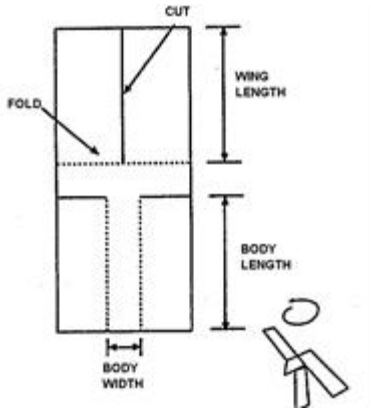
# DOE It Yourself

## Fun science projects compiled by Mark J. Anderson, Principal, Stat-Ease, Inc.

*Give design of experiments a try! These are my favorites for doing at home or in class – in no particular order. You don't need any unusual equipment. The details are sketchy but they should be sufficient. Use your imagination*! If you have your own favorite DOE that anyone can do, send me the details. I'll add it to the list.*
---Mark

**(To maximize creativity, I encourage you to get friends and family together for some brainstorming. Use a 'fishbone' diagram to organize your ideas. See a helpful description by the American Society of Quality of this tool, also known as a cause-and-effect diagram, at http://asq.org/learn-about-quality/cause-analysis-tools/overview/fishbone.html.)*

1. **Paper Helicopter** (From "George's Column: Teaching Engineers Experimental Design with a Paper Helicopter", *Quality Engineering*, 4 (3), pages 453-459, 1992, by George E. P. Box):




- The diagram shows how to make a helicopter. You can experiment on paper type, length and width of various parts, and anything else you can think of. See how long you can keep it in the air.* By making use of various DOE methods, Box's students achieved hover times of over 4 seconds from a step-ladder.

*(For a video of South Dakota School of Mines and Technology engineering students dropping paper helicopters, see: www.statsmadeeasy.net/2011/05/video-of-paper-helicopter-fly-offs-at-south-dakota-school-of-mines-technology/.)

- A variation on this experiment makes use of foam cups. Just make three cuts from the opening to the base, fold it up to make the wings, and tape it to the bottom of a second cup.

2. **Tabletop Hockey** (Presented to the 1994 *Applied Statistics Conference* by Mark Anderson, Stat-Ease, Inc. - detailed instructions available at www.statease.com/pubs/hockey.pdf.):

- We've used this experiment in class several times with good success. It is simple to do. Just make a "puck" by gumming 4 quarters together (one buck). Then give it a wrist shot or slap shot with a flexible ruler. In addition to shot type, you can experiment on stick length and the windup. Our students have come up with many other test factors. Use your imagination! Then measure shot distance. (Hint: analyze this in log scale.) The experiment produces an unexpected interaction between two of the factors. The interaction graph at right shows what happens, but with the factors disguised. You will need to do it yourself to find out which factors interact!

3. **Eye-Hand Coordination** (From *Linking High School Math and Science Through Statistical Design of Experiments*, Macomb Intermediate School District, 1995, page 2-1, by Bert Gunter. Detailed instructions available at www.statease.com/pubs/handeye.pdf.*):

- Draw circles on either side of a piece of paper or print the template from the link above. See how many dots you can alternately mark in the circles within 10 seconds. Try it with your other hand. Experiment with size of the circles, how far they're apart, etc. Don't be surprised to find interactions. Be sure to randomize the test plan so the learning effect doesn't bias results.

**The contrast in size of the circles is a bit extreme, but you need to push the limits of factors to see effects more clearly. Don't get too frustrated with the small, lightly drawn circles. Remember that in experimentation of this type it's good to create failures. You learn from your mistakes.* - Mark

4. **Impact Craters** (From same source as above, page 3-1):

- Drop ball bearings (or marbles) of varying size into shallow containers filled with fine sand or granular sugar. Measure the diameter of the resulting crater. Try different drop heights and any other factors you can come up with. Be prepared for some powerful interactions. P.S. If you do this with children, put some little dinosaurs in the sand. Count how many become extinct. For details see www.nasa.gov/pdf/180572main_ETM.Impact.Craters.pdf and view a very cool demo at www.youtube.com/watch?v=q1n-XgNKY2I by Fair Lawn High School Planetarium Director and Science Educator Andrew Temme.

- To simulate the impact of meteorites, members the Salt Lake Astronomical Society wanted to drop bowling balls from very high altitudes onto the salt flats of Utah. However, workers in the target area from the U.S. Bureau of Land Management objected to the experiment. ("News of the Weird", Chuck Shepherd, 3/6/03)

5. **Nutty Raisins** (From *Wonder Science*, American Chemical Society):

- Here's a fun way to illustrate how DOE works and how factors interact to produce an unexpected response. Gather together four clear bottles of a clear carbonated beverage. Replace the contents of two bottles with water. Chill all of the bottles in a refrigerator. Then, drop several shelled peanuts into one bottle of water and one bottle of carbonated beverage. Observe the reaction. (You won't see much.) Now repeat the experiment with several raisins. Be prepared for a surprise: the raisins interact with the carbonation and do a delightful dance. I've found this to be an excellent experiment for our workshops on design of experiments. It leads to more complex test matrices that can be used to investigate many factors in a minimal number of runs. Give it a try! Can you think of other factors that might make the raisins dance better?
*(Also see https://funlearningforkids.com/dancing-raisins-science-experiment-kids/ for detailed instructions and a fun video posted by Lab 360 www.youtube.com/watch?v=mEGCvj977_A.)

6. **Paper Clip Strength** (Used by Stat-Ease in workshops – detailed instructions available at www.statease.com/pubs/paperclipdoe.pdf.):

- Here's a simple way to demonstrate the power of simple comparative experimentation using the Student's t-test. Get two different brands of #1 coated paper clips. Randomly choose half a dozen or so of each. Then, at random, bend each one back and forth until it breaks. Count the bends. Be careful to follow the same procedure every time! Then do a t-test to determine whether the average difference is significant. (Or do a one-factor analysis of variance with Design-Expert® software from Stat-Ease).
- If you do this in a group, you can save time by doing a paired test. Just give each person one of each type of paper clip. Then ask each person to choose one of the clips at random and break it. After they break the other clip, record the results and do a paired t-test. (Or do a blocked one-factor analysis with Design-Expert). You might be surprised at the variation between people, but the analysis removes this as a factor, so you get a good test.

7. **Flight of the Balsa Buzzard** (Contributed by statistical consultant Roger Longbotham.):

- This is a fun DOE that anyone can do. Depending on your ambition, purchase 10-20 balsa airplanes at your local hobby shop. Roger suggests testing five factors: vertical stabilizer frontward or backward, the same for the horizontal stabilizer, wing position to the front or back, pilot in or out, and nose weight as-is or increased. If you do test these five factors, try a half-fraction of a two-level factorial. For each configuration make two flights and input the mean distance and range as separate responses. Watch out, you may discover that certain factors cause increased variation in the flight path.

8. **Paper Airplanes** (From "Teaching Taguchi's Approach to Parameter Design", *Quality Progress*, May, 1997, by Sanjiv Sarin.):

- This experiment will make the school-teachers cringe. Students shouldn't need any training on how to do it. Let them apply their imagination to come up with factors. Here are some things done by grad students at North Carolina Tech: use multiple sheets, alter the design, change the width and length, increase launch height and/or angle. Desired responses are length and accuracy.

- If you search the Web, you will find dozens of neat paper-airplane designs and instructions on how to make them. Charlie Tricou of Penn State University showed me one called a "snub-nosed delta" that he experimented on at home. Here's an excerpt from an e-mail Charlie sent me (5/14/04) with suggestions on how to vary angles on the wings, ailerons, etc.:
*"….I used a… small and inexpensive…adjustable plastic angle guide [for] woodworking…[that provides]…~ 0.5 degree accuracy… by sighting down the creases…Measure the angles immediately following the flights to ascertain if the paper folds "relaxed" during flight…We optimized for maximum straight-line distance, built the craft, and on the first launch the craft traveled all the way across the room and hit the far wall while still two feet off of the ground and going strong. It had traveled 22 feet and was only about 6 inches off the centerline. I estimate that it had easily 6 to 10 feet of travel left before first impact."*

9. **Ball in Funnel** (From "Through a Funnel Slowly with Ball Bearing and Insight to Teach Experimental Design", *The American Statistician*, Vol. 47, Nov. 1993, by Bert Gunter.):

- This experiment is loosely based on Deming's funnel experiment. You time how long it takes for the ball to spin through the funnel set at various heights. The ball can be fed through a tube. Vary the inclination and entry angle. Consider using different types of balls. Fasten the funnel so it's somewhat loose. You might then find that the effect of ball size depends on whether or not you hold the funnel - an interaction. There are many more factors that could be studied. Have a ball!

10. **Statapult** (Air Academy: https://airacad.com/statapult/)

- Put a hollow rubber ball in a cup at the end of a wooden arm. Then pull it back against tension from a big rubber band. Let it rip! Vary the cup setting, pull-back angle, type of ball and many other factors. You can develop accurate predictions on bombardment distance. Just be sure you've got a big room with nothing breakable!

- A variation on this is to use a **trebuchet**, which propels objects via a counter-weight as opposed to tension. South Dakota School of Mines and Technology (Rapid City) supplies these devices to first-year engineering students to experiment on. If set up properly, these trebuchets can fling tennis balls over 100 feet. Golf balls would probably go even further, but they might be a bit more dangerous!

11. **Golfing Toy** (Developed by Leonard M. Lye, Professor of Engineering and Applied Science, Memorial University, Newfoundland. Available for purchase at www.footworker.ca/doe-golfer/):

- This golfing toy accommodates up to 6 factors—brand of ball, length of club, weight of club, angle of swing, type of greens (carpet), direction (floor may not be flat), etc. The team that requires the least number of strokes to get to within 0.5 inches of a line is the winner.

12. **Play putty** (From statistical consultant Paul N Sheldon.):

- Mix ordinary white glue, and a couple of crosslinking agents from the laundry; starch and borax. Desirable properties are bounciness, elongation and possibly surface sheen and tackiness. I gave this a try with some unforeseen results reported in the December 2002 issue of *Stat-Teaser* posted at www.statease.com/news/news0212.pdf.

13. **Gravity Simulator** (Suggested by Stephen Rowe.):

- Affix a trough to a rectangular mount and see how far various balls travel and how far from a target they come to rest. Factors include angle of trough and coordinates of the ball release.

14. **Hot Wheels** (Developed by Archer Bretzel:)
Read all about Archer's amazing series of races at www.statsmadeeasy.net/2018/12/1994-hot-wheels-car-wins-2018-christmas-time-trials-on-corkscrew-crash-track/. Set up your own track and test out your collection of 'wheels.

15. **Boat Buoyancy**:

- Create various foil boats and determine which carries the most cargo. See what happens in fresh versus salt water. Try other activity variations suggested by DiscoverE at www.discovere.org/sites/default/files/Foil Boats_082616.pdf. See what happens when taking on too many pennies as passengers in the video posted at www.statsmadeeasy.net/2020/05/doe-it-yourself-hits-the-spot-for-distance-learning-projects/.

16. **Paper Towels** (Suggested by Peter Kolesar of Columbia University.):

- "Here is a tip on a great experiment either for kids or for people involved in quality: Experiment on the properties of paper towels—strength, absorbency, softness and cost. I first learned of it through an American Association for the Advancement of Science (AAAS) program for teaching kids about science, but many schools have picked it up and you will find many sites via Internet."*

*www.fundafundaacademy.com/diy-summer-camp-activities-paper-towel-absorbency-experiment/

17. **Color-Changing Celery** (Inspired by 2020 South Dakota School of Mines Experiment Design Made Easy student Megan R.) See SciShow Kids video at www.youtube.com/watch?v=KIug9Foou3s for the procedure and scientific explanation. Measure the height over time for varying colors and fat versus skinny stalks.

18. **Bouncing Ball** (Inspired by 2020 South Dakota School of Mines Experiment Design Made Easy student Elini M.) For the procedure, see this post by Frugal Fun For Boys and Girls: https://frugalfun4boys.com/bouncy-ball-science-experiment-temperature-ball-affect-bounce/. Their experiment tests the affect of temperature. Other factors to consider are height of the drop, diameter and/or type of ball, the floor surface and other fun things you think up (pun intended!).

19. **Katie's Kids' Favorites** (As requested by a reader of my "Mark's Experiment" articles in the *Stat-Teaser*, here's a collection of fun experiments I did at home with my lead research-assistant Katie and my other four children.):

- Coke vs Pepsi taste test* – see how well these and other colas can be distinguished when the brands are disguised ('blind' subjects), but don't do what Katie did (read the referenced article).

*(May 2004, Stat-Teaser, www.statease.com/news/news0405.pdf)

  - In a variation on this, I tested my two sons' reaction time as a function of drinking varying colas: with or without sugar (regular versus diet) and caffeinated or not. One son (Hank – the younger of the two) never tried very hard, while the other (Ben) continually jumped the gun, so nothing turned out significant. ☹

- Microwave popcorn—try different brands at differing times and power settings, plus other variables (do some brainstorming!) that you think may affect the taste and yield. I had a great time doing this with Hank as his 5th grade science project. When I wrote up the results as a 'how-to' for DOE, the editor of *Process Industries Quality* put my son down as a co-author, so he became published at age 12! The manuscript for the article, published in July/August 1993, can be viewed at www.statease.com/pubs/popcorn.pdf.

- In a variation on this, my Stat-Ease colleagues did a taste testing of various microwave popcorn brands bought haphazardly by the staff. See my report in the December 2001 *Stat-Teaser* posted at www.statease.com/news/news0112.pdf.

- Mac & cheese taste-test—cook up various brands and see if any emerge as significant winners. A variation on this can be done with trail mix, for which a handy set of guidelines and worksheets (suitable for any food or beverage) is provided by the National Agriculture in the Classroom at https://naitc-api.usu.edu/media/uploads/2015/08/13/Taste_Test_Guidelines_handout.pdf.
- Slinky walking–send different brands of spring toys down a board at varying angles. Time how long it takes. See Sept. 2000, *Stat-Teaser*, www.statease.com/news/news0009.pdf.
- Frisbee fly-off– toss varying types of flying disks to see what affects length and accuracy. Katie and her cousin hypothesized that the color made a difference. I scoffed at this, but an expert on plastics who read about this experiment said that due to variations in pigment, disks of varying color could differ in density, thus affecting their flight! See Sept. 2002 *Stat-Teaser* www.statease.com/news/news0209.pdf.

20. **Shari's fun experiments** (Here are some interesting DOE's done at home by Shari Kraber, Stat-Ease Statistical Consultant.):

- Flower-growing* – see whether fertilizers, such as Miracle Gro®, actually promote growth. Also, try varying pot sizes put in locations with more or less sun/shade. Based on a tip Shari read in a gardening magazine, she tried pinching off flower buds to make plants stronger. Shari also varied the watering. What else might affect how well your plants grow and flower? See March 2003, *Stat-Teaser*, www.statease.com/news/news0303.pdf.
- Peanut butter balls* – Shari reports that she became aware of many variations on the recipe for this tasty treat, so she decided to do a designed experiment on it. Shari varied the peanut butter (creamy vs chunky), with butterscotch chips mixed in at times. She also tried differing "crispies" (cereals vs graham crackers) and chocolate types. Shari's dog liked all her peanut butter balls very much! See Dec. 2003, *Stat-Teaser*, www.statease.com/news/news0312.pdf.

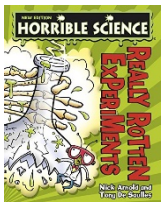
21. **Mark's mixture designs** (These are experiments I've done to apply more sophisticated DOE tools for optimizing formulations. They all can be done at home with participation from family members – mandatory when taste and other sensory preferences must be quantified.):

- Jelly beans—combine varying flavors for interesting taste sensations. I subjected my colleagues at Stat-Ease to combinations of apple, cinnamon and lemon. See the results in Table 2 of www.statease.com/pubs/MIXprimer.pdf.
- Soap bubbles* – combine varying amounts of dishwashing soap with water and corn syrup and measure the time it takes for blown bubbles to burst. Suggestion: Do this DOE outside to avoid unsightly syrup rings! See Sept. 1997, *Stat-Teaser*, www.statease.com/news/news9709.pdf. Also check out the "formulae" posted by the Exploratorium at www.exploratorium.edu/ronh/bubbles/bubbles.html)

- Pound cake* – after teaching DOE to food scientists and master bakers at Sarah Lee, I was inspired to experiment on this classic dessert with a simple recipe: Equal weights of flour, butter, eggs and sugar. Of course I could not leave well-enough alone and so I varied the relative quantities. You can do the same in your kitchen and possibly add in other ingredients or try margarine versus butter, etc. See www.statease.com/pubs/cake.pdf.
- Machine-made bread* – try changing the types and perhaps amounts of ingredients that go into your home machine. Fiddle with the settings as well if you are brave. However, be prepared for some disasters, because unlike the sun, bread does not always rise! See Sept. 1997, *Stat-Teaser*, www.statease.com/news/news0106.pdf.

22. ***Really Rotten Experiments***:

- The author, Nick Arnold and illustrator, Tony De Saulles won the Junior Prize for the Aventis Prizes for Science Books by providing revolting experiments that kids love, such as making green slime. The book, a million-seller in the UK, explains the scientific process behind each experiment. It includes cartoon stories, quizzes and bizarre facts, for example about eccentric scientists who ate tadpoles for tea. This sounds like a terrific book for anyone interested in experimenting at home.




23. ***Kids & Chemistry*** (This American Chemical Society (ACS) program offers complete instructions and worksheets for many great experiments at middle-school level. For details on the those below and others, see https://www.acs.org/content/acs/en/education/outreach/kidschemistry.html.):

- Chemistry's Rainbow: "Interpret color changes like a scientist as you create acid and base solutions, neutralize them, and observe a colorful chemical reaction."
- Jiggle Gels: "Measure with purpose and cause exciting physical changes as you investigate the baby diaper polymer, place a super-absorbing dinosaur toy in water, and make slime."
- What's New, $CO_2$?: "Combine chemicals and explore the invisible gas produced to discover how self-inflating balloons work."