AC 2012-3081: LOW-COST HANDS-ON DOE EXPERIMENTS

Dr. Kirstie A. Plantenberg, University of Detroit Mercy

Low cost hands-on DOE experiments

Abstract

At the University of Detroit Mercy, "Design of Experiments (DOE)" is a graduate level class that teaches students multiple methods of experimental design. Each DOE method allows the student to systematically, efficiently and accurately gather data and make objective conclusions based on their analysis. This is a very important skill for engineers to have, however, the class is heavily mathematical and traditionally not applied. The traditional lecture only class format left students wanting and frankly bored. It is the goal of many teachers to weave hands-on experiences into the traditional lecture format. One roadblock to doing this, in this particular case, was budget constraints. Developing and building five to six instrumented engineering experiments can be costly. This paper describes five low cost DOE experiments that can be purchased and implemented by just about anyone. The main objectives for each of the experiments are to illustrate the DOE method currently being lectured on, to give the students an opportunity to apply the method to something real, to give them an opportunity to analyze data and communicate their results. A survey given at the conclusion of the class showed that all the students "agreed" or "strongly agreed" that each experiment "Helped them understand the DOE principle being illustrated." Even though the experiments described in this paper are simple, they are an effective tool for illustrating DOE principles and give students practical hands-on experience.

Introduction

Class Structure

At the University of Detroit Mercy, "Design of Experiments (DOE)" is a graduate level class that teaches students multiple methods of experimental design. Each DOE method allows the student to systematically, efficiently and accurately gather data and make objective conclusions based on their analysis. The main topics presented in the class include the following.

- Simple comparative testing
- ANOVA (analysis of variance)
- RCBD (randomized complete block design)
- Full factorial design
- Fractional factorial design

Until recently, the class has been presented in a traditional lecture format. This implies that a subject was presented and then a few examples where solved to illustrate the concept being taught. At the end of the semester, the students would perform a final experiment, write a report and present their results to the class. The student's final experiment usually employed a full or fractional factorial design.

Need for change

Being able to design experiments properly is a very important skill for engineers to have, however, the subject is heavily mathematical and traditionally not applied (at least within the classroom environment). The lecture only class format left students wanting and frankly bored. It is a challenge for instructors of any class to keep students focused and involved in the lecture, but DOE has two additional challenges. One, the highly mathematical nature of the class makes it hard to infuse physical relevance which engineering students crave. Two, DOE examples are generally computationally intensive which makes them very long and the brute force calculations don't add much to the conceptual understanding. So, the question becomes, "How do you present and example, teach the calculations (without doing the calculations) and keep it interesting?" The solution presented here is, "The addition of hands-on experiments that reinforce the concepts and examples presented in class."

It is the goal of many teachers to weave hands-on experiences into the traditional lecture format. It has been shown, that among other benefits, hands-on learning helps students remember what they are being taught [2-5]. It was clear (at least to me) that what the "Design of Experiments" class needed was "EXPERIMENTS!" This sentiment is echoed in a paper by William G. Hunter [1] , a noted statistical text book author. Hunter stated that students get plenty of practice analyzing data through homework, but little or no practice designing a realistic experiment. Ideally, the objective for each of the hands-on experiments would be to illustrate the DOE method currently being lectured on, to give the students an opportunity to apply the method to something real and to give them an opportunity to analyze real data and communicate their results.

One roadblock to including experiments, in this particular case, was budget constraints. Developing and building five to six instrumented engineering experiments can be costly. This paper describes five low cost DOE experiments (listed below) that can be purchased and implemented by just about anyone. All of the experiments listed, except for the "Dice Experiment" and the "Final Experiment", are original and of my own making.

- Dice Experiment (Central limit theorem)
- Wood Block Experiment (Simple Comparative Testing)
- Water Experiment (ANOVA)
- Exercise Experiment (RCBD)
- Friction Experiment (Full Factorial)
- Bioplastics Experiment (Fractional Factorial)
- Final Experiment (student choice)

Experiment Descriptions

Each of the following experiments has multiple objectives. The main objective is to illustrate the DOE concept being presented in class. It also gives the students experience running a real experiment. The experiment connects the DOE concept to a real experiment. This gives the students an opportunity to perform runs in a random order and analyze real data riddled with experimental error. When analyzing book problems, the students don't have a chance to sample the data in random order. Randomization is an important concept that may be overlooked if they are not physically doing it. Also, book problems give data that are usually nice and neat and conform to the normality and independence assumptions. This is not always the case when performing real experiments. The students are often forced to think about reasons why their data is not normal or independent.

Secondary objectives of each experiment are to give students experience writing experimental reports and using statistical analysis software. In this case the statistical software used was MINITAB.

The following is a description of the experiments that were performed during the Fall 2010 offering of the DOE course. Each description contains the experiment's objectives and a brief summary. A detailed description of the *experimental equipment*, *experimental procedure*, *results and analysis* instructions and approximate *cost* for each experiment may be found at the following url.

www.engineeringessentials.com/doeexperiments

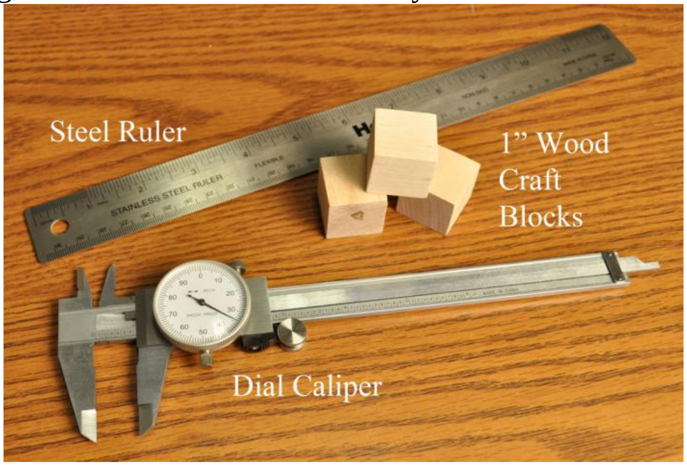
Dice Experiment

The objective of the "Dice Experiment" is to introduce the students to the statistical software (MINITAB) and allow them to get a feel for writing a technically correct experimental lab report. At least 95% of the students entering the class have no prior MINITAB experience. The "Dice Experiment" is conceptually simple, but requires the use of a statistical software to complete. Also, approximately 70% of the students are taking this class in their first semester in the United States. This segment of the class generally doesn't know what U.S. instructors expect in their lab reports. The "Dice Experiment" gives them the opportunity to practice writing an experimental lab report.

The "Dice Experiment" is a commonly used example for illustrating the *central limit theorem*. I use it because of its simplicity, low cost and for the reasons stated above. Basically, the students are tasked with showing that if you plot the histogram of 30 dice rolls, the probability distribution will most closely match a *uniform* distribution. However, if you repeat the 30 rolls 7 more times and sum the 8 columns the histogram will move to a more *normal* distribution.

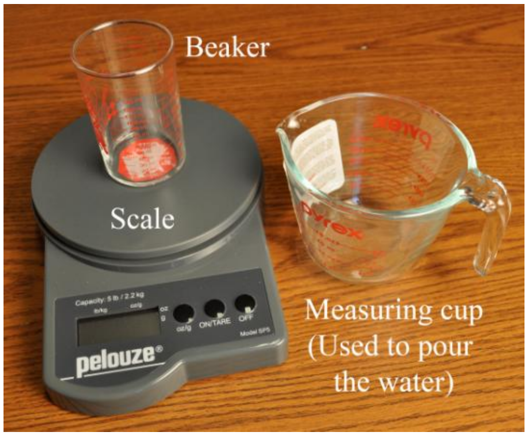
Wood Block Experiment

The objective of the "Wood Block Experiment" is to illustrate simple comparative testing. Specifically, the *one sample t-test* and the *paired t-test*. The students are given a simple wooden block that is supposedly 1-inch cube (as stated on the packaging). They are asked to confirm or reject the manufactures claim that the blocks are 1-inch. In addition, the students are given two measuring instruments: a plain ruler and a supposedly more accurate caliper. The students are then asked to determine if the two measuring instruments measure differently.



The students are given no further instructions than what is stated above. They are required to design and implement their experiment. This leads to many heated debates among the students. The students discussions tend to gravitate towards "What does 1 inch block mean?", "How should we measure the block?", "How do we minimize error?", "Should only one person measure?" and "How do we randomize?"

Water Experiment



The objective of the "Water Experiment" is to illustrate the *ANOVA* procedure or *F-test*, which is used to compare multiple group means. The students are tasked with competing to see who in their group can fill a beaker with water the most accurately. The students really get into this experiment because of its competitive nature. It is fun and there is usually a lot of laughter.

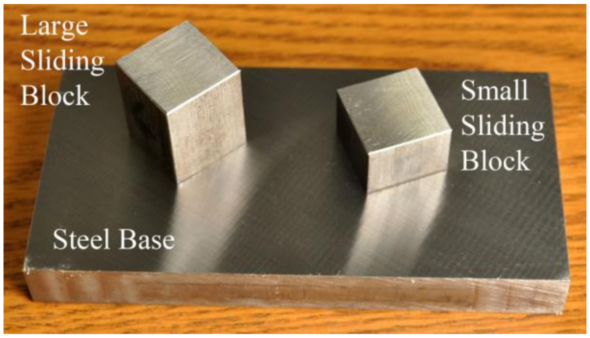
Exercise Experiment

The objective of the "Exercise Experiment" is to illustrate the importance of blocking against nuisance factors. The students are tasked with determining which of the following exercises can be performed the fastest (10 sit-ups, 10 pushups, 10 jumping jacks, 10 squats).

The students first run an RCBD (randomized complete block design) using *Person* as a blocking factor. This usually results in finding a significant difference between performance *Time* of the different exercises and results in a low *P*-value for *Person*. They can then conclude that *Exercise Type* affects *Time* and that *Person* is a good blocking factor. The students then run an RCBD using *BMI* (Body Mass Index) as a blocking factor. The usual result is that *BMI* is not a good blocking factor and ends up having a large *P*-value. Finally, the students run a straight ANOVA (*F*-test) with no blocking and try to draw some conclusions. They are usually unable to determine a performance time difference between the exercises.

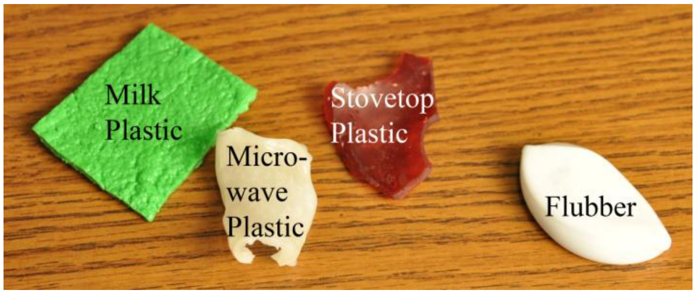
Friction Experiment

The objective of the "Friction Experiment" is to familiarize the students with running a *factorial* experiment. The students run a 2^3 full factorial to determine the importance of some factors that can influence the static friction force between two dry contacting metal surfaces. The factors being tested are *surface roughness* and *normal force*. To test these factors, a steel base and two sliding blocks of different weights are used. The base and blocks both have a rough and smooth side. The effect of *surface roughness* on the friction force is tested by changing between the rough and smooth sides of the contacting surfaces. The effect of *normal force* on friction is tested by changing between the small and large sliding blocks. The specific factors and levels being tested are; steel base surface roughness (rough, smooth), sliding block surface roughness (rough, smooth), sliding block size (small, large).



Bioplastics Experiment

The objective of the "Bioplastics Experiment" is to show the students the advantages and disadvantages of running a *fractional factorial*. The students run a 2^{k-1} fractional factorial to determine which levels of bioplastic ingredients and cooking method produce the best quality bioplastic. The students break up into four groups. Each group selects a different bioplastic; Milk plastic, Stovetop corn plastic, Microwave corn plastic and Flubber. Each recipe has four factors that can be tested at two different levels. The factors can either be ingredient amounts, cooking times or cooking temperatures. As the students quickly learn while running the experiment, each run takes a significant amount of time. Therefore, the advantage of running only 8 runs as opposed to 16 runs of the full factorial is significant. They also learn, through their analysis, the disadvantage of aliasing that is inherent in a fractional factorial design.



Final Experiment

The objective of the "Final Experiment" is to give the students a chance to plan, design, conduct and analyze an experiment of their own using appropriate DOE techniques. The context of the experiment is limited only by the student's imagination. They may conduct experiments directly connected to their research, a project that they are involved in at work, or they could conduct a "household" experiment. Students use the knowledge that they have gained by running the previous in-class experiments to plan their own experiment. The "Final Experiment" gives them a real taste of everything that goes into planning and conducting an experiment on their own.

Assessment

As an instructor, I was happy to see students experiencing the knowledge that they were learning in the classroom. However, were the hands-on experiments making a difference? A survey given at the conclusion of the class showed that all the students “agreed” or “strongly agreed” that the experiments “Helped them understand the DOE principle being illustrated.” This led me to conclude that the addition of the hands-on experiments to the classroom had a positive effect.

The survey that the students completed had two parts. The first part asked general questions about the in class experiments as a whole. The second part asked specific questions about the effectiveness of the individual experiments. Eighteen students completed the survey. For the first part of the survey, the students were asked to respond to each survey statement using a scale from 1 to 5 (1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree). The results for the general experiment questions are given in Figure 1. Overall the results show that adding the experiments had a positive effect on the class. They showed that the experiments helped the students understand the DOE principle being illustrated. They also helped the students connect these principles to the real world and understand concepts such as randomization, assumptions, method consistency and experimental error. A side benefit, but no less important, the experiments were fun and improved the students skills in software analysis and report writing.

The second part of the survey asked the students to rate the effectiveness of each experiment on a scale from 1 to 5 (1 = Not effective, 2 = Not very effective, 3 = Neutral, 4 = Somewhat effective, 5 = Very effective). The results are given in Figure 2. The results show that the “Wood Block Experiment”, “Exercise Experiment”, “Friction Experiment” and the “Final Experiment” were the most effective. Although, written comments indicated that students really enjoyed the “Water experiment”. The “Dice Experiment” is meant only as a practice experiment and therefore, it is not surprising that it received lower scores. The “Bioplastics Experiment” was new this year and there is room for improvement.

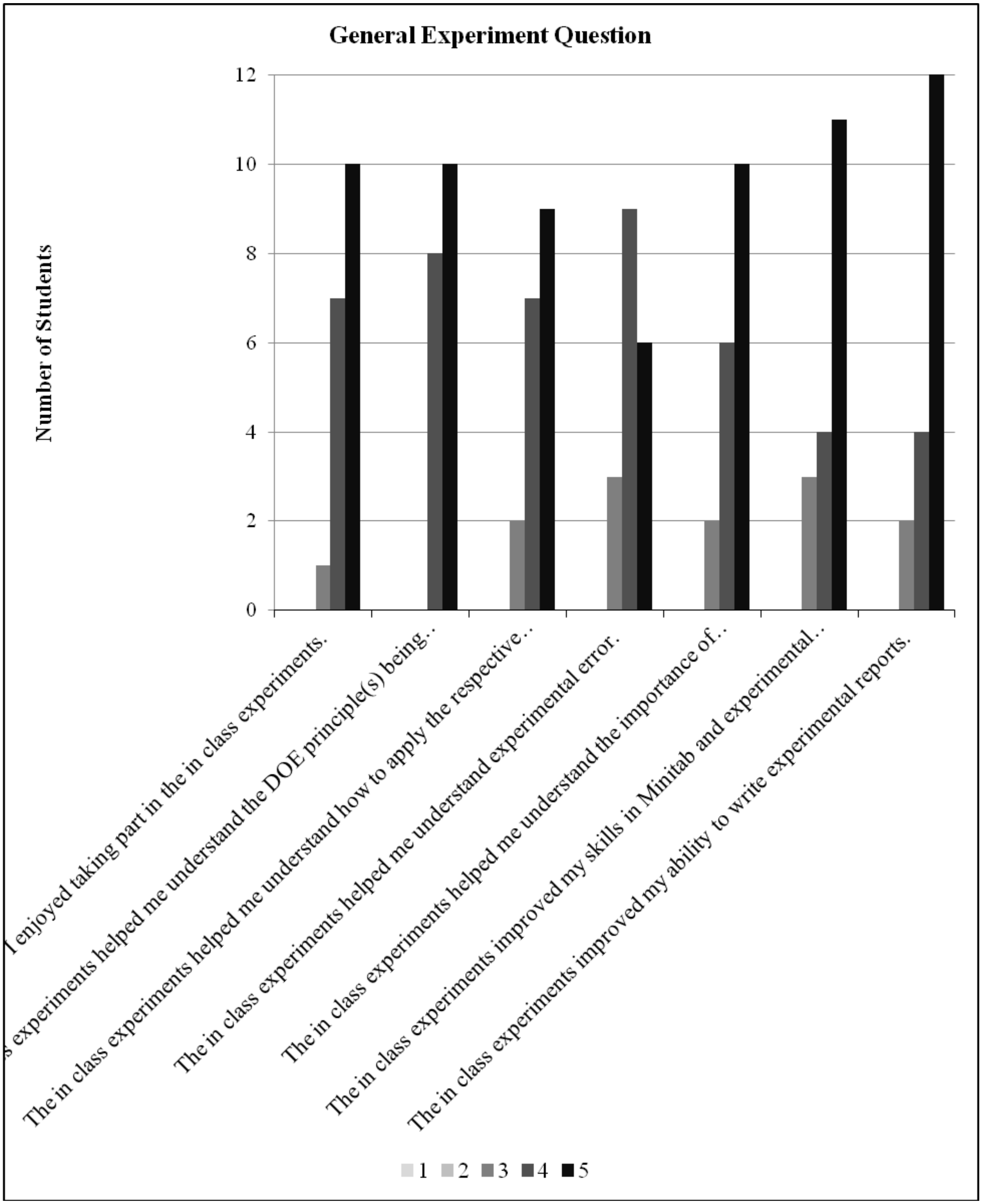


Figure 1: Assessment results of the hands-on experiments

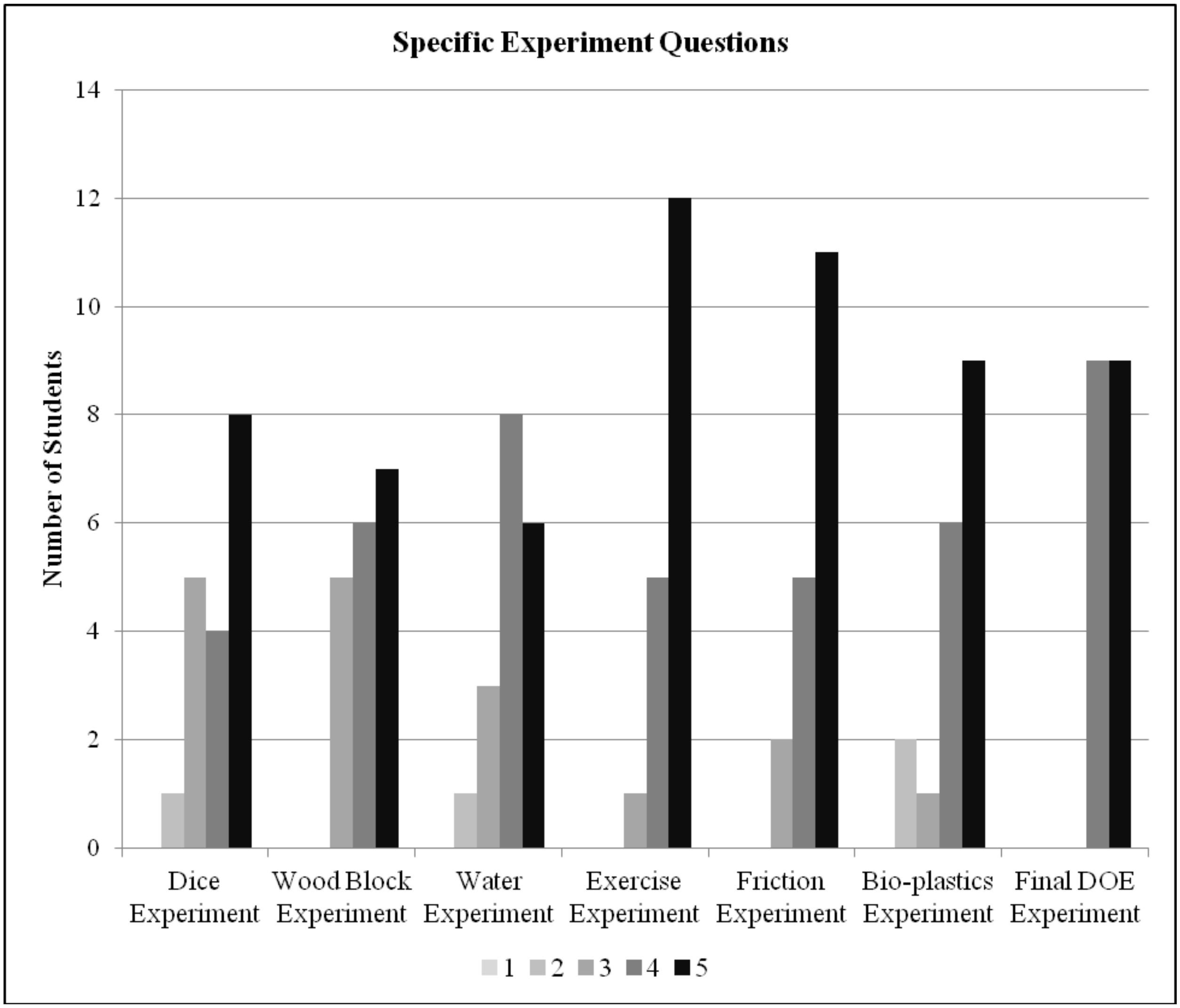


Figure 2: Assessment results of specific experiments

Conclusions and Recommendations

Assessment results show that adding hands-on experiments to a traditional lecture format class has a positive effect on learning. The experiments helped the students understand the DOE principle being illustrated, and helped the students connect these principles to real world concepts such as randomization, assumptions, method consistency and experimental error. The experiments were fun and improved the student's skill in software analysis and report writing.

The experiments described in this paper are simple and low cost. They are also an effective tool for illustrating DOE principles and give students practical hands-on experience. I feel that almost anyone can purchase and implement these experiments with great success. However, there is always room for improvement. Whereas many of the experiments were rated "very effective" by the students, the "Water Experiment" and the "Bioplastics Experiment" were rated slightly lower and could be improved to better illustrate the concepts being taught. As mentioned before, the "Bioplastics Experiment" was new and a bit rushed in its implementation.

I learned that the *Milk plastic* and the *Flubber* produce the best results. By this I mean that they produced a good standard recipe plastic and when the recipe was changed, the properties changed enough to measure. The *Stovetop plastic* makes a good standard recipe plastic, but the properties don't change much when the recipe is varied. The *Microwave plastic* does not make a good standard recipe plastic. I believe that the amount of oil needs to be adjusted. I will continue to adjust and use the "Bioplastics Experiment" in the future and hopefully produce a "very effective" experiment. For further information, please visit www.engineeringessentials.com/doeexperiments.

References

[1] Willam G. Hunter, "101 ways to Design an Experiment, or Some Ideas About Teaching Design of Experiments", http://williamghunter.net/articles/101doe.cfm, 1975

[2] David L. Haury, Peter Rillero, "Perspectives on Hand-On Science Teaching", http://www.ncrel.org/sdrs/areas/issues/content/cntareas/science/eric/eric-2.htm, 1994

[3] Resource Are for Teaching (RAFT), "A case for Hands-on Learning", http://www.raft.net/public/pdfs/case-for-hands-on-learning.pdf, 2009

[4] Bicknell-Holmes, Tracy, "Teaching in a Hands-On Environment", *Library Conference Presentations and Speeches.* Paper 27,.http://digitalcommons.unl.edu/library_talks/27, 2000

[5] B.D. Coller, "An Experiment in Hands-on Learning in Engineering Mechanics: Statics", http://www.ceet.niu.edu/faculty/coller/images/handsOnPreprint.pdf

[6] M. Koretshy, D. Amatore, C. Barnes, S. Kimura, "Enhancement of Student Learning in Experimental Design Using a Virtual Laboratory", IEEE Transactions on Education, Vol. 51, No. 1, February 2008