AC 2008-498: INDUSTRY-UNIVERSITY COLLABORATION TO IMPROVE TEST DATA QUALITY

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Industry-University Collaboration to Improve Test Data Quality

Abstract

A major engine manufacturer, Cummins, Inc., had organized a charter[1] to provide training to a group of employees involved with data collection. Their objective was to improve data quality by improving the calibration of test instruments. The group of employees would also be encouraged to take the Certified Calibration Technician examination as part of obtaining this certification offered by the American Society for Quality. Essentially, their training served as a preparatory class for the CCT exam. However, other benefits outside of the exam were identified. They included improved efficiency and knowledge of calibration issues, establishment of a common vocabulary about calibration, and development of a professional development path for technicians. According to the Cummins, Inc. charter, "at the end of the day value will be added to Cummins as data quality, productivity and efficiency improve."

After conducting the class once, Cummins decided it was too costly for them to continue and approached the Purdue University College of Technology in Columbus, Indiana about offering the class as part of their curriculum. The mechanical engineering technology (MET) department of the College of Technology decided to implement the class. An outline of the class with desired objectives was submitted to the curriculum committee of the MET department and approved as a "Special Topics in MET" class. The class was offered with no prerequisite classes and approved as a technical selective for the two-year associate of science degree in MET. Employees from local industry as well as current students in MET were encouraged to register for the class. This class has been conducted during the fall semester in 2005, 2006 and 2007, serving over 40 students.

This work details the organization of the class including objectives, hands-on activities, assessments, and course materials. Basically, the Book of Knowledge[2] published by the ASQ for calibration technicians was adopted as the text book but was supplemented often with materials from MET classes as well as classes from the Organizational Leadership and Supervision program that involve quality concepts.[3] Descriptions of the hands-on activities include the calibration of a Bourdon tube pressure gauge, measurement of temperatures and volts for thermocouples and use of simulation software[4] to provide lessons in using measurement equipment.

Introduction

According to the National Institute of Standards and Technology (NIST) "Calibration is a measurement process that assigns values to the property of an artifact or to the response of an instrument relative to reference standards or to a designated measurement process".[5] The purpose of calibration is to eliminate or reduce bias in the user's measurement system relative to the reference base. The calibration procedure compares an "unknown" or test item(s) or instrument with reference standards according to a specific algorithm." For manufacturing companies many types of measurements are critical to the creation of quality and reliable products. Among those are measurements of length, weight, torque, temperature and power. Calibration of the instruments making those measurements is critical to good business. The American Society of

Quality (ASQ) offers a program including a four-hour exam for technicians leading to the designation of "Certified Calibration Technician (CCT)". ASQ has also created a Body of Knowledge related to calibration and the CCT exam is based on the contents of this Body of Knowledge.

A large diesel engine manufacturer, Cummins, Inc., had assumed the job of training their technicians and preparing them for the CCT exam internally, using their personnel and resources to offer a 40-hour training class to its employees. Although the class was a success, a more efficient alternative was sought. Representatives of the company approached faculty members from a local College of Technology about the possibility of the College offering the course. Faculty members from two departments – Organizational Leadership and Supervision, and Mechanical Engineering Technology – decided to collaborate to offer the class. The MET faculty member submitted a proposal to the MET Curriculum Committee to have the course be considered a for-credit course that would satisfy a technical elective requirement for the Associate of Science degree in MET. The proposal was accepted and the class was offered not only to local companies for their employees but also to MET students looking to fill that requirement.

Benefits to Employers

Initially, Cummins, Inc. created a charter to support the training class effort. Figure 1 shows graphically the five elements they identified that result in competent calibrations – motivation, CCT certification, properly using software to automate the process, task proficiency and systems thinking. Four of these elements are addressed in the class in the sense that employees learn the common language of calibration, become aware of the bigger "system" picture of how measurement instruments affect the entire data collection process, and learn or re-learn some basic math skills required for the CCT exam. While having students pass the CCT exam is one

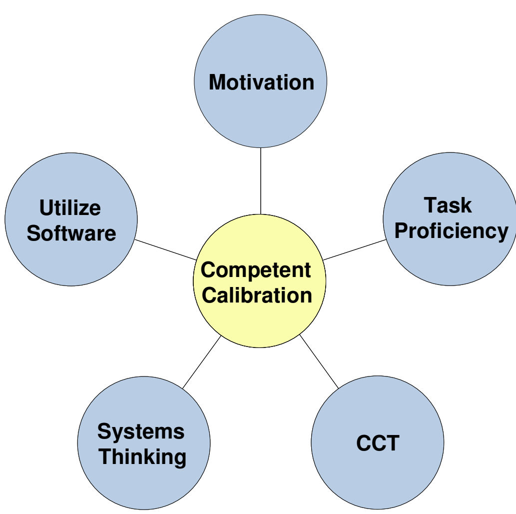

Figure 1. Organizational Model for Competent Calibrations

goals of the company, they have identified other benefits, chiefly that the knowledge gained, including the common vocabulary, will allow technicians to expand their thinking and problem solving skills when confronted with a measurement issue not previously experienced. Also, the training and certification program are identified as a path of professional development for calibration technicians and recognition of their skills. Finally, the company believes it is beneficial for a group of technicians to meet and discuss calibration issues, resulting in an increased understanding of the calibration process, regardless of their performance on the CCT exam.

Proposal for a 3-Credit Hour Class

The most important element of a proposal for a new class in the MET department is the adoption of the core learning objectives that align with the department's objectives and outcomes. Those are defined below.

Class Objective

The objective of the class is to familiarize students with methods and procedures to evaluate and improve data acquisition and the quality of the data acquired. Topics covered include general metrology, measurement systems, calibration systems, applied mathematics and statistics, quality systems and standards, and uncertainty. Students will have the opportunity to acquire the Certified Calibration Technician (CCT) designation from the American Society of Quality.

Class Outcomes

Upon successful completion of this course, the student should be able to:

1. Define and calculate various derived units, including degree, ohm, Pascal, Newton, joule, coulomb, hertz, etc.
2. Describe and apply inspection, measurement, and test equipment standards in measuring the following: length, temperature, pressure, force, mass, voltage/current/resistance, time/frequency, displacement and strain.
3. Identify and respond to various measurement data considerations including readability, integrity, traceability, resolution, variability, sensitivity, repeatability, bias, linearity stability, and reproducibility.
4. Identify and describe basic concepts of Measurement Assurance Programs (MAPs), including inter-laboratory comparisons, proficiency tests, gauge R&R studies, etc.
5. Define and use common calibration methods, including spanning, nulling, zeroing and linearization.
6. Recognize various sources of industry-accepted metrology and calibration practices.
7. Convert various units of measurement between English and metric units, including length, area, volume, capacity, and weight.
8. Determine the slope, intercept, and linearity of data sets.
9. Read tables and graphs to determine intermediate and extrapolated values.
10. Classify data distributions as being normal, rectangular, triangular or U-shaped.
11. Calculate the variance, root mean square, root sum square and standard error of the mean for a data set.

12. Identify various methods and tools used in the development, validation, improvement and review of a quality system.
13. Select and apply the basic quality tools: cause and effect diagrams, flowcharts/process maps, check sheets, Pareto diagrams, scatter diagrams, control/run charts and histograms.
14. Identify appropriate behaviors, such as those listed in the American Society of Quality Code of Ethics, for various situations requiring ethical decisions.
15. Determine and select areas for data improvement using various quality tools.
16. Identify various type A and type B uncertainty components, including environment, human factors, methods and equipment, item under test, reference standards and materials.

Assessments and Grading

An addition concern for the MET curriculum committee is assessments in the class. Cummins, Inc. officials expressed concern about requiring employees who have not been in any type of school for a long time being pressured to earn a satisfactory grade for reimbursement of their expenses. The thought was that if many employees/students have a bad experience, do not pass the class with the required grade and do not receive reimbursement of their expenses, enrollment in future classes would be severely affected and that was not a desirable outcome for the company. Consequently, homework is assigned on a weekly basis and for most of the semester the homework is focused on basic math and statistics skills such as using a calculator, performing unit conversions, determining basic statistical quantities using linear regression with a calculator, using fractions, performing linear interpolations, and computing basic geometry quantities like perimeter, circumference, area, surface area, and volume. The assessments mentioned above are graded and returned to the students so they receive some feedback on their performance. The compromise proposed to company officials was to have the final, officially recorded grade be either *Pass or Fail* and that the bulk of the grade is based on attendance and class participation with a small percentage based on the results of the assessments.

This assessment and grading plan has been utilized for the first three offerings of the class. The author has noted that those students who are taking the class specifically for the three hours of MET credit and are uninterested in taking the CCT exam are sufficiently unmotivated and require some additional inspiration. This class has been offered in the fall semester leading up to the CCT exam offered by ASQ in early December. A sample practice exam similar to past CCT exams is given to the class by the author usually a week or two prior to the official exam. The exam is approximately the same number of questions as the CCT exam and students are given 4 hours to complete the exam. Although this exam is graded and returned to the students, it has only a minor connection to the final grade. Those students who are preparing for the CCT exam are understandably motivated and usually perform quite well on the practice exam. Those students taking the class for college credit have not been motivated to perform well on the practice exam and their scores reflect this lack of motivation. In future offerings of the class, those students taking the class for MET credit will be required to achieve at least a 60% to obtain a passing grade. Those students preparing for the CCT exam have consistently scored 80% or better on the practice exam, so the 60% passing score should be reasonable.

Class Schedule

Table 2 shows the schedule proposed and used for the class. The class meets once per week for 2 ½ hours, which results in total class time of 40 hours, typical for a 3-credit hour class and equivalent to the internally-organized class at the company. Although the content in the schedule is similar to that used by the company in their course, the addition of lab activities was an additional benefit that the College of Technology brought to the class. One representative of Cummins, Inc. has continued to assist with the class by teaching the two modules on uncertainty.

Lab Activities

Weighing M&Ms

On the first day of class, the instructor brings a bunch of small bags (18 grams) of M&M candy. The students then weigh all the bags with mass balance scales. Typically there are at least six scales but one or two of them are different than the others. One, in fact, only measures in ounces while the rest use grams. As the bags are weighed, the instructor records the weights on the board for further evaluation. A unit conversion is required for the one scale that measures in ounces. Then, a statistical analysis is performed using a rather simple and inexpensive calculator ($15) that is chosen to demonstrate that an advanced, expensive calculator is not needed for this work. Quantities such as mean, median, mode, standard deviation and range are determined. The subsequent discussion focuses on why there are differences between the various bags of candy and how these data could be used to validate or check a manufacturing process. Sampling methods are also discussed as are quality tools like an $\overline{X} - R$ chart. Other attributes like the number in each bag, the number and type of colors in the bags of the M&Ms are also considered.

Bourdon Gage Calibration

The MET department has a hydrostatic bench that contains manometers for measuring pressure difference, viscometers for measuring viscosity, a barometer for measuring atmospheric pressure and a Bourdon gage to measure pressure. All the necessary equipment is available to calibrate the Bourdon gage and this procedure is completed during one of the classes. Water is placed in a cavity connected to the Bourdon gage. Known weights (used with some discussion about the error in the known weights and how they may be traceable to standards) are then placed on the cavity and the pressure on the Bourdon gage is recorded. In this procedure, the weight is placed on the cavity filled with water and falls due to gravity to the bottom of the cavity, limiting the amount of time the Bourdon gage may be accurately read. Of course, as the weights get heavier the time decreases giving the students less time to read the gage. The exercise involves recording the pressure and the weights, computing the true pressure (weight divided by area) and then calculating the percent error of the Bourdon gage. Discussion of the exercise includes all the sources of error in the process. Students are required to complete their table and submit it the following week with the required calculations.

Table 1. The Schedule for the Improving Data Quality Class

WEEK	LECTURE	SUBJECTS COVERED	LAB ACTIVITY
1	Mathematics & Statistics	Technical & Applied Mathematics Notation, Interpolation,	Weighing M&Ms
2	Mathematics & Statistics	Applied Statistics Linearization, Regression,	Unit Conversion Practice
3	General Metrology	Base and Derived SI Units Fundamental Constants	
4	General Metrology	Traceability Measurement Standards Calibration Standards	Dimensional Measurements, Error, Significant Figures
5	Measurement Systems	Measurement Methods/Data Characteristics of Measurements	
6	Measurement Systems	IM & TE Specifications, Errors, Measurement Systems, MAPs	Bourdon Tube Calibration
7	Calibration Systems	Calibration Procedures Calibration Methods	
8	Calibration Systems	Industry Practices & Regulations Control of Calibration Environment	Temperature Measurements
9	Calibration Systems	Systems Records & Records Management Reporting Results	
10	Mathematics & Statistics	Central Tendencies, Dispersion, Probability, Distribution, Sampling	Amatrol Measurement Tools 1 Software[4]
11	Quality Systems & Standards	Management Systems, Quality Control Tools, Audits	
12	Quality Systems & Standards	Preventive & Corrective Action, Supplier Qualification, Ethics & Conduct	Light Measurement Devices
13	Quality Systems & Standards	Occupational Safety Requirements, Quality Standards & Guides	
14	Uncertainty	Introduction, Measurement Process, System & Models	Strain Gauges
15	Uncertainty	Uncertainty Budget, Decision Rules	
16	Practice Exam		

Temperature and Light Intensity Measurements

Both of these lab activities involve students recording values of either voltage or current from thermocouples, thermisters, or optic sensors. The exercise involves setting up the proper electronics and connections for the experiment. A heat bar is used for the thermocouples and thermisters. Thermometer wells containing water are also placed on the heat bar and the temperature from the thermometer is also recorded. An additional activity for the students is to plot the data and then perform a linear regression to linearize the data, illustrating how this technique is used in practice. A similar activity is performed with photovoltaic cells.

Measurement Tools 1 Software and Portfolio/Assessment Package

An overview of the software by Amatrol, Inc. states that "The Measurement Tools 1 unit includes a complete set of computer software, written text, and laboratory activities that will teach students the fundamentals of technical precision measurement."[4] The first section of the software teaches skills that include taking measurements with a machinist's rule and a tape measure in both U.S. Customary and SI Metric units and converting between them. The second part focuses on precision measurement tools including lessons in dial calipers, digital calipers, and micrometers. The final section discusses dimensional gauging, and collecting and displaying data using data acquisition software. During the lessons, students are required to properly position a part and measure its length, diameter, width and other dimensions by using one of these instruments, and actually learn how to properly read the instrument. All this happens as a simulation and no hardware is required. Appropriate class discussions include how accurately a particularly instrument can be read and what the error is for that instrument.

Strain Gages

This exercise again involves the students setting up the proper electronics and wiring and applying weights to a bar. Moments, stresses and strains are computed and compared to the strain gage reading. Data are plotted (strain vs. weight) and linearized. Students complete these calculations and submit their work the following week.

Practice Exam

Each chapter of the CCT Body of Knowledge has 60 – 80 sample questions at the end of the chapter. While a few of these questions are covered during class time, some of the ones that aren't covered are included in the practice exam. The questions are multiple choice and 130 questions are included on the exam. The actual CCT exam contains 125 questions. Students have 4 hours to complete the exam, which is graded by the instructor and returned to the students prior to the official offering of the CCT exam.

Conclusions

This class, focused on improving the quality of test data, grew from a request from a local company and became a collaboration between Cummins, Inc. and the Purdue University College of Technology in Columbus. Using materials and general ideas from the company's own offering of the class, the university faculty developed a set of objectives and outcomes, a schedule and an assessment plan leading up to the offering of the CCT exam by ASQ in December. So far, through three offerings of the class, over 40 students have participated. Most have been technicians from local companies but about 25% have been MET students who took the class for three hours of MET credit toward the AS degree in MET. The author made the effort to build the class and then submit it to the MET curriculum committee, which approved the class as eligible for credit towards the AS degree program. Active laboratory exercises were added to the basic, company-sponsored class by the faculty of the Purdue College of Technology to enhance student learning. These activities included taking actual measurements with scales, thermocouples, strain gauges, pressure gauges, and optical sensors; performing statistical analyses with calculators; learning to read precision measurement instruments; and calibrating a Bourdon Tube pressure gauge. None of these activities were included in the original class taught by Cummins, Inc. due to a lack of resources.

The author is aware of 13 students who have taken the CCT exam of which at least 12 have passed. Ultimately, this is one of the best assessment tools of the class.

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