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TEACHING BRIEF

Using a Rubber Band to Teach the Management of Quality*

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INTRODUCTION

This article describes the use of a simple two-phase hands-on gage of repeatability and reproducibility (GR&R) study to illustrate the three stages of quality management (QM) described by Hanna and Newman (2001): detection, prevention, and ongoing improvement. The overall objective is to simply help students understand measurement system analysis and its effects on process improvements. While it can be argued that the link between the measurement system analysis and process improvement is indirect, the variability of a process can significantly impact quality. Understanding the processes provides the framework for determining the effects of variation and proper management decisions (Evans & Lindsay, 2005).

This two-phase GR&R study utilizes groups of students to measure a tabletop. A GR&R study is used to measure (or gage) variability in processes. Such studies measure the ability of an operator to repeat the same measurement (which gages the equipment variation), and also measure the ability of a second operator to reproduce the first operator's measurement (gages the operator variation). In the first phase, the students measure a tabletop with a rubber band. This is followed by a hands-on discussion to detect the QM issues. After detecting the issues, we proceed to implement a preventative action to reduce variation. In the second phase, the students measure the same tabletop using a photocopy of a 12-inch ruler, which is again followed by another discussion of the observed variation. A summary of the phase is provided in the Appendix (Table A.1).

This study can be completed in about 40 minutes, making it feasible to be completed in a standard 50-minute class time block, and can be readily extended to discuss the role of technology in QM and the importance of feedback in the transformation process for those classes scheduled in a 1-hour-20-minute time block.

PHASE 1 OF GR&R STUDY

In this phase, the students are required to measure the tabletop with a rubber band and record their results of their measurement. After explaining the basic rules

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and distributing materials, students are divided into groups of 4 (or 5) students. I then place a standard measuring unit at one end of the tabletop and explain the measuring procedure to the students. The basic rules, materials required, and measuring procedure is provided in the Appendix.

Notes for the Instructor (Analogies to the Real World)

After stating the basic rules and demonstrating the measuring procedure, some students may have questions. Regardless of the questions, my default answer is a restatement of the rules and another demonstration—stressing that they follow the rules and procedure. What may (or may not) be disclosed to the students is the obvious—measuring the tabletop with a rubber band is going to be difficult. By design, we expect to see a great deal of variation in their measurements. First, the rubber band is significant to the lesson because we are using "old" and inefficient technology and invites discussion on newer and more efficient technologies. Second, different individuals will "eyeball" the measurement differently, which also adds to the sources of variation.

The significance of these basic rules is that they represent management policy. Having each student measure the tabletop five alternating times represents time in-between inspections and minimizes the autocorrelation in the measurements. We ask the students not to talk and not to share their data in order to represent the "silos" and lack of communication still found in firms. Sometimes the management policy creates obstacles that inhibit the inspector from being efficient in their job, which is represented by not allowing the standard measuring unit to be moved. It is also interesting to see how the students react when they are not allowed to deviate from the procedure. Most often this invites the students to re-engineer the procedure, which also adds to the sources of variation during the study.

While the students are measuring the tabletop, I tend to stay to one side of the room. By staying to one side of the room it appears that I am trying to stay out of their way, but it represents the "absence of supervision" and "lack of feedback" to the students. The students may re-engineer and change the procedure to simplify their work without realizing that it is disrupting their ability to repeat their prior work. I allow the deviation in the procedure, but I use it as an example during the Phase 1 discussion.

Phase 1 Results and Discussion Points

Once the students have completed Phase 1, I ask them to complete the data collection by calculating the average of their observations. Next I allow them to share the data within the groups and among themselves discuss what they each observed about the study. We then create a box plot of the individual averages by group on the blackboard (e.g., see Figure A.1 in the Appendix).

The box plot of the measurements illustrates the "unstable" conditions observed. This tends to be more beneficial to the students because they already interacted with the process and collected the data themselves. I begin the discussion with "wow, look at all of those measurements—they're all over the place." This usually prompts someone to state the most obvious—the fact that we are using a rubber band to measure and that it is not efficient. The other points of discussion

(sources of variation) are not as obvious and include: the basic rules, the procedure, and finally the individual persons that are measuring the tabletop (these real-world analogies were discussed in the prior section).

PHASE 2 OF THE GR&R STUDY

After the discussion of the Phase 1 results, we implement the most obvious preventative action for a process improvement—use a ruler to perform the measurements. (Note that someone might suggest a tape measure, but we suggest the use of a ruler as the most logical next technology improvement to the rubber band.) We begin by distributing the copies of a standard 12-inch ruler, one of which is copied at 90% and unknown to the students.

Keeping the same groups, the students now repeat the GR&R study by measuring the tabletop with a photocopy of the ruler. Again, they are to follow the basic rules from Phase 1. After they complete the fifth iteration, they are to compute the averages and create a box plot the results. An example is shown in Figure A.2 (in the Appendix).

Phase 2 Results and Discussion Points

Clearly we can see a reduction in variation, which we can base on our preventative action. But we then notice that group 5's measurements are slightly higher than the others—raising the question of its cause. (Recall that one of the rulers being used was photocopied at 90%, so we should expect to see one set of results slightly higher than the others.) If the students do not recognize this, then I may start by asking, "hey, what's going on here?" At this point, the students tend to make jokes about the odd group, namely that they do not know how to measure.

I then remind the students of the third stage of QM—ongoing improvement (to further reduce variation). While we did reduce most of the variation with a change in the measuring tool, there appears to be other factors at play. What typically gets mentioned at this point is that we need to verify (or calibrate) the measuring instrument. How do we know that we are in fact using a 12-inch ruler? After we carefully verify each of the rulers against a defined "golden unit," we find a discrepancy with one of the measuring tools. It so happens that the ruler assigned to the group that had slightly higher measurements has a smaller ruler. We then determine that the slightly higher measurements would be consistent with a smaller ruler. We could then verify the measurements with a calibrated 12-inch ruler and we should find those measurements consistent with the other groups.

I point out to the students that the use of a slightly smaller ruler (in this case a photocopy at 90%) is used to illustrate two issues with QM. The first issue is the calibration of the measuring tool. Examples can be found in (1) food service industry where the use of thermometers to check food temperatures for food safeness and/or scales needed to weigh portions for inventory control and (2) diagnostic equipment in the health care industry.

I further point out a second issue in QM that may not be immediate and is focused on the behavior itself—raising the question of QM integrity (human behavior toward the inspection process). In this GR&R study we used a slightly

smaller ruler unknown to the students (the inspectors). Had all of the groups' measurements been in line, then we would have reason to suspect loss in integrity. This practice can also be used with known "bad parts" to see if the inspector would reject the parts and report the discrepancy.

CONCLUSION

The hands-on GR&R study is used to help the students understand the sources of variation—namely to gage the equipment variation (repeatability) and to gage operator or manpower variation (reproducibility). The four major causes of variation are identified as the 4M's: **M**easurement instrument, **M**anagement policy, **M**ethod, and **M**anpower. The discussion points provide the students with a hands-on learning experience on the purpose of a GR&R study. Some typical goals target basic operations management objectives. Improving quality addresses issues on achieving higher quality of products and services and reduction of waste. Improving costs focuses on increasing productivity and reducing process time. Improving customer service (or customer satisfaction) also increases competitive advantage.

REFERENCES

Evans, J., & Lindsay, W. (2005). *The management and control of quality,* 6th ed. Thomson/South-Western.

Hanna, M., & Newman, W. (2001). *Operations management: An integrated approach*. Upper Saddle River, NJ: Prentice-Hall.

APPENDIX

Basic rules:

1. Each student will measure the tabletop five alternating times.
2. Each student is responsible for data collection.
3. Students are not allowed to talk, nor share data during the study.
4. Students are not allowed to move the standard measuring unit (used during Phase 1).
5. Once the student begins to measure, they must continue and are not allowed to re-start that iteration.
6. Students are not allowed to deviate from the procedure.

Materials required:

1. Rubber bands (with one cut to form a rubber band string)—one per group
2. Standard measuring unit—a 10-inch line drawn diagonally on an $8^1/_2 \times$ 11-inch sheet of paper—one per group
3. Photocopies of a standard 12-inch ruler, of which one is copied at 90%—one per group

Measuring procedure:

1. Holding the ends of the rubber band (one in each hand) stretch it to the length of the standard measuring unit.
2. Keeping that length in mind, start measuring the length of the tabletop from one end to the other by moving the rubber band one standard unit at a time—one will have to visualize (or "eyeball") the measurements.
3. The final move may or may not be a full standard unit, which the students will need to visualize the fraction of the standard unit (i.e., $^1/_2$, $^1/_4$, $^3/_4$, etc.).

Table A.1 Summary of phases.

Phase	Procedure	Teaching Points (Analogies to the Real World)
1	1. Explain basic rules 2. Using a rubber band demonstrate measuring procedure 3. Have students form groups 4. Distribute materials 5. Have students measure tabletop and record measurements 6. After five alternating measurements, allow students to share and discuss data within group 7. Prepare a box plot of measurements by group 8. Discuss observations and sources of variation 9. Determine preventative action to reduce variation (most obvious is to use a ruler in Phase 2)	1. Rubber band represents old and inefficient technology 2. Rubber band also represents low technology instruments that are primarily manual devices 3. Basic rules represent management policy and often outdated company inertia 4. Students not allowed to talk or share data represents the "silos" and lack of communication still found in firms
2	1. Restate rules 2. Demonstrate measuring the tabletop with the photocopy of a 12-inch ruler 3. Students remain in the same groups 4. Distribute materials 5. Have students measure tabletop and record measurements 6. After five alternating measurements, allow students to share and discuss data within group 7. Prepare a box plot of measurements by group 8. Discuss observations and sources of variation	1. Ongoing improvement to reduce variation 2. Calibration (why and frequency) 3. Human behavior toward the inspection process

Figure A.1: Box plot of Phase 1 GR&R study.

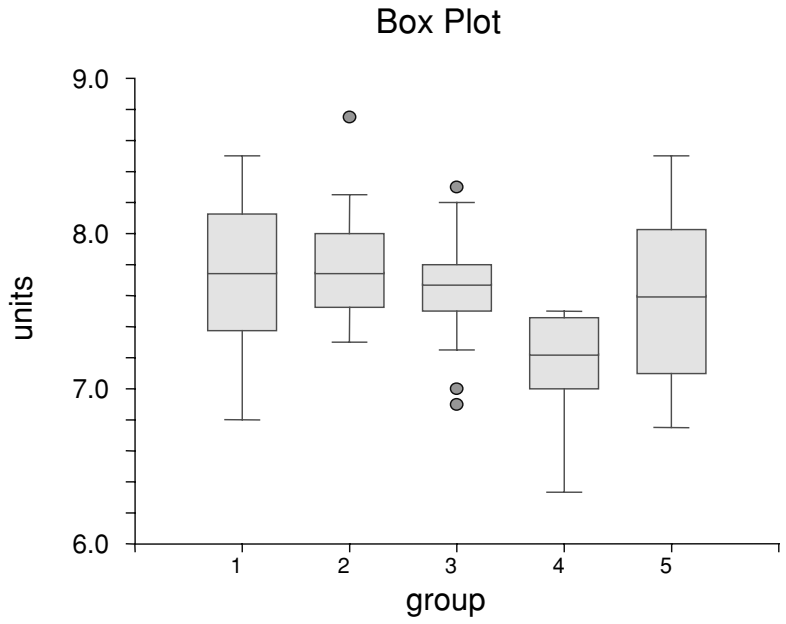

Figure A.2: Box plot of Phase 2 GR&R study.