

ACTIVE LEARNING EXERCISES FOR UNDERSTANDING STATISTICAL PROCESS CONTROL

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INTRODUCTION

Statistical Process Control (SPC) is a statistical based methodology for distinguishing a real shift in a manufacturing process (assignable cause variation) from random fluctuations (common cause variation). Historical data are used to generate upper and lower control limits. Production samples are selected and measured and the results plotted on a control chart. If the process is unchanged, new sample data should fall between the control limits. If a process shift occurs it becomes more likely that a new data point will be outside of the control limits. The process is improved by eliminating assignable causes and reducing the common cause variation.

It is important that students in the Industrial and Manufacturing Engineering (IME) department at Oregon State University (OSU) obtain a solid understanding of statistics and SPC. Many of the IME students participate in the Multiple Engineering Cooperative Program (MECOP) and are frequently expected to utilize SPC during one of their internships.

To apply SPC, students must gain a solid understanding of its statistical foundation and be exposed to some of the issues associated with its application. In practice, statistics is hard to learn. The concepts are not intuitive and students have few “hooks” to attach the material. Most SPC textbooks do a good job of presenting and explaining its theoretical foundation but do not provide hands-on exercises.

This paper describes a series of nine active learning exercises that have been developed to assist students in understanding SPC and basic statistical concepts and to present some SPC application issues. Used during a two-hour class period, the exercises provide students with laboratory like learning experiences including data collection and analysis using little or no equipment.

REASONS FOR CREATING ACTIVE LEARNING EXERCISES

Active learning has been defined as activities that “involve students in doing things and thinking about the things they are doing”¹. This definition caught my eye as I struggled to deal with a frustrating situation. It seemed that no matter how much explanation and how many examples were provided in class, many students were unable to correctly conduct a basic statistical analysis. It got even worse when students were presented with a new situation that didn’t match earlier problems. Lecture was just not enough.

One of the problems with the lecture – homework format is that it does not address the need for students to experience learning activities that complete Kolb’s four quadrant learning cycle²:

1. **Why** is the material important? Provide a concrete experience for the student to understand the situation that makes the material relevant.
2. **What** are the facts, the body of knowledge. This is typically done through lecture.
3. **How** does it work, how can the theory be applied to solve a problem? This is usually accomplished through laboratory exercises and homework.
4. **What-if** the situation is changed, what-if some real-world components are added to the problem?

It is a circular model for learning because what-if questions can lead directly to new questions where the student learns why the next set of material is important. Completing several cycles is important in a course like SPC because dealing with real-world issues is an integral part of the implementation of the methodology. Implementing a more complete application of Kolb’s learning cycle by adding active learning exercises to the traditional lecture format was the motivation for the new exercises.

LEARNING OBJECTIVES FOR ACTIVE LEARNING EXERCISES

Fortunately, the four-quarter credit hour SPC course in the IME department at OSU consisted of one, two-hour laboratory in addition to three, one-hour lectures. The two-hour laboratory was not well utilized. The exercises were not synchronized with the lecture and students worked individually to complete assigned exercises. The laboratory time was completely restructured to link directly with the lecture material. The active learning format provided the opportunity to expand the learning objectives for the laboratory to the four described below.

Improve Students’ Understanding of Basic Course Concepts

Students followed detailed, step-by-step instructions to apply class material that had been presented in the previous one to two lectures. Students worked in teams and individually recorded the solutions in their instruction booklet. The informal format gave me the opportunity to work with students as they solved the problems. More importantly, it gave me the opportunity to ask students to justify their approach and to respond to what-if questions. Many times the informal questioning lead to reactions such as “Ah, now I’m beginning to understand”.

Create Situations With Real-World Application Issues

Some of the exercises were targeted directly at application issues. Discovery of the issues was a natural outcome of collecting and analyzing experimental data. SPC is about understanding the sources of variation in a process. The process of collecting data to generate control limits created the opportunity to ask additional questions. For example, asking why a process has so much variation leads directly to exploring the possible causes of the variation.

People skills

It is extremely important that engineers possess excellent people skills³. Students in the IME department are introduced to the basic principles of effective teams in a second year course. Team projects are included in most IME courses. In the SPC laboratory, students worked in

teams of two to four. Team assignments were made randomly each week so that the students learned how to rapidly form a productive team. To provide structure to the process, many of the exercises incorporated team-based quality improvement tools such as affinity diagrams, multivoting and brainstorming⁴.

Communication skills

In addition to communication among team members, a representative from each team presented their findings to the class. For many students, this was the first time that they had had to stand in front of a group of their peers to explain their results and defend their conclusions. Traditional laboratory reports were not required. Instead, each student wrote a one-page report that identified and discussed two meaningful lessons that were learned in the laboratory. Getting students to reflect on the entire experience instead of reporting facts proved to be quite a challenge. Reports were graded for content and grammar.

ACTIVE LEARNING EXERCISES

Each of the nine exercises is outlined in this section. The applicable **Why**, **What**, **How**, and **What-if** axis of Kolb's learning cycle is shown in bold. A copy of the exercises in Word 97 format can be obtained at <http://www.engr.orst.edu/~shea/ALE>.

At OSU, students must complete a course in engineering statistics prior to taking the SPC course. The first two exercises were designed to refresh the student's knowledge of basic statistics because there is frequently a one-year gap between the two courses. Exercises three through five focused on the role of control charts and other tools in the overarching goal of continuous process improvement. The next three exercises concentrated on issues associated with the application of SPC to production processes. The final exercise covered the statistical basis of sampling inspection.

Exercise #1: Binomial and Normal Probability Distributions

The primary objective of the first laboratory was to refresh students' knowledge of basic statistics – the **What** step in Kolb's cycle. Most SPC applications use either the binomial or normal probability distributions to model the process. The production process of flipping fair coins was modeled with the binomial distribution. Students compared their experimental results with theoretical expectations and determined if they were in agreement. The thickness of steel washers was used to represent the normal distribution. Students were surprised to discover variability in the thickness. This created an excellent opportunity to discuss **Why** it is necessary to use statistics to describe the output of a production process.

Exercise #2: Sampling From a Population

It makes intuitive sense that better estimates of the mean of a population can be obtained by taking more samples. Yet, the details of this relationship have proven to be quite confusing to students. Exercise #2 described **What** the relationship is between the distribution of the population and the distribution of the sample mean for a given sample size. Students were provided sample data drawn from four different populations and the mean of 50 samples of sizes

2, 10, and 25. Histograms of the sample means provided graphical representation that can help students construct an accurate mental model of the relationship between the distributions.

Exercise #3: Control Charts Using the Binomial Probability Distribution

Students struggle to understand **How** a mathematical probability distribution, a very abstract concept, can model the results from a real-world experiment. In this lab, a paddle with 50 holes was inserted into a box containing a mixture of 1100 white and black beads. The outcome of the experiment is the number of white beads on one paddle.

Student teams worked through the process of analyzing the experiment and determining the appropriate distribution based on the conditions that were present. To simplify the calculations, students had to ask the question “**What-if** the sample size was small compared to the size of the population?” Since this was true for the experiment, the Binomial probability distribution could be used to describe the outcome. Additional exercises, using the data generated with the paddle and beads, gave students practice in developing confidence intervals and control chart limits.

Exercise #4: Quality Improvement Tools

Check sheets and Pareto Diagrams are two examples of the many tools that have been developed to facilitate process improvement. The tools are relatively easy to understand but difficult to use. Thus, a case approach requiring a structured approach to solving a process problem was used to teach both **What** the tools are and **How** they are used.

Exercise #5: Deming’s Red Bead Experiment^{5,6}

The distinction between common cause and assignable cause variation seems clear. In practice, people tend to assign specific causes for variation when it is really the natural (common cause) variation of the process. Videotapes of the Red Bead Experiment were shown in order to ensure that students understood **Why** the distinction is important.

Deming creates a production process using a setup similar to that used for Exercise #3. Volunteers (workers) insert the paddle into a bucket of beads. The number of red beads on the paddle varies, which represents the common cause variation of the process. In the Red Bead Experiment, the workers have no control over the number of red beads on the paddle. Deming is making the point that management is quick to assign the variation to the workers, not the system. Student teams utilized brainstorming, affinity diagrams and multivoting to analyze assigned discussion topics.

Exercise #6: Filling Containers with Sugar

Textbook problems include data, which makes it easier for students to learn the mechanics of calculating control limits. Unfortunately, this approach can be too abstract to communicate **How** to apply SPC to a production process. In this exercise, students filled film containers with sugar and used balance scales to measure the weight. Control limits were calculated and the data plotted. Team discussion was used to identify the sources for the common cause variation.

Exercise #7: What Variables to Chart?

What-if financial considerations must be considered in the application of SPC? A process using a computer numerically controlled (CNC) machine was used to introduce this real-world

constraint. The CNC machine was used to drill and mill the pattern shown in Figure 1 into a wax block. Students used brainstorming to create a list of possible variables to chart. An enhanced version of Potential Problem Analysis⁷ was used to rank the list in order of importance and identify the optimum set of variables to chart.

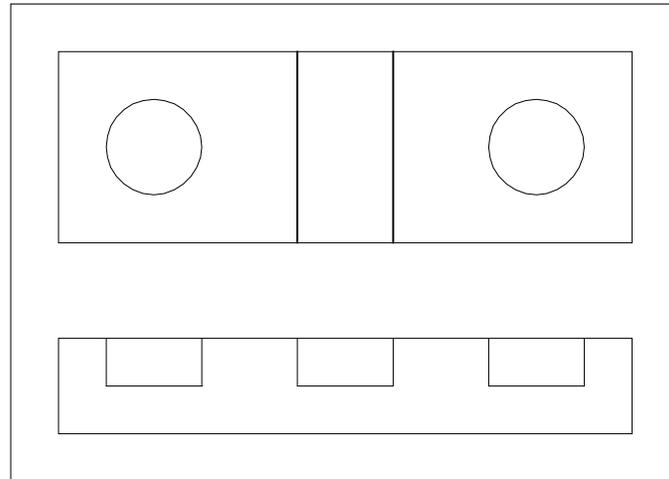


Figure 1. Top and Side View of Wax Block used in Exercise #7.

Exercise #8: Gage Capability Analysis.

The variability of the gage used to measure a process or product parameter must be measured to know the true variability. Gage capability analysis is a statistical approach to measuring the variability of the gage. It requires the repeated measurement of the same dimension on the same set of parts by different people.

To better understand **How** gage capability analysis is performed, students used micrometers to measure the thickness of metal washers. Students charged right into the project and many were quick to blame the gage for the high variability that had been measured. But “**What-if** you contributed to the variability?” I asked. It was only then that it became clear that the large gage variability was due primarily to how it was being used, not the gage itself.

Exercise #9: Sampling Inspection.

Sampling inspection is used to pass or reject a group (lot) of material. A sample of material is drawn from the lot, which is then passed or rejected based on the number of defective units in the sample. A solid understanding of the statistics involved is necessary. Exercise #9 was a hands-on exercise in **How** to generate operating characteristic curves for two sampling plans.

QUALITY IMPROVEMENT TEAM

Quality improvement must be practiced in a quality improvement course. At the end of each laboratory, students answered the following three questions on 3 X 5 cards. Responses were anonymous.

- **Pluses:** What went well in the lab?
- **Improvement:** What should be improved? What did not go well in the lab?
- **Questions:** What question do you have about the material; what topic requires clarification?

Working with a team of student volunteers, the responses were categorized using the affinity diagram tool. Combining the responses with the volunteers' experiences allowed the team to identify what was and wasn't working and to propose changes to the exercises.

Students preferred very detailed instructions when learning new material, the What and How axes on Kolb's learning cycle. This was a hard lesson to learn. It goes against the traditional idea that engineering students should be made to struggle when learning the material. Students liked the individual attention, what-if questions, hands-on generation of data, and the small teams. The students were less enthusiastic toward activities such as Exercise #7 that focused on real-world application issues.

RESULTS

The nine active learning exercises presented in this paper were developed to compliment the lecture portion of the course. This was done because students in previous classes continually struggled to grasp the concepts and apply them to new situations. It is hard to determine if these objectives were met. My qualitative assessment is that the students were better able to handle more challenging questions on the exams, but there is no hard data. What is known is that students actively participated and felt that the exercises were very helpful. The exercises also created the environment where students had to develop teamwork and communication skills. These are skills learned over a period of time and must be included in the learning objectives for all engineering courses.

CONCLUSION

The active learning exercises demonstrate an alternative to traditional lecture-only classes. The exercises presented students with laboratory-like experiences without major investments in equipment and facilities. This is important at OSU because many of the engineering classes are being converted from three to four quarter-credit hours. The new structure will provide the opportunity for faculty members to experiment with new approaches to instruction and learning.

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