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Teaching Gage Reproducibility and Repeatability using the Mouse Factory

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Teaching Gauge Repeatability and Reproducibility using the Mouse Factory

Abstract

The Mouse Factory contains a set of web-based, active learning laboratories for teaching statistical quality control and design of experiments. The sixth laboratory in the Mouse Factory Learning suite is gauge reproducibility and repeatability (R&R). Learning materials from the Mouse Factory foster higher-order cognitive skills utilizing an active learning approach. The current pedagogy in today's classrooms is often based upon lectures and homework problems from textbooks. This approach typically focuses on the knowledge and application domains of Bloom's Taxonomy. The current pedagogy removes students from applying higher order cognitive skills. Students will conduct gage repeatability and reproducibility studies using gage blocks constructed from a high-resolution rapid prototyping machine. Students use commonly found measuring instruments including a steel rule, dial caliper, digital caliper, micrometer and digital micrometer. The cubes were constructed with varying amounts of variability in the height, width and depth dimensions facilitating different outcomes. Assessment of student performance and perceptions (behavior and attitudes) from a small-scale (initial) pilot study will be measured, evaluated and discussed.

Introduction

Montgomery states that "determining the capability of the measurement system is an important aspect of many quality and process improvement activities."[1] Quality is integral component of most organizations and is a primary method in which organizations compete.[2] The Society of Manufacturing Engineering (SME) has repeatedly identified quality as an important competency gap in the field of manufacturing.[3,4]

This paper presents a method to address the quality competency gap in the use of gauge R&R studies. An integral component of this research is the inclusion of pedagogical sound techniques in the development, implementation and evaluation of the module for teaching gauge R&R. It is the authors' experience that most engineering instruction is still largely conducted in a lecture format. While lecturing is an excellent method of communicating large amounts of information, students experience passive learning and the amount of learning that occurs is often small.[5] There are many excellent textbooks in the field of quality, such as Montgomery[1], that provide explanations of quality topics and practice problems. However the use of textbooks and homework problems emphasize the lower-order cognitive skills from Bloom's taxonomy[6] such as knowledge, comprehension and application. But this mode of instruction is less likely to emphasize the higher-order cognitive skills of analysis, synthesis and evaluation. In this learning module that teaches gauge R&R, students must design a sampling plan for a gauge R&R study that involves different measuring devices with different characteristics, conduct and evaluate multiple gauge R&R studies, and recommend a measuring device based upon the analysis of the gauge R&R studies.

The remainder of this paper will present the Mouse Factory learning system, the gauge R&R project, results from the pilot implementation, discussion, recommendations for future research, and acknowledgements.

The Mouse Factory

The Mouse Factory is a web-based simulation of a manufacturing plant for producing USB computer mice. There are four components for each laboratory or project of the online Mouse Factory: a web site containing the learning assignments, a website containing a complete description of the Mouse Factory and Java Server Face (JSF) web-based applications that generate data. Note that the gauge R&R project does not use JSF applications to generate data but rather requires the students to make their own measurements of a set of gauge blocks.

Students typically access the learning materials through the assignment web-site located at http://quality.engr.utpa.edu/ccli/SPCLaboratories. A screen capture of the assignment overview page is shown in Figure 1. From this screen, users can select Project 6 – Measurement systems analysis.

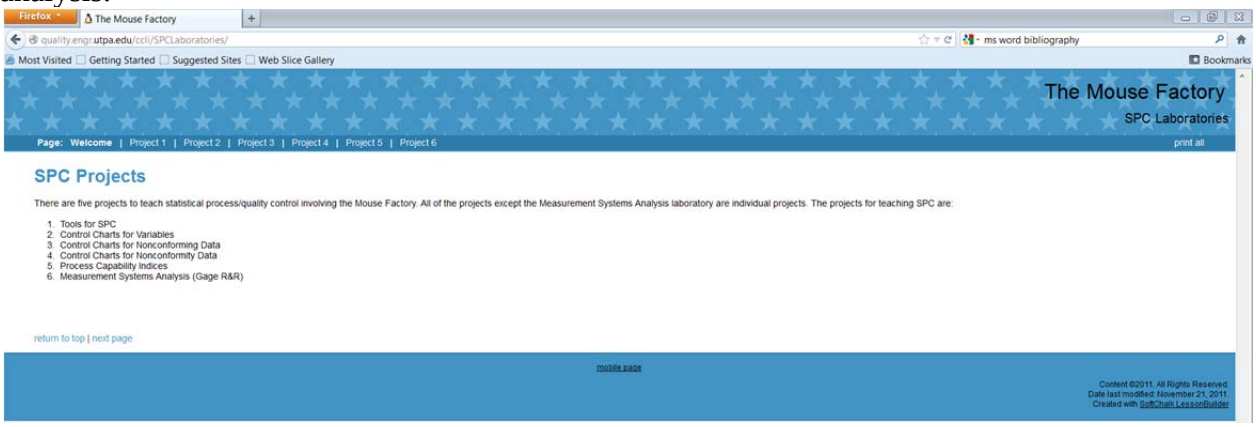

Figure 1. Assignment Overview Web site

Figure 1 displays links for six projects. The first project is "Tools for SPC." Students use fundamental tools of SPC such as check sheets and Pareto diagrams to benchmark the performance of the Mouse Factory plan and develop a quality improvement plan. Further information for the first project is available in Timmer and Gonzalez[8] and Timmer, Gonzalez, Borror, Montgomery and Pena[9]. The second project allows students to implement and evaluate the impact of control charts for variables upon the quality and production of the Mouse Factory[10]. The third and fourth projects involve control charts for attributes[11]. Project three utilizes control charts for nonconforming data (*p*- and *np*-charts) and the fourth project utilizes control charts for nonconformity data (*c*-charts). Project six provides students the opportunity to utilize process capability indices. The final SPC project is the gauge R&R project described in this paper. In addition to the SPC projects, there are additional projects to teach design of experiments[12] and response surface methodology[13, 14].

Gauge R&R Project

Students in an undergraduate senior-level quality control course taught in the Fall 2012 semester at the University of Texas – Pan American were divided into three groups to perform the gauge R&R Project. Therefore, each group had either three or four students. A screen capture of the course website is shown in the Figure 2 shows the group assignments. Each group was assigned a dimension of the gauge blocks and three measuring devices from a set of measuring devices

that included a steel rule, dial caliper, electronic caliper, manual micrometer and electronic micrometer. Each measuring device has a different cost, precision and amount of training required to successfully use and thus should provide differing repeatability and reproducibility results. The measuring devices used in the Gauge R&R Project are shown in Figure 3. The gauge blocks contain three dimensions: height, depth and width. Each dimension of the gauge block has a different amount of variability and the dimensions are clearly labeled on each block. A set of figures displaying the four labeled faces of a block is shown in the Figures 4 – 7.

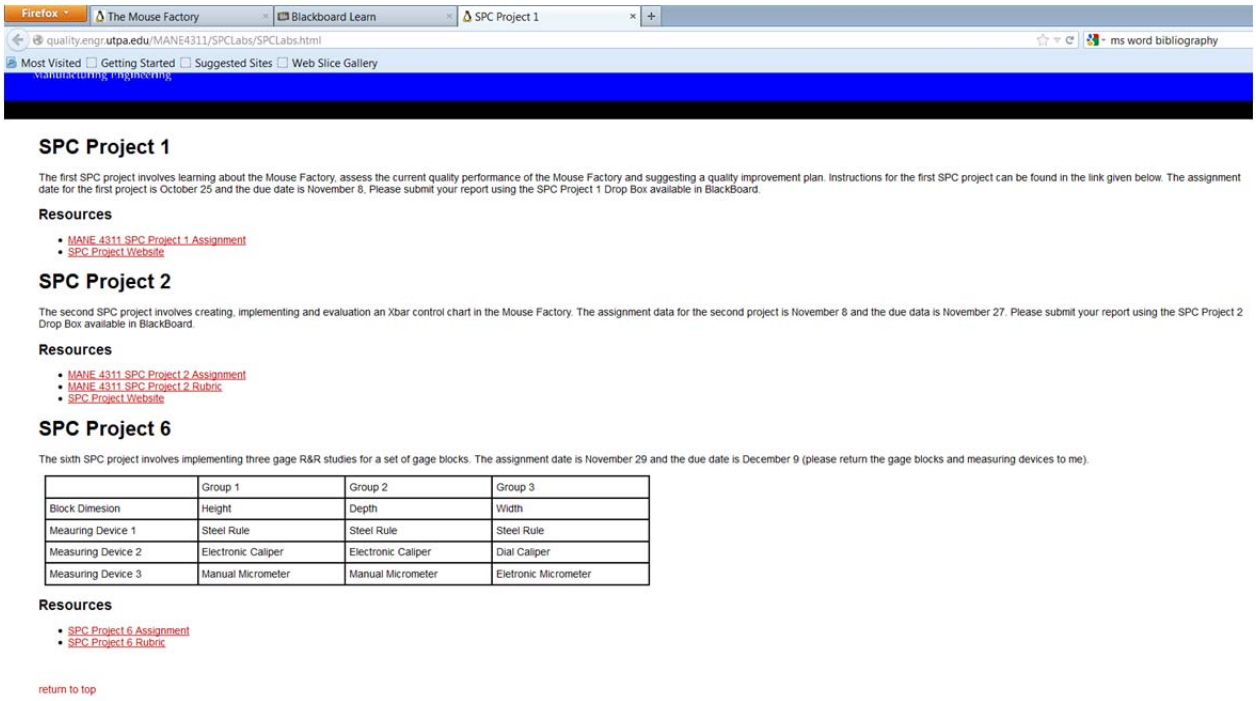

Figure 2. Course Project Website

Figure 3. Measuring Devices

Figure 4. Label Face

Figure 5. Depth Face

Figure 6. Height Face

Figure 7. Width Face

The Gauge R&R Project has three learning goals:

- Design a sampling plan for gauge R&R studies,
- Perform a gauge R&R analysis for your specified dimension using the three assigned measuring devices, and
- Recommend a measuring device for your assigned dimension.

An important consideration in developing the learning goals was a focus on higher-order cognitive skills. Based upon the learning goals, a list of deliverables is provided to the students. Students are required to provide:

- A professional, type written report,
- A detailed discussion of the sampling plan,
- Three sets of gauge R&R analyses corresponding to the three measuring devices,
- Provide a recommendation for the best measuring device for the Mouse Factory, and
- Include the (raw) subgroup data from the gauge R&R analyses.

The list of deliverables is the linkage between the learning goals and the evaluation of the student performance. Student performance is evaluated using the rubric shown in Figure 8.

SPC Project 6 Rubric
Name:
Score:

Component	Exceptional (9 - 10 points)	Effective (8 - 9 points)	Acceptable (7 - 8 points)	Unsatisfactory (0.0 – 7.0 points)	Score
Explanation of Sampling Plan	A complete and detailed explanation of sampling plan	A thorough explanation of sampling plan	An adequate explanation of sampling plan	An incomplete or inaccurate explanation of sampling plan	
Gage R&R Analysis for rule	A complete, detailed and accurate gage R&R analysis	A thorough gage R&R analysis	An adequate gage R&R analysis	An incomplete or inaccurate gage R&R analysis	
Gage R&R Analysis for caliper	A complete, detailed and accurate gage R&R analysis	A thorough gage R&R analysis	An adequate gage R&R analysis	An incomplete or inaccurate gage R&R analysis	
Gage R&R Analysis for micrometer	A complete, detailed and accurate gage R&R analysis	A thorough gage R&R analysis	An adequate gage R&R analysis	An incomplete or inaccurate gage R&R analysis	
Recommended measuring device	A complete, detailed and correct recommendation	A thorough recommendation	An adequate recommendation	An incomplete or inaccurate recommendation	
Raw Data	A complete listing of the three data sets in an appendix	A partial listing of the three data sets in an appendix	An inadequate listing of the three data sets in an appendix	An incomplete listing of the three data sets in an appendix	
Report	Report is well-written, grammatically correct and free of spelling errors.	Report contains very few grammatical errors and misspelled words.	Some grammar and punctuation errors; report content is sometimes confusing .	Several grammar, spelling or punctuation errors; report is very difficult to read.	

Comments:

Figure 8. Gauge R&R Project Rubric

The final component of the gauge R&R laboratory is assessment. Group performance for this project is evaluated using the rubric shown in Figure 8. Students were voluntarily asked to complete a demographic information sheet and student survey after submitting the project but before receiving feedback reflecting their performance as defined by the rubric. The survey focused on the students' perceived understanding of the project learning goals and confidence in ability to implement the learning goals in real life.

Results

The Gauge R&R Project was implemented at the University of Texas – Pan American (UTPA) in MANE 4311 – Quality Control during the Fall 2012 semester. Eleven students were enrolled in the course and eight submitted the (voluntary) demographic and survey sheets. The assessment results are provided in Tables 1 – 3.

Table 1 contains the student demographic information. Participation in the demographic survey was voluntary. The demographic information is reflective of the overall student demographics at UTPA, the demographics of the students in the College of Engineering and Computer Science, and the student demographics of the Manufacturing Engineering program at UTPA. Male students comprised 87.5% of the enrolled students in the course. All enrolled students were Hispanic. The 2011 UTPA OIRE fact book indicates that the overall university enrollment of Hispanic students is 90.2%.7 An interesting statistic is the fact that only 25% of the enrolled

students had English as a first language. Table 1 also contains information about family income, student GPA, weekly employment, marital status, number of children, parents' educational achievement and enrollment information.

Table 2 contains the evaluation of the group performance. The enrolled students were divided into three groups because gauge R&R studies require at least two operators to be conducted. Student performance was evaluated as Exceptional (A-level), Effective (B-level), Acceptable (C-level) and Unsatisfactory (D-F level). In general, the student performance was unsatisfactory. Only one group performed a gauge R&R study using the steel rule at an acceptable level. The analyses of gauge R&R studies using the caliper and micrometer were unsatisfactory for every group. All groups made the same mistake when gathering data for the gauge R&R studies for the caliper and micrometer: each operator only measured one part instead of the set of eight parts. Thus, they did not have data to perform a gauge R&R study. Possible explanations for this outcome and remedies will be discussed in the Discussion and Future Research section.

Table 3 contains the student survey information. Individual students were asked two questions for each learning goal. The first question was "Did the use of this laboratory improve my ability to accomplish the learning goal." The second question of the pair was "Did the use of this laboratory increase my confidence in being able to accomplish the learning goal." The final question was should this laboratory be used in future classes. The results were quite encouraging. No student replied with a "Disagree" or "Strongly Disagree" to any question. Three scores of "Neutral" were received. Interestingly, one score each was received in the three confidence questions: improved confidence of designing sampling plans, improved confidence of performing gauge R&R studies and improved confidence in selecting appropriate measuring device.

Table 1. Student Demographics

Question	Response	Count
Gender		
	Male	7
	Female	1
Ethnic Group		
	Asian	0
	Black	0
	Caucasian (Non-Hispanic)	0
	Hispanic	8
	Native American	0
	Other	0
Family Income		
	$0 - $20K	1
	$20K - $40K	2
	$40K - $60K	3
	$60K - $80K	0
	$80K - $100K	1
	>$100K	0
English as first language		

	Yes	2
	No	6
GPA		
	<2.5	0
	2.5-3.0	6
	3.0-3.5	2
	3.5-4.0	0
Weekly Employment		
	<12 hours	4
	12 - 15 hours	3
	>15 hours	1
Marital Status		
	Single	8
	Married	0
Number of Children		
	0	8
	1	0
	> 1 child	0
Mother's educational achievement		
	Less than high school	0
	High School/GED	3
	Some College	0
	Two year college degree	2
	Four year college degree	3
	Master's degree	0
	Doctoral degree	0
	Professional degree (MD or JD)	0
Father's educational achievement		
	Less than high school	0
	High School/GED	2
	Some College	2
	Two year college degree	0
	Four year college degree	3
	Master's degree	0
	Doctoral degree	0
	Professional degree (MD or JD)	1
Current Enrollment		
	<12 hours	0
	12-15 hours	8
	>15 hours	0

Table 2. Group Performance

Component	Exceptional (A)	Effective (B)	Acceptable (C)	Unsatisfactory (D-F)
Sampling Plan Explanation	1	1	1	0
Gauge R&R for rule	0	1	0	2
Gauge R&R for caliper	0	0	0	3
Gauge R&R for micrometer	0	0	0	3
Recommended measuring device	0	0	3	0
Raw Data	2	1	0	0
Report	3	0	0	0

Table 3. Student Survey

Component	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Improved understanding of sampling plans for gauge R&R studies	4	4	0	0	0
Improved confidence of designing sampling plans	5	2	1	0	0
Improved understanding of gauge R&R studies	5	3	0	0	0
Improved confidence of gauge R&R studies	4	3	1	0	0
Improved understanding of selecting measuring devices	4	4	0	0	0
Improved confidence of selecting measuring devices	4	3	1	0	0
Recommend lab 6 for future classes	5	3	0	0	0

Discussion

The low level of achievement in conducting gauge R&R studies is a major concern. Most of the project teams were not able to correctly collect and analyze data for a gauge R&R study. Instead of every student making repeated measurements on every part, the teams assigned parts to their members and only measured their assigned parts (not the entire set). While this reduces the number of measurements needed, it does not provide valid to perform a gauge R&R study. There is an easily identifiable factor that contributed to this occurrence. The instructor had a death in the family that occurred during the lecture portion of the course that covered measurement systems analysis. Videos from previous lectures were provided. Apparently, the use of videos from previous lectures was not effective. Additionally, a project report guide was not provided for this project. Previous project assignments contained a report guide. The use of report has been effective in the past and is reasonable compromise between providing no help and an example report.

An interesting observation provided by a reviewer is that the instructor's evaluation of the performance was low and the student survey results reflected an increased understanding and confidence the use of gauge R&R. This can potentially be explained because the students had not received their performance feedback before submitting their surveys. Thus they were not aware of their poor performance but felt confident in what they had submitted

Future Research

There are two significant action items related to future research. The first action item is the preparation of a project guide. Project guides have improved student performance in the past and should improve student performance in the future. The second action item is to recruit more test sites. The current state of this project is that a small pilot test using three groups from one university has been conducted. To achieve meaningful results, more widespread use of this project is required.

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