AC 2012-3545: A SELF-ADMINISTERED GAGE ANALYSIS INTERVENTION AND ASSESSMENT

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A Self-Administered Gage Analysis Intervention and Assessment

Abstract

A solo gage repeatability and reproducibility (gage r and r) study exercise was developed and individually administered to a population of Engineering Technology students. This paper includes the intervention procedure that was developed to self-guide a student through the performance and interpretation of a gage r and r. This paper also presents the assessment used to determine the effectiveness of the exercise. Students' comments regarding difficulties pertaining to the performance of the exercise are presented. The gage intervention was moderately successful as judged by the assessment tool.

The Need

There have been a number of instances in which students have needed to perform a gage analysis but did not have the knowledge or training. This intervention was developed to help address these instances. The gage r and r procedure is covered in a metrology class, but not all students are required to take the class.

The Procedure

The intervention was administered using classroom management software. It was offered as an extra credit exercise to three of the author's classes. The exercise was offered to a programming class, a mechanics class, and a lab section of materials and processes students. The students were to take a pre-test, perform the exercise, and then take a post-test. Fourteen students successfully completed all portions of the assignment in the correct order. The classroom management software provides date stamps that indicate when students complete an assessment or submit a completed spreadsheet. From these date stamps it could be determined that the gage r and r took a minimum of approximately ten minutes and no more than one day. The exercise is included in its entirety below. The exercise may be obtained from the author in an electronic format upon request. A pre-existing spreadsheet is provided to the student to perform the calculations. A graphical representation of the spreadsheet is provided below.

Exercise Purpose

The purpose of this exercise is to familiarize the user with the Gage R&R measurement procedure. This exercise describes how to complete a brief version of a Gage R & R involving 5 parts measured 2 times (***trials***) by one operator (***appraiser***) for a total of 10 measurements. Please note that a typical Gage R & R involves 10 parts measured 3 times by each of three operators for a total of 90 measurements. There are other combinations of parts, trials and operators that can be performed.

Student Procedure

Step 1 - Gather 5 various pens and pencils (parts) and a ruler (measuring device) with which to measure their length. (Any 5 similar items and an instrument with which to measure some feature of the items will suffice).

Step 2 – Label the pens/pencils (parts) 1 thru 5 using tape or some other marking method. Or you could place them in a certain order and maintain that order throughout the exercise. You must be able to identify parts 1 thru 5 throughout the exercise.

The ***resolution*** is the finest increment of the measuring instrument. For example, a ruler might have 1/16 inch or 1/10 centimeter as the smallest increment or resolution.

Step 3 – Measure the length of the first part (pen/pencil) using the finest increments of the ruler and record the measurement in figure 1 for Operator A, trial 1, part 1. You can use a calculator to convert any fractions to decimals, for example, 1/8=0.125, so 4 and 1/8= 4.125 The spreadsheet will also convert the fractions to decimals. Measure the rest of the parts one time and record the measurements in decimal form in the trial 1 row and the column for the correct part number in figure 1.

	No Operators:				Tolerance:			
	Number of Trials:				Number of Parts:			
	Trial	Part						
Operator	Number	1	2	3	4	5	6	
A	1							
	2							
	3							
	Average							
	Range							

Figure 1 – Write your measurements in this table or enter them directly into the spreadsheet.

Bias- If you asked an operator to measure the same part two times in a row, he/she would tend to report the two values to be the same – ***even if they obtained two different measurements***. This is an example of ***operator bias***. Therefore the operator must normally be prevented from knowing which part they are measuring. This is not practical with one person as in our case.

Step 4 – Measure each part a second time and record the values in the trial 2 row of figure 1. Be careful not to bias the readings by letting the first measurement influence the second measurement. That would be operator bias. It is fine to have different measurements. These differences are precisely what this exercise is trying to capture and quantify. This variation in the first and second measurement is the ***repeatability***.

Step 5 – Enter your measurements in the attached spreadsheet. Also, enter 1 for the number of operators, 0.25 for the tolerance, 2 for the number of trials, and 5 for the number of parts. An example of a completed spreadsheet is in Figure 2. The Average and Range values are calculated automatically by the spreadsheet.

No Operators:		1			Tolerance:		0.25
Number of Trials:		2			Number of Parts:		5
	Trial	Part					
Operator	Number	1	2	3	4	5	6
A	1	15.20	14.60	13.50	15.00	16.40	
	2	15.00	15.00	13.80	15.00	16.00	
	3						
	Average	15.10	14.80	13.65	15.00	16.20	
	Range	0.20	0.40	0.30	0.00	0.40	

Figure 2 – Example of a completed spreadsheet for pencil lengths in centimeters.

The purpose of this analysis is to introduce some definitions and concepts that are important in discussing and analyzing a gage (measurement system)

Background

All measurements have error and variation. When making decisions based on measurements one should understand the amount of uncertainty in the measurement. A gage repeatability and reproducibility (Gage R & R) seeks to determine the amount of measurement variation that is due to ***repeatability*** (the same operator measuring the same part several times) and ***reproducibility*** (variation from operator to operator). Since we are using just one operator we cannot determine the gage reproducibility. You would normally want to use three operators to determine the reproducibility. Furthermore, it would be preferred to use the actual operators that would be using the gage in their workplace.

Results analysis

Results include a ratio of the combined repeatability and reproducibility to the part tolerance and/or total variation. If the R&R variation is less than 1/10 (10%) of the part tolerance or total variation, the gage is typically considered acceptable. If the R&R variation is greater than 3/10 (30%) of the part tolerance or total variation it is generally considered unacceptable.

The gage may fail in two ways per the attached spreadsheet:

1) If the total gage variation (%RR-TV) is greater than 30% of the total variation.
2) If the gage cannot place the parts into at least 5 distinct categories (ndc) to create a histogram. (see figure 3)

The ***part variation*** is an indication of how much variation there is from part to part.

The ***total variation*** is the part variation plus the gage variation.

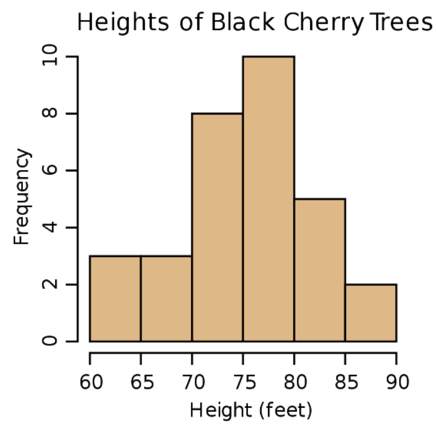
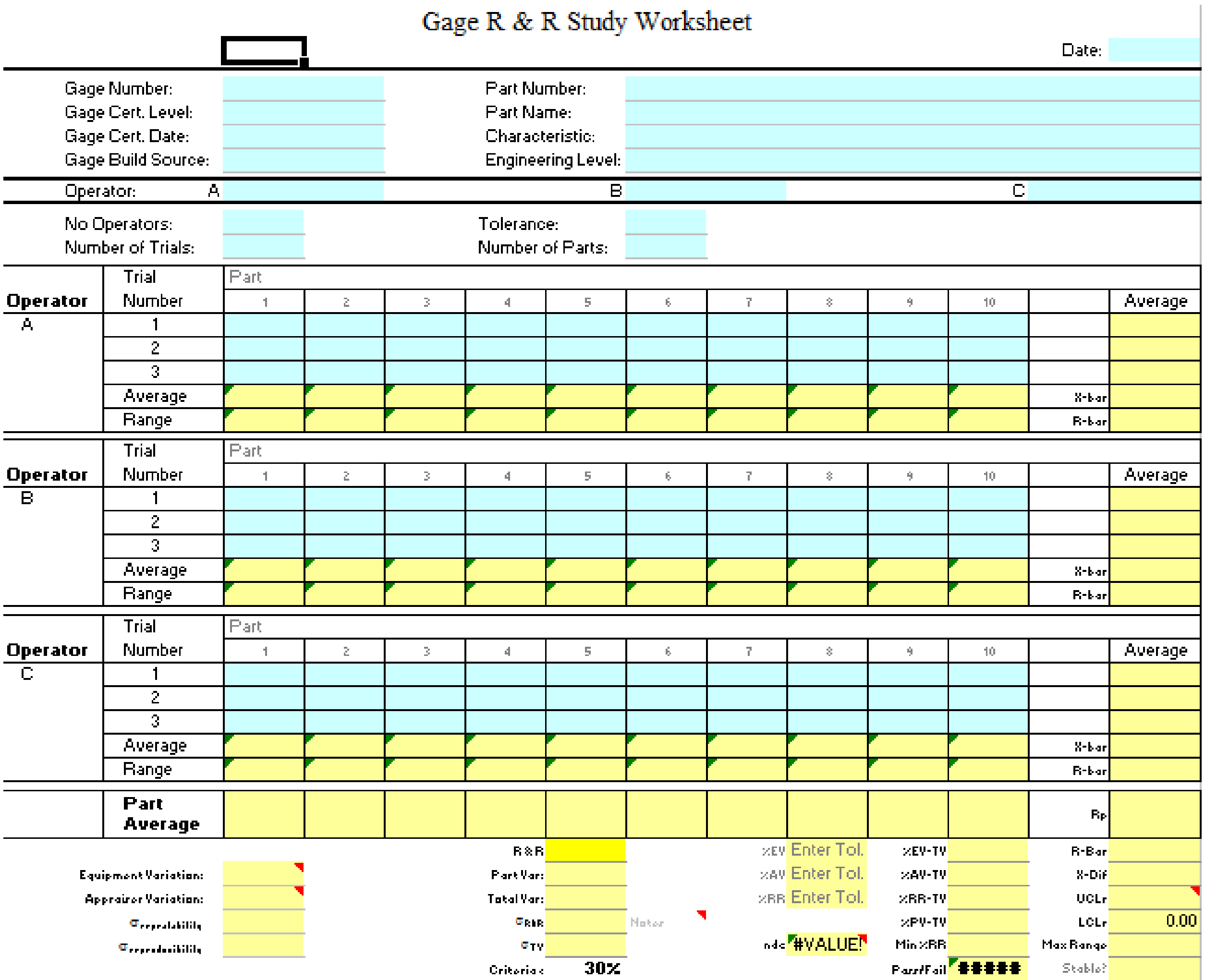


Figure 3 – An example of a histogram with six distinct columns. Note that the columns show the shape of the distribution of the tree heights. This is desirable.

R & R	0.23041		%EV	92.2%	%EV-TV	21.88%	R-Bar	0.2600
Part Var:	1.02765		%AV	0.0%	%AV-TV	0.00%	X-Dif	0.0000
Total Var:	1.05316		%RR	92.2%	%RR-TV	21.88%	UCLr	0.8502
$\sigma_{R\&R}$	0.04474	Notes			%PV-TV	97.58%	LCLr	0.00
σ_{TV}	0.20450		ndc	6	Min %RR	21.88%	Max Range	0.4000
Criteria <	30%				Pass/Fail	Pass	Stable?	Yes

Figure 4 – Results from bottom of spreadsheet for the example data in Figure 2.

Figure 4 shows the result of the example data in figure 2. The gage passed criteria 1 since the RR shown in the upper left portion of figure 4 is .23 which is 23% which is less that 30%. The ndc value indicates that the gage can result in a histogram with six columns (ndc=6). This is greater than 5 which is our passing criteria. These results are on the lower right hand side of your spreadsheet. Please look at your results now. Did your gage pass? What is the Min %RR value directly above the Pass/Fail box? Is it less than 30% ? If it is your gage passed. Do not take it personal if the gage passed or failed. This is just a learning exercise.



Gage R & R Study Worksheet

Date:

Gage Number:
Gage Cert. Level:
Gage Cert. Date:
Gage Build Source:
Part Number:
Part Name:
Characteristic:
Engineering Level:

Operator: A B C

No Operators:
Number of Trials:
Tolerance:
Number of Parts:

Operator	Trial Number	Part 1	2	3	4	5	6	7	8	9	10		Average
A	1												
	2												
	3												
	Average											X-bar	
	Range											R-bar	

Operator	Trial Number	Part 1	2	3	4	5	6	7	8	9	10		Average
B	1												
	2												
	3												
	Average											X-bar	
	Range											R-bar	

Operator	Trial Number	Part 1	2	3	4	5	6	7	8	9	10		Average
C	1												
	2												
	3												
	Average											X-bar	
	Range											R-bar	
	Part Average											Rp	

Equipment Variation:
Appraiser Variation:
σrepeatability
σreproducibility
R&R
Part Var:
Total Var:
σR&R
σTV
Criteria: 30%
Notes
%EV Enter Tol.
%AV Enter Tol.
%RR Enter Tol.
ndc #VALUE!
%EV-TV
%AV-TV
%RR-TV
%PV-TV
Min %RR
Pass/Fail #####
R-Bar
X-Dif
UCLr
LCLr 0.00
Max Range
Stable?

Figure 5 – Example of entire spreadsheet before completion

Gage Variation Reduction

The gage variation can often be reduced by using a different measuring instrument, changing the part alignment/loading/unloading procedure, fine tuning the use of the measuring instrument, or further analysis of the data by using charts showing the part, operator, trial sequence versus the resulting measurements. ***EV*** is the equipment variation which is the variation that occurs when a given operator makes repeated measurements of the same part (repeatability). The appraiser variation, ***AV***, is the variation that occurs from operator to operator (reproducibility). ***PV*** is the part variation. Careful consideration of these and other outputs of the Gage R & R can point towards ways the gaging method variation might be reduced.

Assessment of the Self-Administered Exercise

The pre and post-test were administered using classroom management software. The pre-test consisted of the first thirteen questions in appendix B. The post-test consisted of the entirety of appendix B. The responses to the first thirteen questions were then compared for the correct answers pre-test versus post-test. The results are shown in Figure 6. Eleven of the thirteen questions had more correct post-test answers than correct pretest answers. This indicates that overall the intervention had a positive influence on posttest answers.

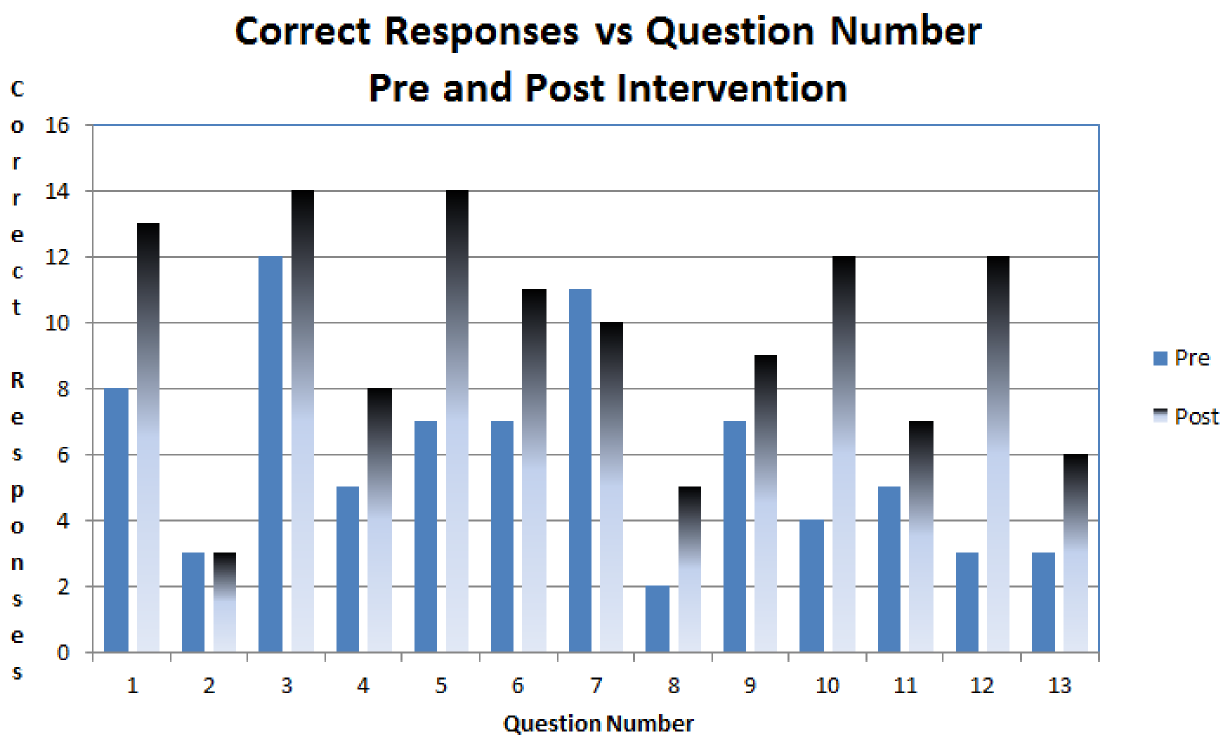


Figure 6 – Responses vs. Question Number

Figures 7 and 8 show Hake Plots which indicates the normalized gain of the individual students and the individual questions respectively. The plots are sectioned into areas of High, Medium, and Low Gain. For the individual students plot, 2/14 had high gain, 11/14 had medium gain, and 2/14 had no gain or a negative gain.

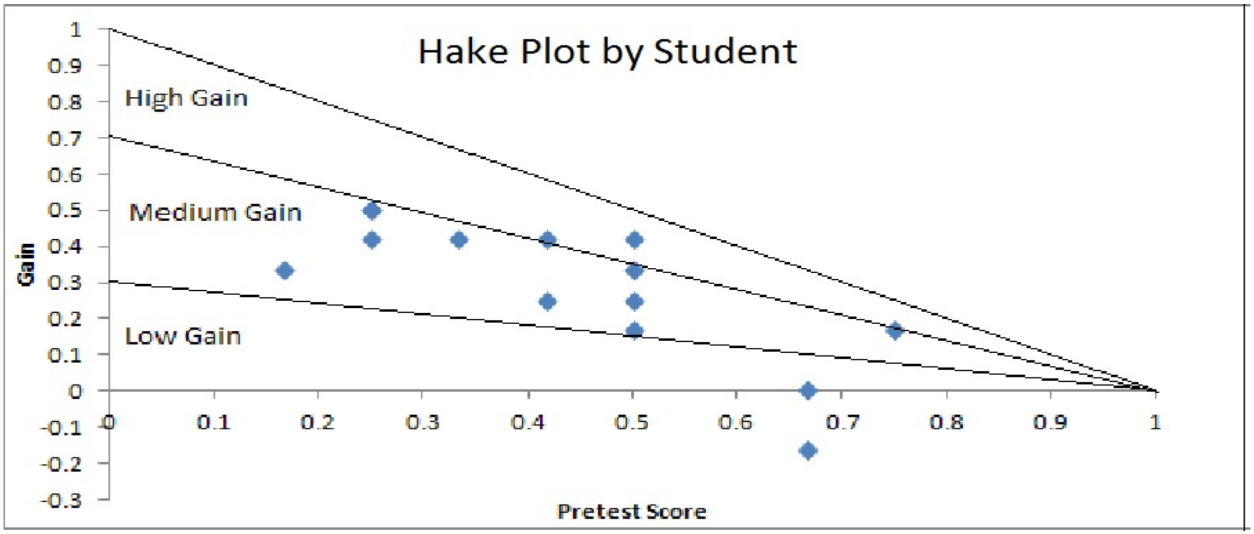


Figure 7 – Hake Plot of Individual Students for All Questions

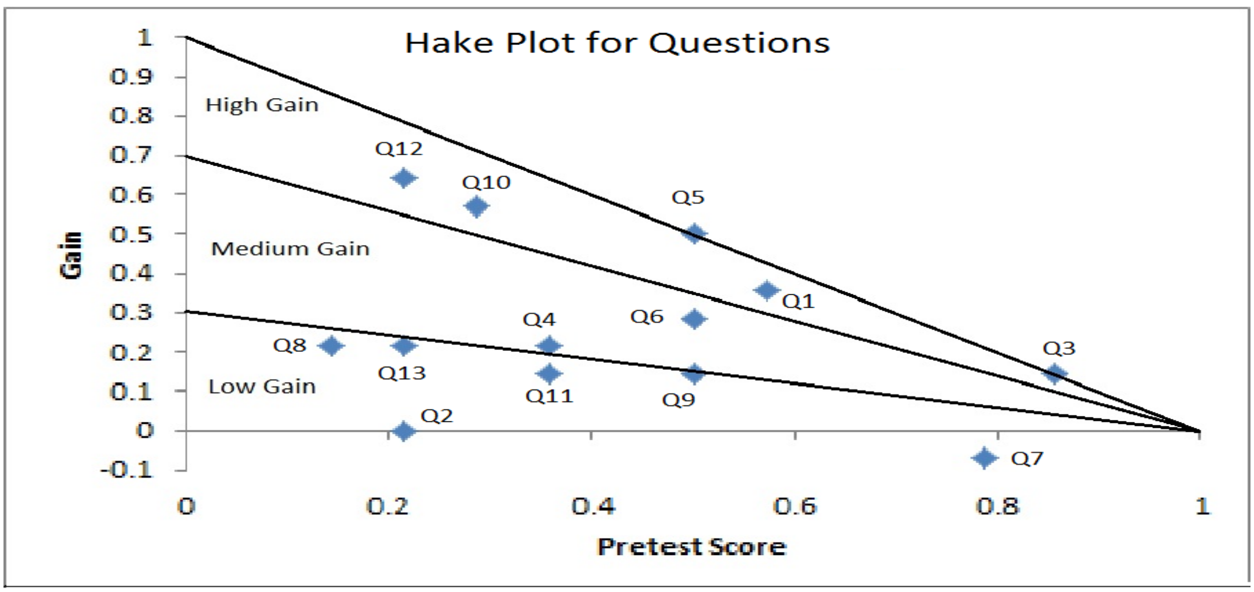


Figure 8 - Hake Plot for Individual Questions

Confounding Factors

Some of the students may have already had training regarding gage analysis in other classes or from work experience. No attempt to quantify or adjust for previous knowledge was made. Students were given no instructions as to the resources they were able to use to answer the pretest or posttest questions. Students were told the assignment was for extra credit but were not told whether correct answers would affect their grade. Some had high pretest scores indicating either prior knowledge or possible internet search engine use.

Conclusions

The exercise resulted in average to medium gains as judged by the results of the Hake plot. Further refinement of the exercise is required to raise the gains to a high level. Further refinement of the assessment tool could prove useful in determining what the shortcoming of the exercise is and how it might be best improved.

Appendix A (Assessment Questions)

1 Repeatability is the variation from:
A. The same parts measured by different operators
B. The same operator measuring the same parts multiple times
C. Different parts having different measurements
D. The range minus the average divided by the standard deviation
E. Recording the wrong value in the wrong column
Answer Key: B

2 The gage is the:
A. Fixturing
B. Procedure
C. Measuring instrument
D. Operator
E. All of the above
Answer Key: E Note – This question erroneously used 'gage' in place of 'measurement system'

3 Why should the operator be prevented from knowing which part they are measuring?
A. to prevent operator bias
B. to keep the parts ordered correctly
C. to ensure the reproducibility is correctly calculated
D. to prevent parallax error
E. to ensure the number of distinct columns is adequate
Answer Key: A

4 Guidelines suggest that:
A. The parts being measured should all be of nearly the same length.
B. The measurement procedure should be tweaked as much as possible while parts are being measured.
C. The gage should be in use at least three months before analysis.
D. The parts should all be from the same production batch
E. The operators that will be using the gage should be involved in measuring the parts
Answer Key: E

5 Reproducibility is
A. Different parts having different measurements
B. The range minus the average divided by the standard deviation
C. Recording the wrong value in the wrong column
D. The same parts measured by different operators
E. The same operator measuring the same parts multiple times
Answer Key: D

6 The variation between one pen/pencil and another pen/pencil is the
A. Gage R&R
B. Part tolerance
C. Total variation
D. Part variation
E. %EV
Answer Key: D
7 Gage variation can be reduced by:
A. Using a different measurement device
B. Changing how the parts are loaded into the fixture
C. Fine tuning the use of the measurement system
D. Analyzing charts that show operator/part interactions
E. All of the above
Answer Key: E

8 %EV is
A. the repeatability percent
B. the reproducibility percent
C. the error value percent
D. the total variation percent
E. the equipment volume percent
F. A and C
Answer Key: A

9 In our example, since we had only one operator we could not determine
A. the repeatability
B. the reproducibility
C. the %EV
D. the %AV
E. answers B and C
Answer Key: B

10 The standard method described in the exercise is to measure
A. 5 parts 2 times by 3 operators
B. 5 parts 3 times by 2 operators
C. 10 parts 3 times by 2 operators
D. 10 parts 2 times by 3 operators
E. 10 parts 3 times by 3 operators
Answer Key: E

11 A Gage R&R is performed to determine:
A. How much error is introduced by the gage
B. If the gage is suitable for a certain measurement
C. If an operator is using a gage correctly
D. All the above
E. Answers A and B
Answer Key: D

12 An acceptable gage will typically use up no more than how much of the total variation?
A. 4%
B. 5%
C. 6%
D. 10%
E. 20%
F. 30%
Answer Key: F

13 An acceptable gage can be used to create a histogram that has a minimum of how many columns?
A. 4
B. 5
C. 6
D. 10
E. 20
F. 30
Answer Key: B

14 My gage
A. Passed
B. Failed
Answer Key: A or B

15 What were the main points you learned from this exercise?
Short Answer/Essay

16 What would you change about your gage to reduce its variation?
Short Answer/Essay

17 What was the most confusing part of this exercise?
Short Answer/Essay