

## 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> .)

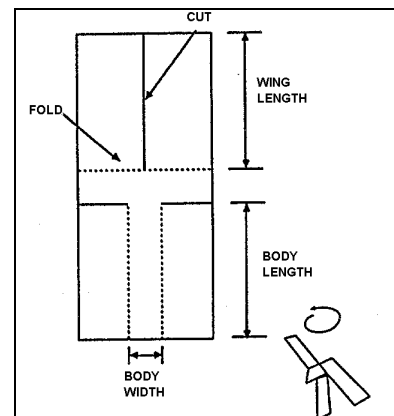
1. **Paper Helicopter** (from "George's Column: Teaching Engineers Experimental Design with a Paper Helicopter", *Quality Engineering*, 4 (3), pages 453-459, 1992, by George E. P. Box.):

- 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 get hover times of over 4 seconds from step-ladder height.

\*(For a video of South Dakota School of Mines and Technology engineering students dropping paper helicopters, see this StatsMadeEasy blog:

<http://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: http://www.statease.com/pubs/hockey.pdf](http://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!

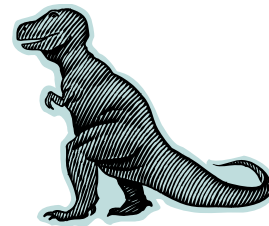
3. **Eye-Hand Coordination** (from *Linking High School Math and Science Through Statistical Design of Experiments*, Macomb Intermediate School District, 1995, page 2-1, by Bert Gunter.\*):

- Draw two circles on either side of a piece of paper. See how many dots you can alternately mark in the circles within 30 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.

\*(For example, see these slides 1-8 reproduced from original materials developed by Stat-Ease with permission to a fellow DOE trainer (Larry Scott): [http://www.doetraining.com/files/ASQ\\_06.pdf](http://www.doetraining.com/files/ASQ_06.pdf).)

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. PS. If you do this with children, put some little dinosaurs in the sand. Count how many become extinct.
- 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 pp110-114 *DOE Simplified*, <http://www.statease.com/prodbook.html>)

6. **Paper Clip Strength**, Stat-Ease, Inc. – detailed instructions available at: <http://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-Ease software).

- 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-Ease software). 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 user - Roger Longbotham, a statistical consultant based in the Denver area:

- 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 forward 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. **Catapult** (available from several vendors of quality training materials.)

- 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** (Dr. Leonard M. Lye, PEng, FCSCE, Professor, Faculty of Engineering and Applied Science, Memorial University of Newfoundland, Canada)

- Professor Lye's golfing toy can consider up to 5 or 6 factors (e.g. 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. See <http://www.statease.com/golftoy.html> for more information, photos and data. There you will find details on how to buy one of these "toys" for teaching DOE.

12. **Play putty** (Paul N Sheldon, <Paul.Sheldon@alliedsignal.com>)

- 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 <http://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. **Drag Racing** (from unpublished article by Mark Rusco)

- Play "Burnout - Championship Drag Racing" simulation.\* Choose from 20 unique cars with over 60 vehicle adjustments. Include environmental conditions if you like. Responses include 1/8<sup>th</sup> mile time, 0-60 mph, and many other speed measures.



\*(May not be available anymore, but the same software publisher now offers a game with similar features, both for IBM PC and Playstation®, under the name "IHRA Drag Racing." See [http://ihra.bethsoft.com/.](http://ihra.bethsoft.com/))

15. **Paper Towels** (suggested by Professor 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 (cites) via Internet.”\*

\*(Such as [http://www.tappi.org/paperu/fun\\_science/teststrength.htm](http://www.tappi.org/paperu/fun_science/teststrength.htm) .)

16. **Katie’s Kids’ Favorites** (at the request from a reader of my “Mark’s Experiment” column in the *Stat-Teaser* newsletter, here’s a collection of fun experiments I’ve done over the years with my youngest daughter Katie and her four older siblings.)

- 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*,

<http://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 5<sup>th</sup> 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 via the link below.

\*(<http://www.statease.com/pubs/popcorn.pdf>)

- In a variation on this, I subjected my Stat-Ease colleagues to a simple comparative taste testing of various brands of microwave popcorn bought on a haphazard basis by the office staff. See my report in the December 2001 *Stat-Teaser* posted at <http://www.statease.com/news/news0112.pdf>.

- Macaroni and cheese taste test – cook up various brands of ‘mac-n-cheese’ and see if any stand out statistically.
- Slinky walking\* – send different brands of spring toys down a board at varying angles and time how long it takes them to reach the end.

\*(Sept. 2000, *Stat-Teaser*, <http://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!

\*(Sept. 2002 *Stat-Teaser* <http://www.statease.com/news/news0209.pdf>)

17. **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?

\* (March 2003, *Stat-Teaser*, <http://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!

\* (Dec. 2003, *Stat-Teaser*, <http://www.statease.com/news/news0312.pdf>)

18. **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.

\*(pp150-153 *DOE Simplified*, <http://www.statease.com/prodbook.html>)

- Soap bubbles\* – combine varying amounts of dishwashing soap with water and corn syrup and measure the time it takes for blown bubbles to burst. (See formulae posted at Exploratorium link.) Suggestion: Do this DOE outside to avoid unsightly syrup rings!



\* (Sept. 1997, *Stat-Teaser*, <http://www.statease.com/news/news9709.pdf>. Also see <http://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 <http://www.statease.com/pubs/cake.pdf> for the manuscript of an article that appeared in *Today's Chemist at Work*, November 1997.)

- 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!

\* (Sept. 1997, *Stat-Teaser*, <http://www.statease.com/news/news0106.pdf>)

## 19. Formula Fueler

- This exercise for teaching design of experiments is aimed at students of design for six sigma (DFSS) quality improvement. Experiment with different fuels (coffee, water or soda pop) in a Hot Wheels® Formula Fueler motorcycle made by Mattel. For details see <http://www.slideshare.net/rbalisnomo/formula-fueler-design-of-experiments-class-exercise-presentation>.

## 20. *Really Rotten Experiments* (a Scholastic Children's Book)

- The author, Nick Arnold and illustrator, Tony De Saulles won the Junior Prize for the Aventis Prizes for Science Books 2004 by providing revolting experiments that kids love, such as making green slime. The book 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. It's sold over a million copies in United Kingdom, but may be hard to find in USA.



### Want to learn more about DOE?

Consider attending our *Experiment Design Made Easy* workshop. See [http://www.statease.com/clas\\_edme.html](http://www.statease.com/clas_edme.html) for details and follow links from there for a schedule of public classes and on-line registrations. Or call us at 612.378.9449.

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