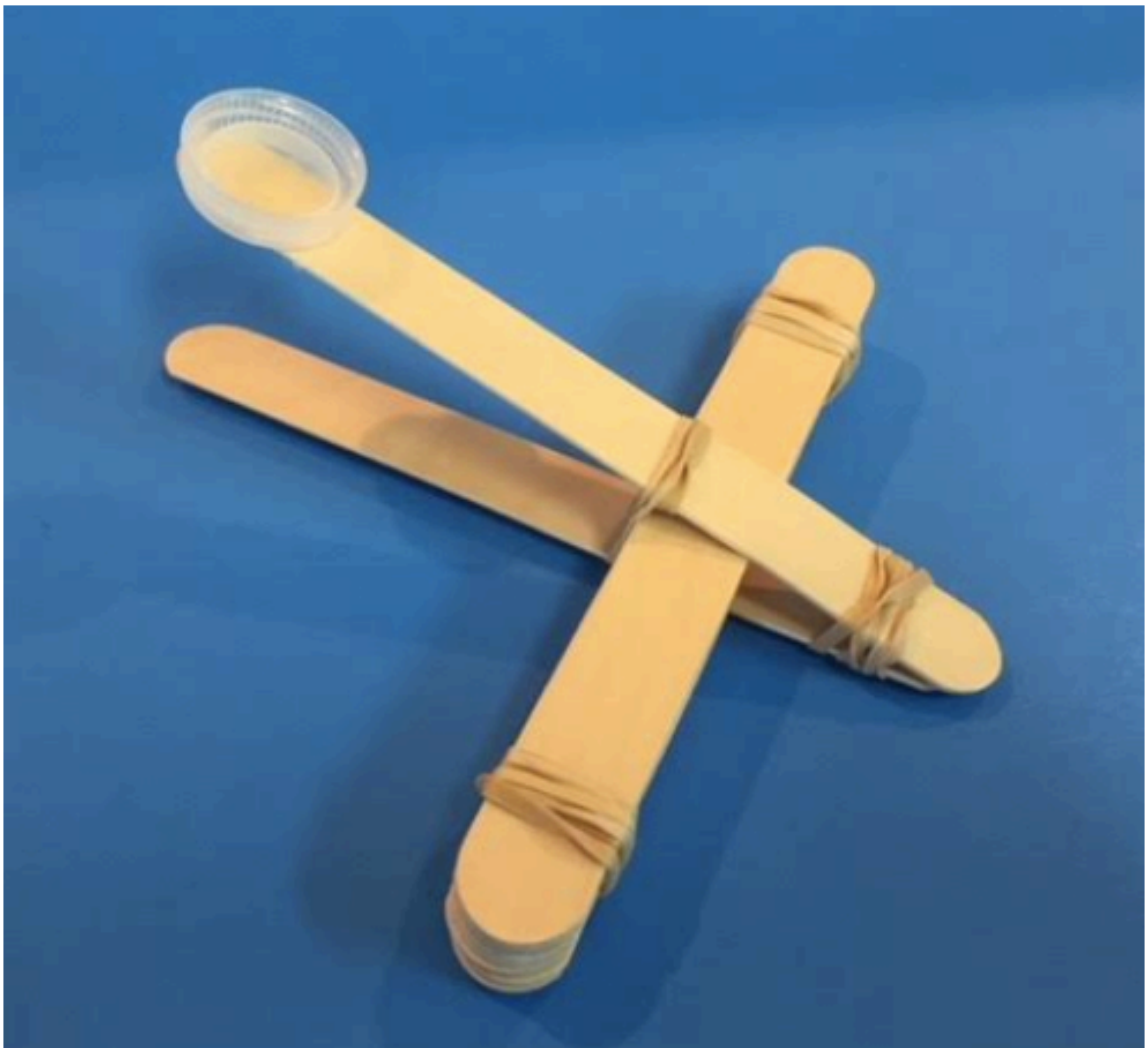
Thus the equation is:

$$y = \frac{-4}{9}x^2 + \frac{8}{3}x$$

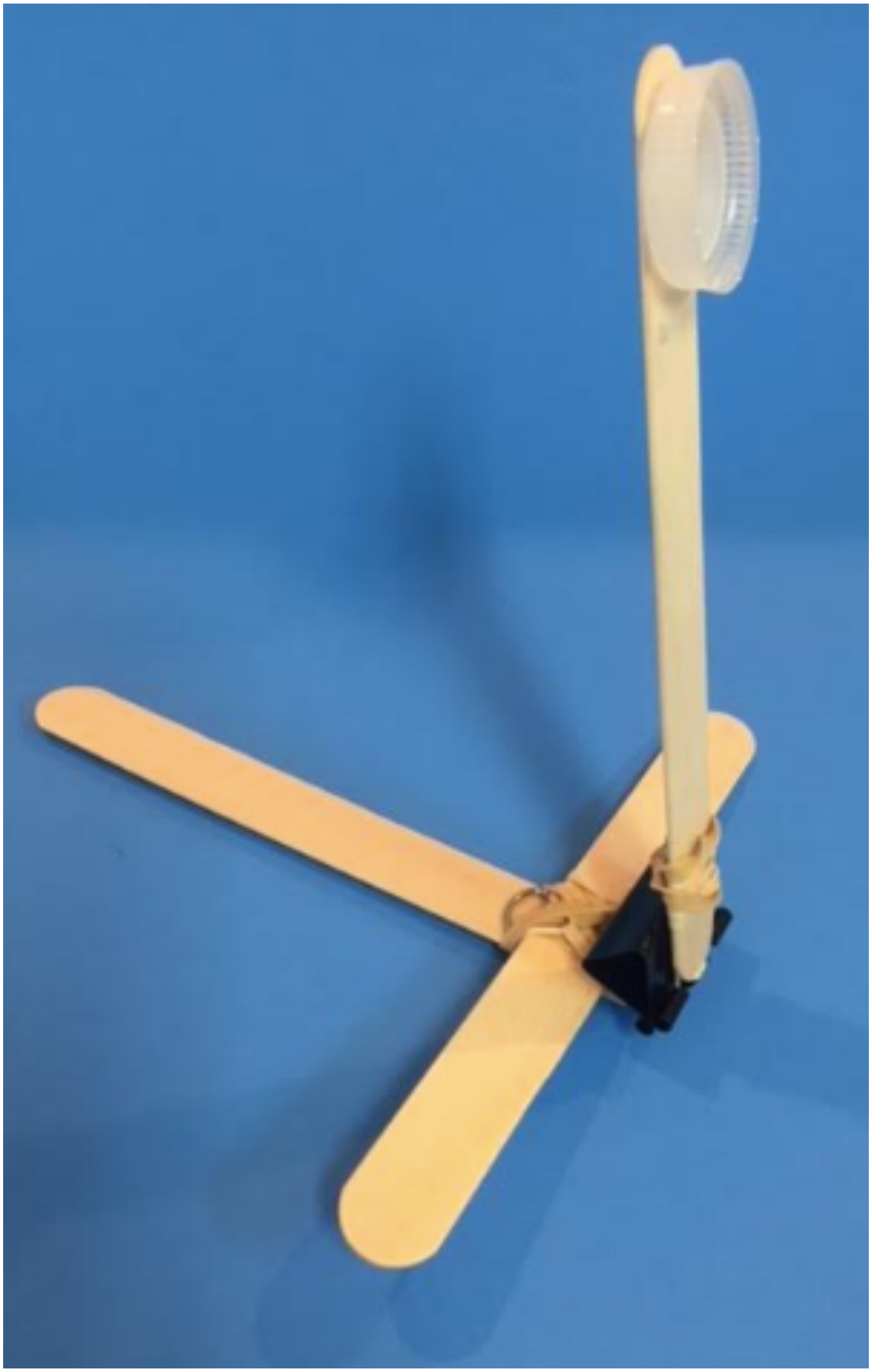
All that from a flying pom-pom!

14. Here are some basic plans using the kit, but encourage your students to invent and reinvent their own designs. All of these designs work on the principle of **elastic forces**. Students can study these in physics. There are two types of elastic forces: **compression** and **tension**. These catapult designs use compression forces in which the tongue depressor, plastic spoon, or binder clip are compressed. On the other hand, a rubber band is a tension force; its elasticity is stretched instead of compressed. Can your students find a way to launch the ammunition like a sling shot using the rubber band's tension force instead of just relying on the compression force of the tongue depressor or spoon?

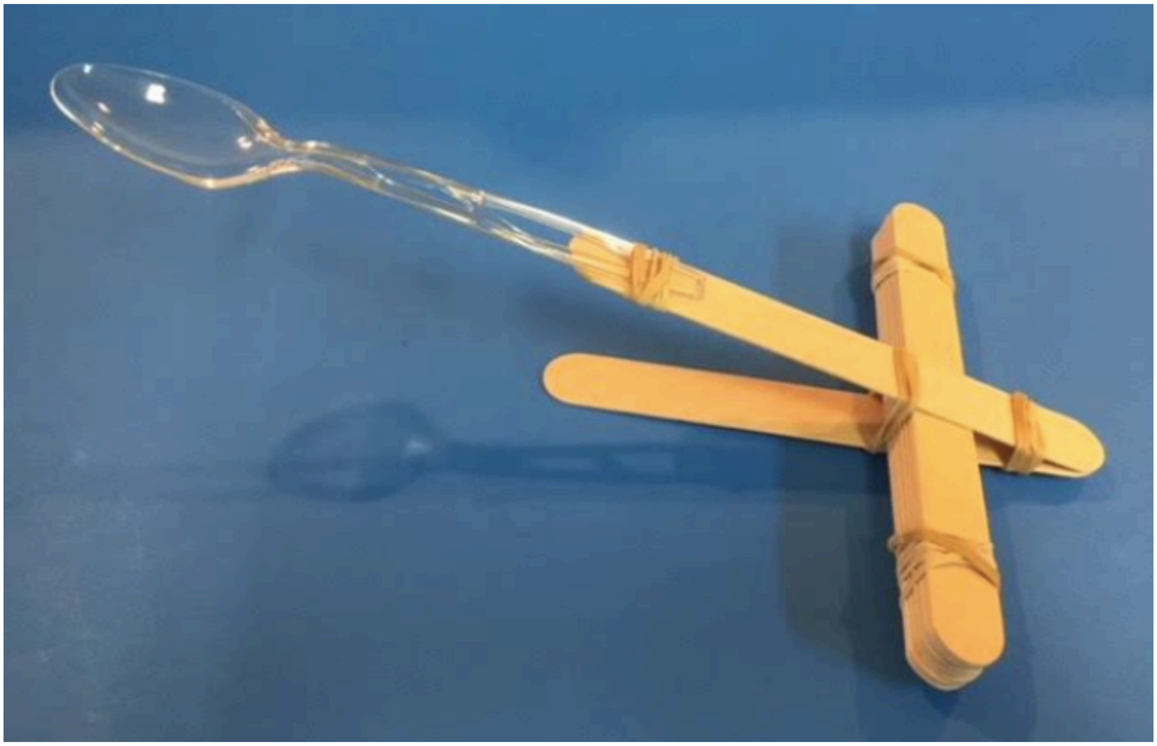
    a. This design uses ten tongue depressors and four rubber bands.



b. This one uses the spring action of a binder clip.



c. Does lengthening the armature help or hinder the launch?



15. On the following pages are some planning guides you may wish to use with your students. The first one is for younger students and the second is for more advanced learners.

Catapult Name____________________

Planning Sheet

Here is what we know about catapults:

____

____

____

Here is our design:

Think Sheet

Name______________________________

Research: What will make your catapult work the best?

____

____

____

Design: Draw a detailed plan of your catapult here. Label all the parts. Could someone else build this if they had your drawing?

Now **build** your catapult and **test** it.

Evaluate and **Improve**: How well did it work? How will you improve your catapult?

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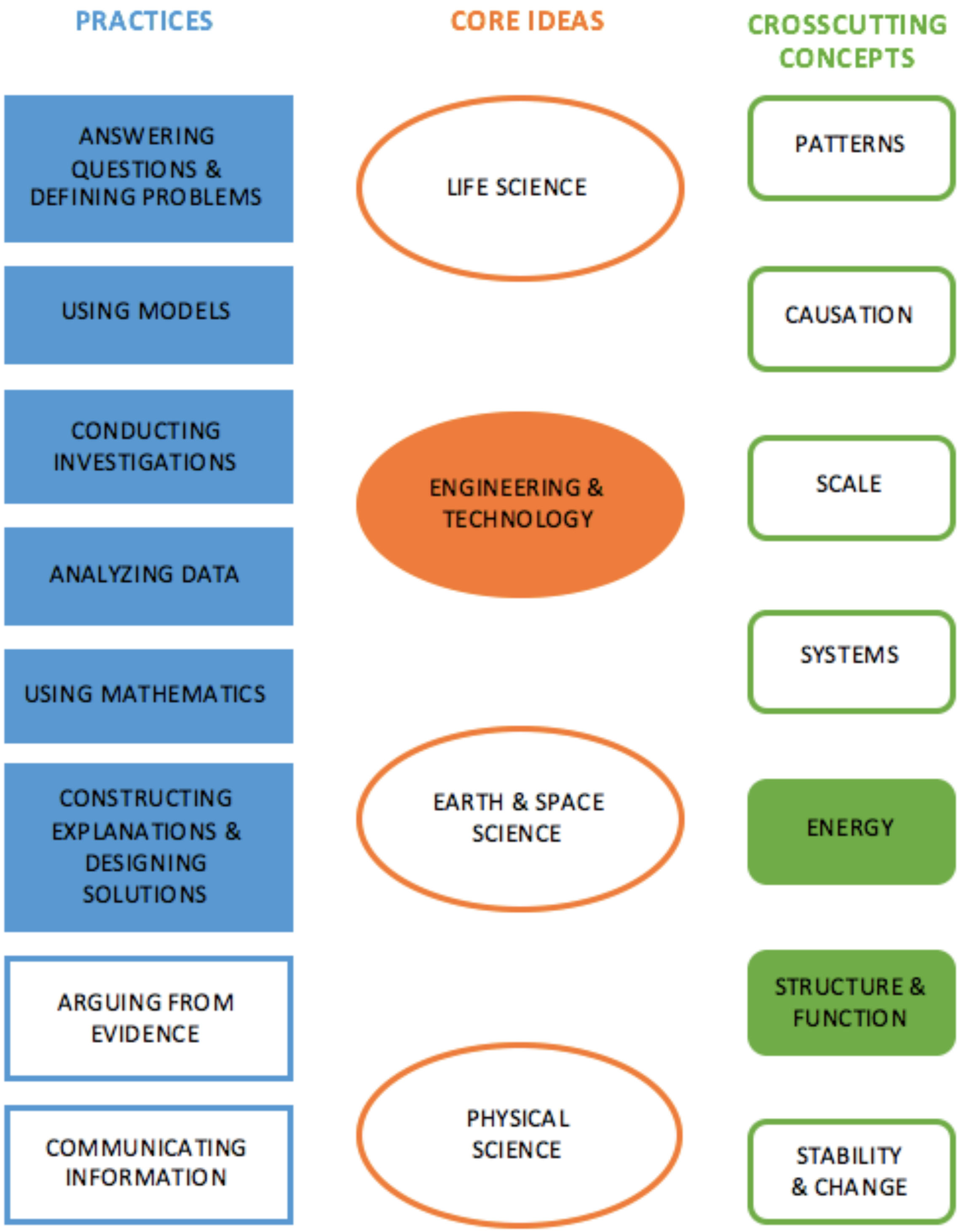
The Next Gen Connection:

Colored shapes indicate the regions that are most strongly addressed in this activity.



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Similar ***S.T.E.M. ON A SHOESTRING*** activities include:

- *Vibrobots* – Use inexpensive electric toothbrushes to make wiggly robots. Then use physics and math to analyze their speeds.
- *Slime Time* – A gooey lab involving Non-Newtonian fluids. Get the PowerPoint too!
- *Ramp Races* – An engaging and exciting way to teach students the principles of physics: forces, motion, speed, friction, and more!
- *Invisible Ink Lab* – Make hidden messages appear using the principles of chemistry and simple kitchen ingredients

Feel free to contact me if you have questions or comments or would like to discuss a staff development training or keynote address at your site.

Happy teaching,

Brad