Enhancing Student Understanding of Control Charts Using a Dice Activity

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Abstract

Students majoring in technology and engineering technology often struggle with statistical concepts associated with quality related topics. More specifically, it is often difficult for students to conceptualize the use of Statistical Process Control (SPC) in continuous improvement. This paper outlines a simple, yet effective classroom method demonstrating what process improvement looks like when presented in an X Bar R chart (an SPC tool). The method utilizes gaming dice to simulate an improvement in a manufacturing process. Students are instructed how to construct and interpret control charts with emphasis on relating the results of the dice activity to the processes they routinely encounter at their workplaces.

1. Introduction

Statistical Process Control (SPC) is being used by manufacturers throughout the United States. There are numerous technological solutions for gathering, displaying, and analyzing data in real time. Some manufacturing managers claim SPC is used on the shop floor because their operators have been trained how to produce control charts. However, the responsibility for the analysis of the control charts may be given to quality control personnel, thus preventing real-time control of processes. Such delays could also result in bypassing potentially valuable input from shop floor operators and technicians. In contrast many manufacturers prefer the total involvement of shop floor personnel for the implementation of SPC. While it is the generally accepted that shop floor employees, who are responsible for manufacturing production, are the best personnel to monitor processes, they often lack the educational background to fully comprehend statistical principles. These employees need to be able to relate training to their job responsibilities. Shop employees are unaccustomed to a classroom setting. Developed and used for numerous workshops, this paper presents a simple yet effective method to introduce shop floor employees to SPC. This successful approach was also subsequently introduced into the college classroom to enhance learning and provide a training tool that students could take with them to real-world manufacturing.

2. Objectives

The objectives for the development of this activity were:

- It would be an experiential training method (hands-on).
- It would be an authentic training method (relatable to shop floor).
- It would clearly demonstrate what an improved process looks like in an SPC chart
- It would lay the foundation for understanding statistical principles.
- It would enhance understanding of the computational aspects of SPC.

3. Review of Related Literature

Statistical Process Control History

Before 1900, quality control in manufacturing meant removing substandard goods before they were shipped to the customer. The statistical quality control (SQC) movement began in the United States in the beginning of the 20th century and changed that perception. Western Electric's website notes that the quality movement as it exists today is generally traced to three people who began their careers at Western Electric, a part of the Bell Systems since 1882. Walter Shewhart, W. Edwards Deming, and Joseph Juran developed their ideas at the Western Electric/Bell Laboratories. Their scientific outlook on quality was not readily accepted in the United States, however it became a part of Japanese manufacturing practices after World War II [1].

SQC is involved with products, processes, services, and the entire manufacturing enterprise, or other systems. Walter A. Shewhart, Ph.D., called the father of SPC, brought together statistics, engineering, and economics to create statistical process control theories. Shewhart's theories were innovative because of their extensiveness and their background in the philosophy of science [2].
As an applied statistician, Shewhart proposed a control chart in a sketch on an informal memorandum to his supervisor in 1924. This laid the foundation for Statistical Process Control (SPC) which is a major part of SQC. Harold Dodge and Harry Romig, two statisticians who also worked at Bell Laboratories, went on to apply statistical theory to sampling inspection in the 1930s, which is another major part of SQC in modern manufacturing [2].

These beginning quality theories have many applications. SPC uses a number of statistical tools to achieve continuous process improvements; control charts remain among the most common. However, because of the broad outlook of Shewhart, SPC is not limited to only one procedure, analysis, or application. The breadth of techniques and tools used in SPC includes, but is not limited to the following: capability charts, cause and effect diagrams, control charts, flow charts, frequency histograms, Pareto charts, process charts, and scatter diagrams. These techniques are combined with each other to create process analysis and then infer appropriate management decisions.

From Engineering and Inspectors to the Shop Floor

Because SPC includes three areas: specification, production and inspection, it was necessary to expand its impact throughout the manufacturing process, not to constrain it to a special inspection team. The "Western Electric Statistical Quality Control Handbook," was introduced in 1958 as a method of teaching quality on the shop floor [1]. This need has continued to be recognized and has expanded. In an obituary for Walter Shewhart, W. Edwards Deming alluded to the necessity to train those most involved with implementing SPC when he stated that Shewhart who believed ". . . that practice demands more care if not also greater depth of knowledge than is required for pure research or for teaching. . . If the statistician is wrong his error will be discovered, often without much delay [3]." The shop floor is where that error is almost immediately discovered. Because of this, many organizations give SPC training to managers, designers, and shop floor employees.

An Internet search will reveal many organizations offering classes to both individuals and companies. SPC courses are available online, at conferences, and at the company location. In addition, software developed specifically for quality control applications is available, although general use software such as Excel, SPSS, and SAS may be adapted to generate the appropriate control charts. Correct interpretation of Pareto and control charts, Ishikawa diagrams and process capability indices is not assured by the mere ability to execute the software packages. Even more important is the reasoning required to apply the interpretation of the knowledge gained by analysis of the process outcomes.

The impact of learning about quality on traditional hierarchy of company employees is addressed in journal articles which include "Training needs associated with statistical process control [4]." This article is about the implications for the organizational structure in manufacturing when SPC is incorporated in the process. Control of the process comes to the production floor with control resting in the operating personnel, rather than in control teams. This demands additional training for the shop floor employee [4].

Adult Training

Since John Dewey's "Experience in Education" was published [5], experiential learning has been studied in various scenarios and pedagogies. Adult learning works best when it is authentic and experiential. A central element of experience-based learning is the analysis and application of the experience. When this is incorporated with authentic problem solving, the learning that occurs transmits to the workplace.

Introduction to SPC concepts in classrooms, training rooms, and on shop floors coincide with an increased need for process knowledge of advanced manufacturing techniques. This also means that the experience of many workers is ready to be connected with new knowledge about processes which they implement on a daily basis. This authentic, experiential education remains the basis of continual improvement in manufacturing.

SPC Training Techniques

Many different techniques have been used to teach the rudimentary concepts of SPC. Shewhart originally used a kitchen bowls full of chips of different sizes as a demonstration of population sampling [6]. Teachers and trainers have used M&M candy, dyed beans, colored tooth picks, and gaming dice to teach SPC. All of these techniques emulate Shewhart's bowl; however, these devices did not allow the demonstration of what happens when the process is changed. In these academic activities, the "hands-on" experience of throwing dice to explain SPC concepts offers experiential learning which is then transformed to an authentic experience when it is applied on the shop floor. The present paper describes a method to demonstrate process change by a student activity involving altered gaming dice.

4. Method

The method begins with the collection of data using a pair of common, non-altered, game dice. Students are asked to throw the dice thirty times and record the results on a prepared histogram template. Figure 1 provides two examples of the template and results of the activity. Students then share results with other students. By comparing results, students may or may not see a bell shaped curve because of the limited amount of data. It is important to explain to students that game dice do not make a perfect statistical example, since the bell curve is cut off below 2 and above 12; thus, there is no negative to positive infinity. The histogram is used to explain the central tendency of data, the dispersion of data, and the shape of the bell curve.

Standard deviation is also introduced when students are shown the standard bell curve with percent of population at plus and minus 1, 2, 3 and 4 standard deviations away from the mean (see Figure 2). Students are also introduced to the differences in bell curve shapes depending on standard deviation. Hypothetical standard deviations of 1.333, 1.0 and .666 were used in this particular example. Figure 3 illustrates three bell curves based on these hypothetical standard deviations.

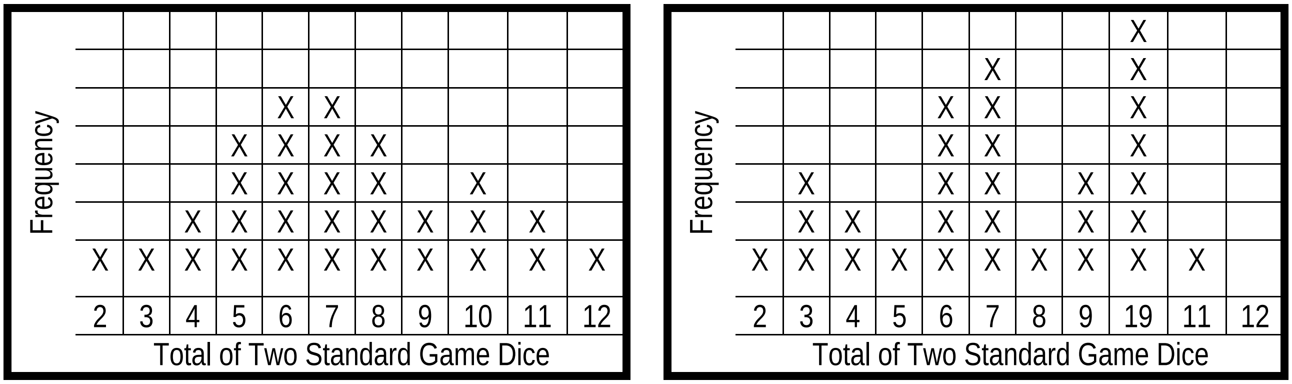


Figure 1: Sample Histograms

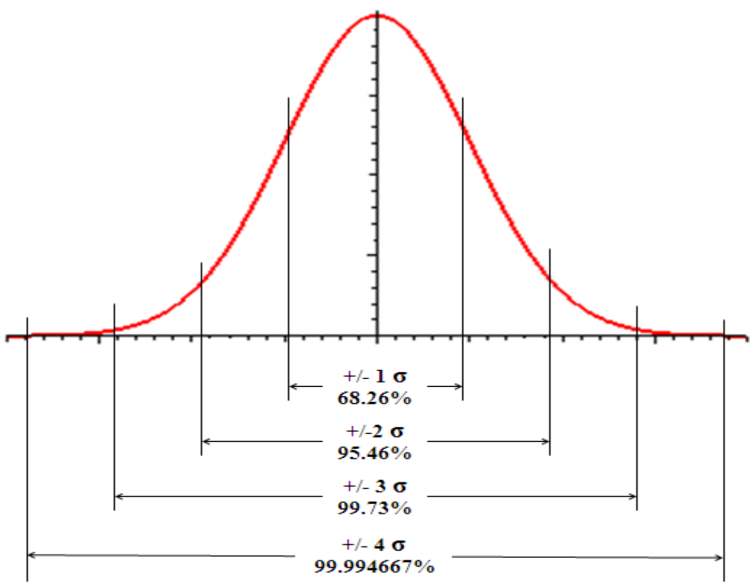


Figure 2: Normal Bell Curve, 4 Standard Deviation Level

Once students understand the concept of the normal bell curve, they are asked to look at their histogram's shape (like those examples shown in Figure 1). Often their histograms do not have the shape of a normal bell curve. Actually, bimodal and skewed curves are quite common for a 30 sample plot. This provides an opportunity for the instructor to discuss the need to collect sufficient data when making decisions. In addition, it should be noted that if students had collected 1000 samples, the result would be an almost perfect bell curve (see Figure 7).

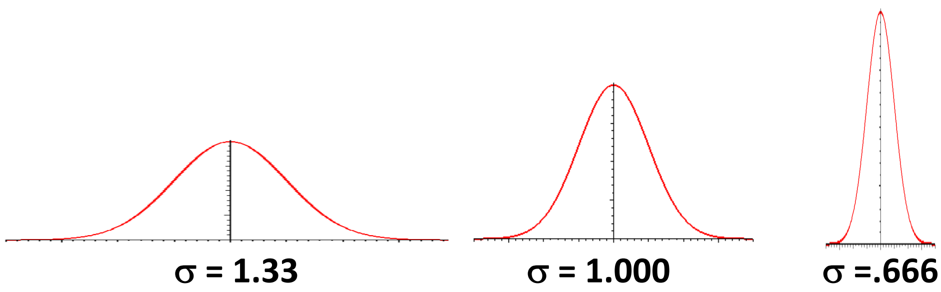


Figure 3: Hypothetical Bell Curve Shapes

The transition to control charts is clarified by discussing the relationship and primary difference between a histogram and a control chart. Figure 4 is used to illustrate the relationship between the bell curve from the histogram and the control chart. Students readily notice that the histogram representation of data lacks the time information implicit in control charts.

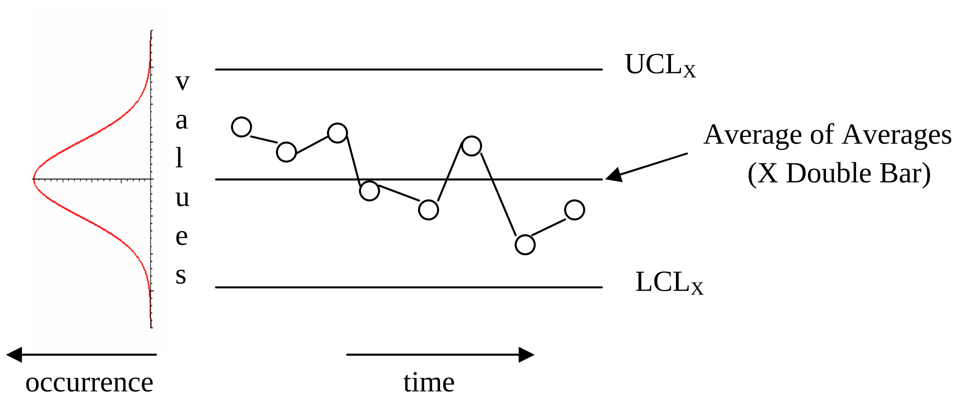
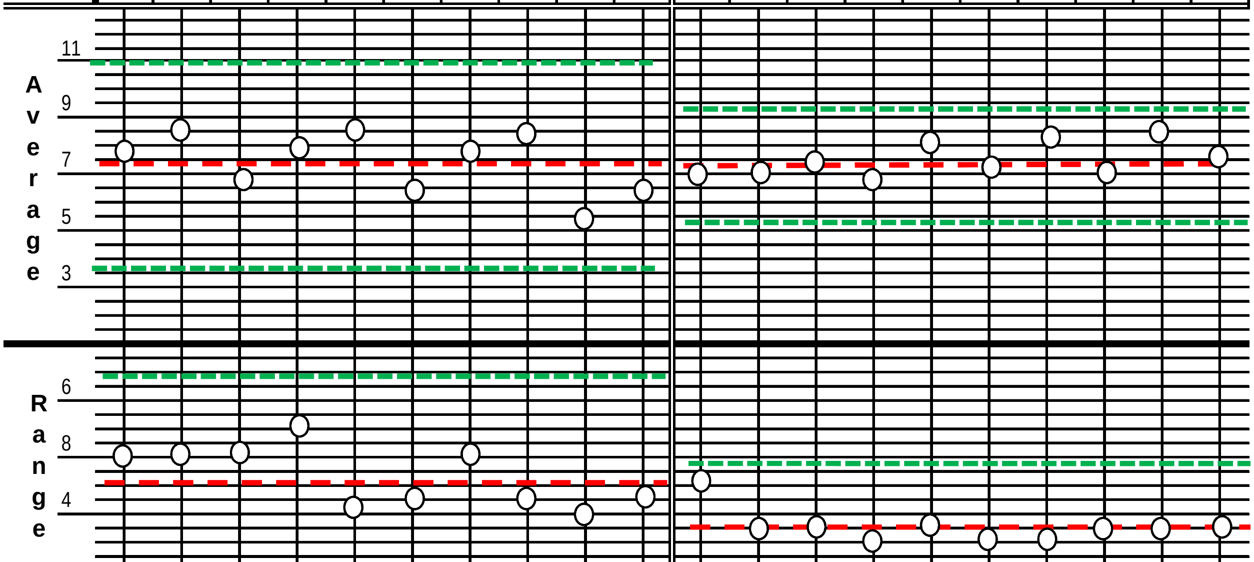


Figure 4: Bell Curve and Control Chart (Averages)

Once this relationship is understood by the students, the worksheet for the dice activity is distributed along with two non-altered game dice. Figure 5 is an example of a worksheet completed by students as they threw the dice and recorded their values. Depending on the size of the workshop or class, students form teams of two or three; however, each student should complete their own worksheet.

Students are then instructed to throw the dice and collect data for ten sets of five samples each. They are told that commonly, in high-volume production, some sample size is randomly selected at some specified time interval throughout the workday; thus, they could think of the ten sets of five being taken at approximate forty-five minute intervals during an eight hour shift. Once the

	Non Altered Dice Sample Sets of 5										Altered Dice Sample Sets of 5									
Sample #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	8	6	5	10	7	8	6	6	4	9	4	8	8	7	8	7	8	7	7	7
2	12	4	12	12	6	4	12	10	6	4	10	8	5	5	7	8	7	5	10	6
3	7	11	4	4	9	3	7	7	5	9	7	8	8	7	9	7	9	8	7	7
4	4	12	6	3	7	7	7	5	8	5	6	6	7	7	6	6	8	5	9	9
5	6	8	7	8	10	6	4	10	6	6	6	5	6	6	7	6	8	7	7	8
Sum	37	41	34	37	39	28	36	38	29	33	33	35	34	32	37	34	40	32	40	37
X Bar	7.4	8.2	6.8	7.4	7.8	5.6	7.2	7.6	5.8	6.6	6.6	7	6.8	6.4	7.4	6.8	8	6.4	8	7.4
Range	8	8	8	9	4	5	8	5	4	5	6	3	3	2	3	2	2	3	3	3



X Double Bar = 7.04	R Bar = 6.4		X Double Bar = 7.08	R Bar = 3.0	
UCL_X = 10.73	LCL_X = 3.35	UCL_R = 13.5	UCL_X = 8.81	LCL_X = 5.35	UCL_R = 6.34

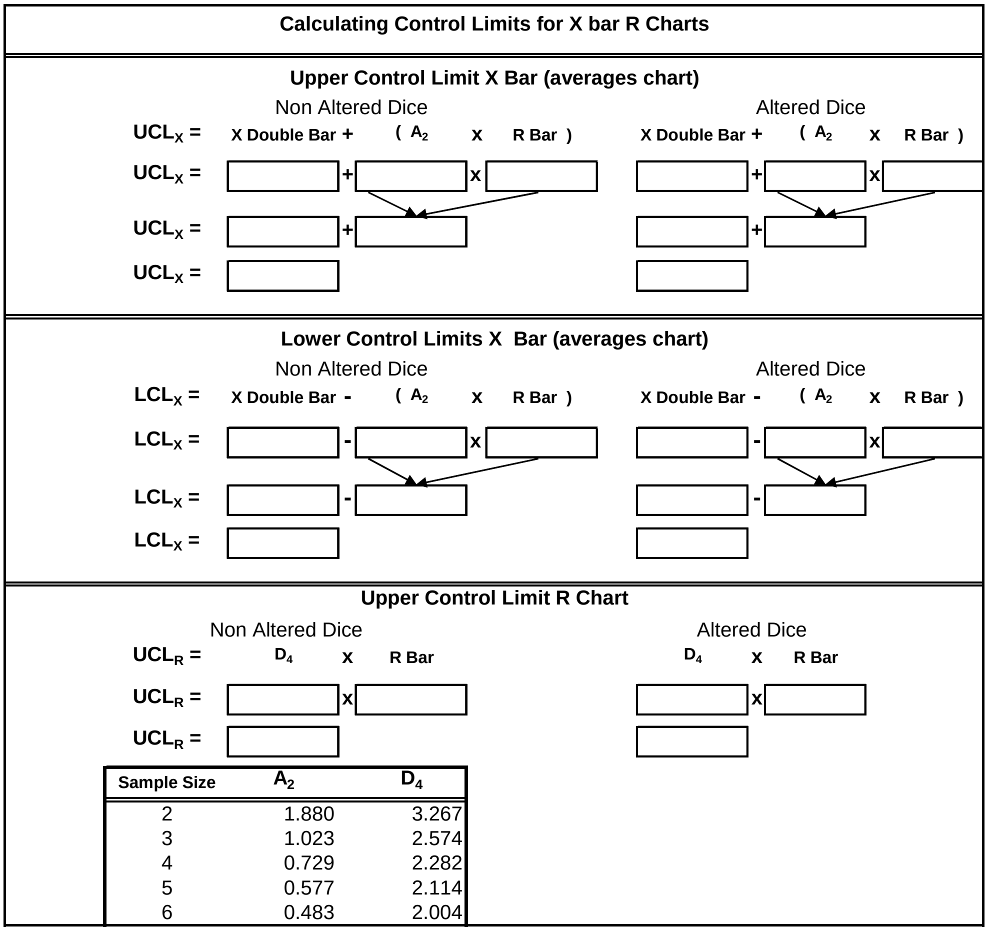
Key: Control Limit - - - - - - - - - - - - **Average** - - - - - - - -

Figure 5: Example of a Completed Worksheet

data is recorded, students are asked to complete the computations below the collected data on Figure 5. It is important to assist students in how to calculate a sum, the X Bar (average) and range. Students are also asked to calculate the X Double Bar (average of the averages) and R Bar (average of the ranges).

The next step is to guide students to plot the X Bar and Range data on the Averages and Range charts. Students are asked to look at the pattern, or in this case lack thereof, established by the data. Students are told there are often patterns in the plotted data that help identify process control problems (e.g. trends). Once the charts are completed, a second handout (calculating control limits for X Bar R charts) is distributed (see Figure 6). Students are told control limits are generally established at +/- three standard deviations from the mean.

Generally, the instructor must work closely with students to complete the calculations. Upper and lower control limits for the averages chart and an upper control limit for the range chart are then plotted on the worksheet (see Figure 5). It is emphasized that the data collected, analyzed and plotted simply represent the way the dice were performing during the activity, and other participant's results will not exactly match theirs; however, the X Double Bar and R Bar will be similar.



Sample Size	A_2	D_4
2	1.880	3.267
3	1.023	2.574
4	0.729	2.282
5	0.577	2.114
6	0.483	2.004

Figure 6: Calculating Control Limits

At this point, the instructor poses the question, "Can we improve the results of the dice activity?" Improvement is further explained as reducing the amount of variation in the process. Generally, students need guidance when looking at variation within the range chart. For example, in the completed worksheet (see Figure 5) notice that sample set 4 has a range of 9 which appears in that set because of the occurrence of a 3 and a 12. The instructor points out that the 3 and 12 values would have to be eliminated to improve the process and these values can occur because there is a 6 and 1 on the dice. After this explanation, the altered dice are given to the students.

Altered dice, for the purposes of this activity, can be created by taking a set of game dice and altering the 6 to a 4 and the 1 to a 3. This is easily accomplished by using white paint to cover two of the black dots on the six sides, and using black paint to make two small dots on the one sides. The instructor then poses the questions, "What will happen to the X Double Bar and the R Bar? What will the two plots (averages chart and range chart) look like?" Often by this time students are beginning to understand the concept and should respond that the X Double Bar should remain about the same, the R Bar will be reduced; the averages chart will not vary as much, and the range chart will be much lower.

Students are told to repeat the activity independently, including all computations and plots. This becomes a strong indicator of which students understand and which do not. Figure 5 is a common result from this activity. Because the non-altered and altered dice are plotted side by side, it is easier for students to see that the control limits on the averages chart narrowed. Further, the range chart provides a vivid picture of reduced variability resulting from an improved process (altered dice). It is important for the instructor to emphasize that had all 20 sample sets been taken continuously, the control charts would be telling the students something changed between sample sets 10 (non-altered) and 11 (altered) which dramatically improved the process.

The instructor then poses the question, "If we had a specification of 7 with tolerance limits of +/-3, which of the two processes (non-altered and altered) would you prefer to be used?" This specification results in a range of acceptable product between 4 and 10. While a detailed discussion of process capability is premature at this point, the instructor can point out that with the common, non-altered dice the LCL_X at 3.35 is below the lower specification limit of 4 and the UCL_X of 10.73 is above the upper specification limit of 10. Students are guided to understand that, if this were a real process, it has the tendency to produce oversized and undersized parts because of the position of the LCL_X and UCL_X in relation to the specification limits.

In addition, students are reminded of the area under the curve chart and asked, "Approximately what percent of the product is acceptable with the non-altered dice?" The obvious answer to this question is slightly less than 99.7%. Attention is then turned to the altered dice where both the UCL_X at 8.81 and the LCL_X at 5.35 have a lot of space between them, and the lower and upper specification limits at 4 and 10. Without actually determining the standard deviation, the instructor can make the point that with the altered dice it is more than four standard deviations to the upper and lower specification limits and this represents better than 99.994% acceptability; indicating a process improvement relative to the non-altered dice.

In an effort to further enhance understanding of the relationship between histograms, bell curves, and the control charts, a 1000 dice histogram is developed for both non-altered and altered dice (see Figure 7). Through this activity, the instructor emphasizes the difference in shape of the bell curve and standard deviation.

This activity is only a portion of an entire quality curriculum. It may also be a part of process learning or lean manufacturing studies. In lengthier industrial class settings, and when data are available from a real world manufacturing processes, students create another control chart to reinforce understanding. In the academic classroom, a golf putting exercise is used where a tape marks a centerline target. Each student then takes five putts (sample of 5) and measures the distance of the ball's location from the target. This distance-from-target data is used to create control charts independent of the instructor.

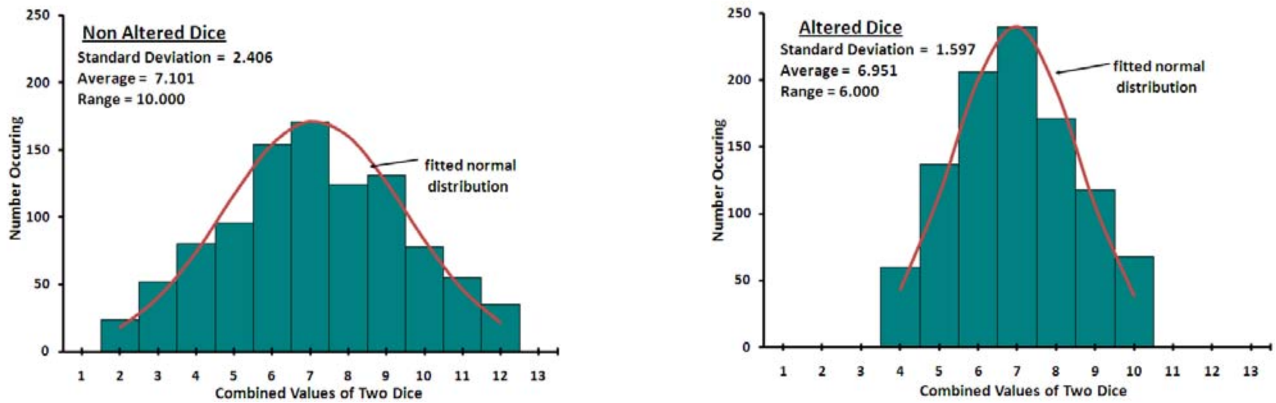


Figure 7: 1000 Dice Throw Bell Curves

The dice activity proposed here enhances the student's understanding of how to create charts, what process improvement looks like in a chart, and process capability; however, it falls short of developing an understanding of process control. Thus, a discussion of chart patterns, their use and interpretation is initiated. If the curriculum design includes other types of variable data specification charts or attribute charts, students are better prepared for that pursuit after the dice activity. Students are encouraged to think about what process parameters for their particular product could be altered to improve process capability similar to changing the dots on the dice.

5. Conclusions and Recommendations

Experiential training was accomplished by students readily undertaking the dice activity. Additional indications were successful completion of activity sheets (histogram, X bar R, and computational sheet) by students. Authentic training was shown through relating shop floor processes to the dice activity. Also, the inclusion of company supplied data reinforces the understanding of SPC. For college classrooms, activities such as golf putting provide additional data for application reinforcement of learning.

An improved process was demonstrated by the obvious change in the average and range charts. Fundamental understanding of statistical principles was observed from the students creating and interpreting control charts. Such understanding was extended to bell curves, control charts, and process capability. Students demonstrated the ability to complete computations independent of instructors.

Follow-up discussions with companies confirmed that shop floor employees can independently create and interpret create control charts. However, sufficient time has not elapsed to obtain college students' feedback regarding knowledge gained from their use of this dice activity in their workplace.

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