Why the Catapult is a Poor Teaching Tool for Design of Experiments

Prepared by: Perry Parendo
Perry's Solutions, Inc.
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A widely used tool in Design of Experiments (DOE) training is the "Catapult." The goal is to launch a ball towards a target, like the gladiator days, with a table top device. It has a wooden throwing arm and rubber bands for power. By changing the arm length, number of rubber bands, type of rubber band, the attachment point of the rubber band and the type of ball, the user can determine how to best hit the center of the target. I have attended several training sessions where this has been used and I have seen first-hand how poorly the Catapult teaches the critical DOE principles.

DOE Training Needs

Why do I consider the Catapult such a poor teaching tool? Let's consider what we need to learn with DOE. First, we need to learn the tools to use and the analysis matrices. Second, we need to learn how to select and set up a matrix for a given situation. Finally, we need to handle open ended, real life situations. We will look at each of these areas and see how the Catapult fails to develop these skills.

Learn Tools and Analysis

Learning the tools and the analysis techniques requires the user to have data. For general training, students likely will not know the technical specifics of the example provided. The problem could be a specific design, manufacturing or marketing application which the student is not familiar with, even if it is something from their own company. It could also be in an industry completely different than their own. Thus, the data provided is just a set of numbers. It really doesn't matter much what the example is to learn the steps for using the DOE tools, so long as the values allow the tools to be explored.

The output data provided for a Catapult is accuracy. People will often measure "distance from center" unless provided with better guidance. This hinders providing a direction for any follow up testing. What is really needed is to measure "error" left or right, and "error" long or short. However, this will create negative values for the output, which limits the ability to use transformations during the analysis. It is not common in most applications to have negative performance values. Additionally, spotting where the ball lands is a huge potential source of noise leading to no analysis results. These issues can be interesting learning points, but can also lead to frustration and no final solution. The frustration is compounded by an application of "projectile accuracy" that is not applicable to most DOE user.

If the output measurement restricts use of transformations, it limits the ability to learn about the analysis options available. In fact, if a poor tool is selected (such as general factorials, to be discussed later in this paper), this will further limit the ability to learn about needed analysis techniques. As we will see, the Catapult application encourages use of this poor DOE tool. It also does not allow for center points, which can be a useful item to consider.

Set-up DOE Matrix

Next, how does one select and set up a DOE matrix? Of the tools available, I typically recommend to avoid 3 level and higher designs during the first phase of testing. I also avoid “general factorials” as they can quickly grow in size and do not have fractional factorial alternatives available such as interactions. The general factorials also negatively impact the ability to learn about analysis options as discussed earlier. This is also based on the real world observation that it is often not needed to have more than 2 conditions for each input variable. If you discover the need to go beyond 2 levels, you probably learned something else during Phase 1 (a new variable, a new variable range or a new output measurement) that would force you to repeat the test anyway. For some reason, new users lean towards the “general factorial” with the Catapult exercise and test every combination. This means the analysis is not what they are going to see in the real world. Or, they do no analysis at all, and just “pick the winner.”

I also see students encouraged to using discrete or categoric Catapult variables instead of continuous variables. While the length of arm could be numerical, in practice the Catapult arm has predrilled holes with a bolt to hold it in place. People will tend to either call the position “high and low” or label it with “position 2” and “position 5.” Best practice is to create numerical inputs where possible. This Catapult exercise does not emphasize this point which leads to sloppy set-up in the real world. I often ask users what the “high” setting was in a previous test, and they no longer remember what it was. This means the test is not reproducible which means the learning is not retained.

Open ended problem solving

Finally, such a prescribed exercise does not provide an open ended problem like they will face after class. The real world challenges come from having more variables to deal with than you have time. At most, the Catapult has 5. In the real world, most situations have at least 20 when you dig into them. Users are also challenged with determining how to define set points for continuous variables in the real world. Life does not provide predrilled holes! While some categoric variables exist in the real world, most applications have a majority of continuous variables. The last real world challenge is having a measurement system with optional approaches, but is not overly complex. If everything is provided to the student for the example, they might as well just be provided another set of random data.

Conclusion

Ultimately, I have found that people training with this tool tend to struggle bridging the gap with their own practical applications. That is the true test of a teaching tool. I have seen people who do this exercise face a major leap to get to real world application. The Catapult was fun and easy in class, but now they are facing things, without support, that they have not had to think about before. There are countless creative ways to have a productive in-class learning exercise. I have used several approaches based on the group that I am working with. It is important to understand the learning objectives described here and ensure your exercise can address them. The value provided is ensuring implementation of the DOE tool in the real world. Anything less is entertainment at best.