

## **Pilot Implementation of a Task-based, Open-ended Laboratory Project using MEMS Accelerometers in a Measurements and Instrumentation Course**

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## **Introduction**

At California State University (CSU), Chico, we have a course entitled Measurements and Instrumentation. The course has been a requirement for the Mechanical Engineering and Mechatronic Engineering majors for many years. It covers such topics as laboratory instrumentation and calibration, static and dynamic signals, computer-controlled data acquisition, data analysis, documentation, and technical writing. All those topics are important and applicable in the two-semester Capstone course in senior design project that the students are required to take, not to mention any future projects they may work on as professional engineers. As such, it is recommended that junior-level students take the Measurements and Instrumentation course before the Capstone project. In practice, however, a number of students take them concurrently.

The Measurements and Instrumentation course is offered only in the spring semester, and is a 3-unit course consisting of two 1-hour lectures and one 3-hour lab session per week. The pre-requisites are 1) Introductory computer programming (e.g. C/C++, MATLAB), and 2) Linear circuit I. The course corresponds to the Accreditation Board for Engineering and Technology (ABET) Outcome criterion (b) “an ability to design and conduct experiments, as well as to analyze and interpret data,” and (k) “an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.”<sup>[1]</sup>

When I joined CSU Chico in 2013 as a new faculty member, I took over the course from a retiring professor, who had been teaching the course for many years. A good part of the lab equipment had been purchased presumably in 1980s and in 1990s, such as HP 3478A Digital Multi-meters (DMM), which we still use. We also have Hewlett-Packard (HP) 34401A DMMs that are getting old but in working order. However, HP 3497A Data Acquisition Units, which we had been using for strain measurements, were clearly outdated by a decade or two and were deteriorating. Fortunately, we were able to transition from 3497A to more modern National Instruments (NI) cDAQ platform for strain measurements in 2015. Large-scale renewal of aging equipment has been generally impractical due to budgetary constraints. Consequently, we have been implementing incremental updates, seeking affordable options.

In recent years, the Measurement and Instrumentation course has been receiving poor ratings in the Student Evaluation of Teaching (SET), notably in the areas of “Course Outcomes” and “Overall Evaluation”. The SET may not be a good measure of teaching effectiveness or the

learning outcomes per se; particularly evaluation items such as “overall effectiveness” are known to be influenced by various irrelevant factors <sup>[2]</sup>. However, it can provide valuable feedback regarding students’ experiences. We suspect that the overall poor ratings may be partially attributed to the equipment that is older than most students. The students might conclude that the lab is pointless because they would never use such old equipment in the “real” world. Part of students’ dissatisfaction may also be attributed to the teaching method employed, limited availability of graders, and unavailability of Teaching Assistants. Increasing enrollment and class size can be another factor affecting student experience. For reference, the course enrollment in Spring 2013 semester was about 55 students (one lecture section and three lab sections). It grew to 95 students by Spring 2015, and then 105 (two sections of lecture and five lab sections) in Spring 2016.

### **Revitalizing Measurements and Instrumentation Lab**

The Measurements and Instrumentation course had been clearly due for an update, or a series of updates. Seeking a hint for improving the course, we looked at common positive feedback from the students from previous years. To summarize, most students enjoyed the labs rather than the lectures, and many felt that they learned a great deal more from hands-on experience than from reading textbook or lectures. Some students said the labs saved them. We also observed that some students who did not perform well in written exams could demonstrate understanding of key concepts and exhibit quick learning abilities in the lab settings. Based on these observations, our approach was to emphasize laboratory portion of the course.

There have been reports of attempts to update or revitalize similar courses in measurements and instrumentation at various institutions <sup>[3][4]</sup>. For example, Smyser and others at Northeastern University reported their case of redesign of labs for a measurements course, where the goals were, among other things, to i) eliminate demonstration in favor of hands-on lab experiences, ii) give students more control over the design and execution of the lab, and iii) institute an experimental design project <sup>[5]</sup>. “Open-ended” was one of their keywords. Garrison and others described their continuing work to redesign a thermodynamics and fluid mechanics laboratory at York College of Pennsylvania <sup>[6]</sup>. One of their ideas was to give students “a task targeted to a specific audience, for example, a CEO needs X”, and the lab reports were to “fulfill the task as targeted to the audience.” An emerging pedagogical trend is the transition from demonstration-type labs to hands-on activities, from using step-by-step lab manuals to task-driven, project-based learning (PBL) approaches <sup>[7]</sup>.

This trend is consistent with our overall Mechanical and Mechatronic Engineering curriculum at CSU Chico as it has evolved over recent years. The Capstone senior design project is undeniably an open-ended, task-based design experience, and is recognized as a highlight of our curriculum. We also have a first-year “Cornerstone” design course, which aims to introduce freshmen to open-ended process of engineering design in hands-on, group-project format. We

believe that task-based, open-ended approach has great merits, although it also brings administrative challenges and other issues, including how to ensure fair grading of group work.

This paper describes our attempt to revive the Measurements and Instrumentation course, as implemented in Spring 2016 semester. Our approach was to emphasize lab portion of the course and introduce a new task-based, open-ended lab project using affordable accelerometers. The “task” was to deliver a measurement system and a test plan for a hypothetical “client”, a biomedical professor, who needed to measure human arm movement to test his research hypothesis regarding stroke-induced impairment. The client, role-played by the instructor, had a few “meetings” with the students to exchange ideas and elaborate on project requirements.

In this pilot implementation, we were interested in the students’ response to the open-ended design format. The main assessment tool was the reports written by individual students. Based on the grading of the report, we aimed to identify common deficiencies and proficiencies so that we can improve instructions, guidelines, and/or structure to help improve students’ performance and learning.

The course structure for Spring 2016 semester and Spring 2015 (for comparison) is described in the following section.

## **Course Structure**

Over the semester, lecture topics were mostly organized along the textbook’s first several chapters. The same textbook, “Theory and Design for Mechanical Measurements” 5<sup>th</sup> edition by Figliola and Beasley was used in both Spring 2015 and Spring 2016 semesters<sup>[8]</sup>. In addition, textbook chapters and sections as they relate to specific lab activities were referenced, such as (Chapter 8) temperature measurements, (Chapter 6) analog electrical devices and measurements, (Chapter 7) Sampling digital devices and data acquisition, (Chapter 11) strain measurements, and (Appendix A) A guide for technical writing.

The main lecture topics included:

- Chapter 1 Basic concepts of measurement methods: general measurement system, test plan, calibration, hierarchy of standards, accuracy and error, resolution, linearity, hysteresis
- Chapter 2 Static and Dynamic Characteristics of Signals: signal concepts, analog and digital signals, dynamic signal, Fourier Series and Fourier Transform, FFT
- Chapter 3 Measurement System Behavior: Linear systems, 1<sup>st</sup>- and 2<sup>nd</sup>-order systems, Step and Frequency Response
- Chapter 4 Probability and Statistics: Histogram, Probability Density Functions, Normal distribution, Student’s t distribution, Standard Deviation of the Means, Least-squares Regression

- Chapter 5 Uncertainty Analysis: Error sources, Systematic and random errors, Propagation of error

The lecture topics stayed mostly the same for both Spring 2015 and Spring 2016 semesters. However, presentation and delivery were adjusted in Spring 2016 so as to emphasize the connection between textbook concepts and lab activities.

In Spring 2016, to make room for additional lectures on MEMS (Micro-Electro-Mechanical Systems) technology and accelerometers as well as mock “client meetings”, we shortened lectures on probability and statistics. The rationale was that most, if not all, students were supposed to have taken a course in which basic concepts in statistics were covered. Lectures on digital sampling, AD converters, and uncertainty analysis were also slightly compressed in Spring 2016.

The course organization is summarized in Table 1.

**Table 1: Course Organization in Spring 2015 and Spring 2016**

	<b>Spring 2015</b>		<b>Spring 2016</b>	
<b>Wk.</b>	<b>Lecture topics</b>	<b>Lab</b>	<b>Lecture topics</b>	<b>Lab</b>
1	Basic concepts	(cancelled)	Basic concepts	Intro to LabVIEW
2	Test Plan, Calibration, Temperature Meas.	Intro to LabVIEW	Test Plan, Calibration, Temperature Meas.	Thermistor A
3	Standards, Linearity	Thermistor A	Standards, Linearity	Thermistor B
4	Curve fitting	Thermistor B	Curve fitting	Thermistor C
5	Dynamic signal	Thermistor C	Dynamic signal	(catch up)
6	1 <sup>st</sup> -order systems	Freq. Resp. Test 1	Freq. Analysis, FFT	Freq. Resp. Test 1
7	2 <sup>nd</sup> -order systems	Freq. Resp. Test 2	1 <sup>st</sup> -order systems	Freq. Resp. Test 2
8	Freq. Analysis, FFT	Freq. Resp. Test 3	(Spring Break)	(Spring Break)
9	(Spring Break)	(Spring Break)	2 <sup>nd</sup> -order systems	Freq. Resp. Test 3

10	Strain gauge, Bridge circuit	Strain gauge Bonding demo	Strain gauge, Bridge circuit	Strain gauge Bonding and Soldering demo
11	Data Acquisition, Log decrement	Strain gauge Soldering demo	Data Acquisition, Log decrement	Strain gauge lab 1
12	Probability, Statistics	Strain gauge lab 1	Probability, Statistics, AD Converters	Strain gauge lab 2
13	Uncertainty Analysis	Strain gauge lab 2	Uncertainty Analysis	Strain gauge lab 3
14	Uncertainty Analysis	Strain gauge lab 3	Uncertainty Analysis, “client” meeting	(new) Accel. demo
15	Sampling, AD Conv.	Strain gauge lab 4	MEMS, Accelerometers, “client” meeting	(new) Accel. 1
16	Technical Writing	(catch up)	Technical Writing	(new) Accel. 2
17	Final’s week	No lab	Final’s week	No lab

### **Description of Lab Activities**

Introduction to LabVIEW: NI LabVIEW was used throughout the semester for automating data acquisition. Since virtually all students were new to it, we introduced LabVIEW graphical programming and demonstrated the basics in the lab. Students, as groups of three per computer station, then created simple programs (VIs) with basic LabVIEW elements, such as numerical controls and indicators, loop structures, shift registers, time delay, and case structures.

In spring 2015, the first week of lab was cancelled, and LabVIEW introduction was done in the second week. The main reason for cancelling the first week’s lab was that the semester started on Tuesday and we wanted to align the pace of multiple (four) lab sections taught by two instructors. Spring 2016 semester started on Monday. So, introduction to LabVIEW was done in the first week. Additionally, in Spring 2016 students were instructed to review at least one of three available LabVIEW tutorial resources: “3-hour Hands-on” PowerPoint by NI, “A New Approach to LabVIEW Basics” Interactive Web Modules <sup>[9]</sup>, or “Learn LabVIEW” self-paced video tutorial for students <sup>[10]</sup>.

Thermistor Lab A, B, and C: This series of lab activities A) introduced thermistor with a DMM to implement a simple data acquisition system via General Purpose Interface Bus (GPIB), B) added another DMM and a thermocouple module as reference to conduct quasi-static calibration

of thermistor, and C) implemented a temperature read-out device with additional features, such as switching display unit of temperature on the fly.

Automated Frequency Response Test: In this lab, students used a function generator and a digital oscilloscope in addition to the DMMs. All instruments were controlled from LabVIEW VI that students wrote to meet a set of specifications. The main objective was to generate discrete-step frequency sweep out of the function generator, send the signal to a set of “black boxes” hiding some combination of passive RLC elements (low-pass, high-pass, or band-pass, 1<sup>st</sup>-order or 2<sup>nd</sup>-order analog filters), measure input and output signals to generate bode plot, estimate corner frequency, and infer the content of the boxes.

Up until 2014, we did not have the equipment to quantify phase shift of the signals, and we only looked at the signal amplitudes using AC Voltage function of DMMs. By Spring 2015, we were able to purchase new digital oscilloscopes (Keysight DSO1002A) and also replace old function generators (HP 8904A) with new waveform generators (Keysight 33511B). The digital oscilloscope let us quantify the phase shift between input and output waveforms. However, we had issues with LabVIEW’s instrument driver for DSO1002A, which caused frustration among students and instructors. In Spring 2016 semester, we devised a tolerable workaround for the issue, but the instrument driver still was not very reliable after all, and consequently this series of lab turned out to be somewhat programming intensive and more time consuming than we would have liked.

Strain Measurement: In this series of lab, students measured strain on a cantilever beam made of 6061-T6 Aluminum Alloy under bending load. They wrote LabVIEW program for data acquisition and analyzed data in Excel or MATLAB. Up to Spring 2014, we relied on the old HP 3497A units with 120-Ohm strain gauge plug-in. We had only five (marginally) working units, while we had up to eight groups per lab session. In Spring 2015, we transitioned to NI cDAQ-9172 (8-slot chassis) with NI 9237 strain module. Still, we owned only five units of cDAQ-9172 for eight groups of students. The groups had to share and take turns to use the device, which predictably caused frustration among students, and we needed a couple extra lab sessions so that all groups could complete data collection. In Spring 2016, we were able to purchase three additional units of NI cDAQ-9171 (1-slot chassis) with NI 9237 strain module so every group could use either 9172 or 9171 without waiting for a turn, which helped in making the lab more efficient.

Introduction of NI cDAQ platform and the 9237 strain module allowed us to sample strain signal at a much faster rate than our old equipment (HP 3497A) ever could achieve; we were able to actually see the dynamic waveform during, for example, natural vibration of the cantilever beam. So, we added a new exercise in Spring 2015 to capture the strain signal during damped oscillation of the beam and estimate the natural frequency and damping ratio by logarithmic decrement method. The exercise was carried over to Spring 2016.

We used to get very positive comments from strain measurement lab, when the class was small enough that we could afford to let student groups actually install the gauge on the aluminum beam specimen, but due to significant increase in enrollment, we had to abandon hands-on installation in favor of demonstration in 2014. The head of our college's tech shop, who is experienced in installation of strain gauges, would come to the lab sections, explain, and demonstrate how to properly install the strain gauge, including soldering of lead wires. In Spring 2015, the demo took two lab sessions (one for bonding and the other for soldering), which was not the most efficient use of time. In Spring 2016, we managed to compress the demo into one lab session. We wish we could revive hands-on installation of strain gauges, but that may not happen unfortunately due to large class size, time constraint, and material cost.

**Acceleration Measurement (newly-added):** This lab activity was new to Spring 2016, and it was presented as a request from a hypothetical "client" who had a technical problem and approached a group of engineers (students) for a solution. The following scenario was given, and the instructor acted as the client during mock "client meetings", where students asked questions to obtain necessary information to draft project requirements.

A biomedical professor wants to test his research hypothesis by quantifying the bandwidth of human arm movement and comparing it between "healthy" subjects and stroke patients. His idea is to measure the acceleration of the wrist while the subject is flexing and extending the elbow joint on a table with an object of various size and weight in the hand (e.g. tennis ball, water bottle, etc.).

With potential large-scale deployment/experiments in mind, he desires a relatively inexpensive setup that can be easily operated by a lay person who is not necessarily technically oriented; the system should be operable, for example, by a nurse with, say, one hour of tutorial at most.

You are an engineer who is aiding in the development of a prototype measurement system for the project. The following items are available:

- National Instruments USB-6009, Low-Cost Multifunction Data Acquisition (DAQ)
- Windows 7 PC with LabVIEW software
- Sparkfun SEN-12786 Triple axis accelerometer breakout board (with Analog Devices ADXL337) – with lead wires installed
- Elastic, wrap-around wrist support/brace (of various brands)

The scenario was written partly to justify the use of inexpensive MEMS sensors that we could purchase with available funding, and the NI data acquisition devices that we already owned, thus minimizing expense. Moreover, we wanted to involve the students in the process of defining technical requirements of the project. Such situation is common in real-life project, where the client does not have fully articulated technical specifications to present to the engineers; the



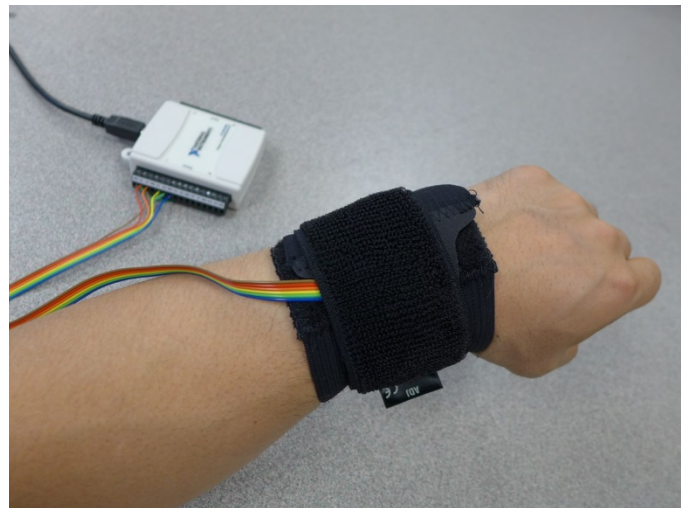
initial process of a project is to define itself. This aspect (i.e. active involvement of students/engineers in problem definition) is also emphasized in our first-year Cornerstone design course as well as in the senior Capstone course.

After the initial “meeting”, which was about 30-min long during one of lecture hours, another “follow-up meeting” was held so that the client/instructor could comment on some questions that he could not immediately answer in the initial meeting, and the students could come back with more questions. For example, students asked about the need for sensor calibration in the meeting. Responding, the client requested that the accelerometer be calibrated using gravity as reference (at -1g, 0g, and +1g for each axis), even though that may not be essential for the assessment of arm-motion bandwidth. The specific calibration procedures were to be designed and tested by the students.

Another requirement was to develop procedures or an algorithm (in MATLAB or Excel) to analyze the acceleration data to find an estimate of the “bandwidth” of the elbow motion, which we defined during the course of meeting as: the highest frequency of the repetitive shaking motion of the elbow based on average of at least 5 consecutive cycles. Simple visual examination of the data plot was considered minimally acceptable, but the preferred method was to establish semi-automated algorithm, to which data file would be the input and the “bandwidth” in Hz would be the output. The instructor suggested a couple approaches in the lecture, one using digital filter and peak detection function to identify each cycle of the “shake” in the data and programmatically look for the period and the frequency, and the other applying FFT to find a peak in the frequency spectrum.



**Figure 1: NI USB-6009 and Sparkfun SEN-12786 with Analog Devices ADXL337 Accelerometer**



**Figure 2: Accelerometer mounted on the Arm by an Elastic Wrist-Support**

Based on the conversations from the mock meetings, the instructor/client generated a rough draft of requirements and conditions, which were to be further developed and examined by individual student. The students were then tasked to design specific experimental procedures, collect sample data, demonstrate data reduction, and deliver a final technical report.

In terms of lab sessions, we had the following organization.

- **Accelerometer Demo:** The instructor demonstrated hardware connection and used a sample VI to capture acceleration signals. The sample VI contained basic driver interface/functions (NI DAQmx VIs) for USB-6009. The VI was given to students, and they were encouraged to explore, improve, and/or customize the features.
- **Accelerometer 1:** Students, as groups, spent more time exploring the provided hardware and the software, to understand and improve on it. Calibration procedures were tried and tested. In this exploration period, students worked mostly as groups, and sharing VI in a group was acceptable. However, their report had to be individually written.
- **Accelerometer 2:** Students ran through their test procedures individually, took notes, documented their experimental process, and saved sample data.

Students were also encouraged to take advantage of lab open-hours to spend more time on the project. A good number of students expressed that they wished to work during the weekend. The instructor agreed to come in and open the lab for them by appointment. This was done on a voluntary basis.

Each student was to deliver a concise final report, including the following contents:

- (10) Objective
- (10) Background
- (15) System Specifications
- (10) Hardware Description
- (10) Software Description
- (20) Test Procedures
- (20) Data Analysis
- (5) Reference

The numbers in parentheses represent the maximum grade point for the content. The report was graded for the technical contents as well as presentation, e.g. language, spelling, format, organization, and effective use of figures (drawing, diagram, plots, etc.). Grading was performed by one instructor. To avoid saturation, the grading standard was set rather higher than the instructor's usual standard.

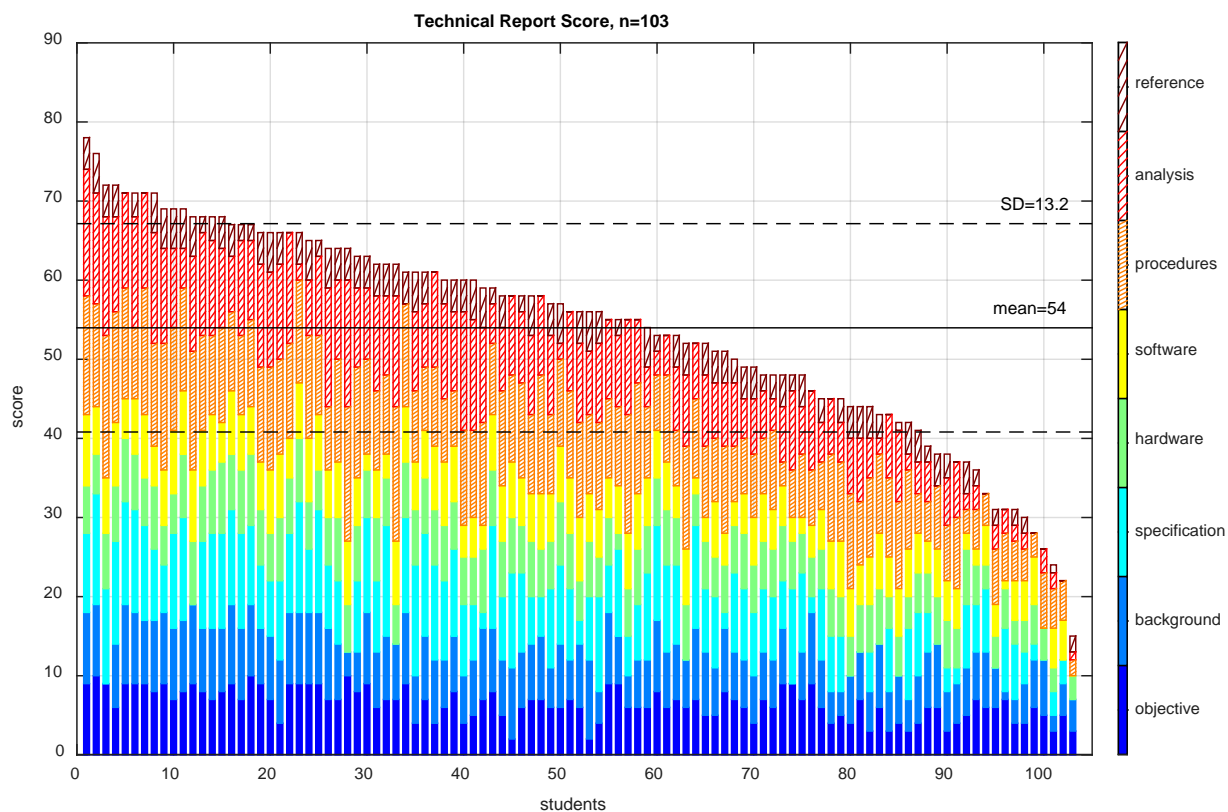
We expected to find out the followings from each content item.

- Objective and Background would indicate students' understanding of the overall task, and the open-ended format.

- System Specifications would reveal students' effort to define technically-specific requirements, based on the draft requirements given by the client.
- Hardware and Software Description would demonstrate the ability to understand, document, and describe the actual set up that they used.
- Test Procedures would show the students' ability to design and conduct experiments as well as the attention to details and documentation. This included calibration procedures.
- Data Analysis would expose their understanding of signal processing and/or frequency analysis as well as their proficiency in technical computing (Excel or MATLAB) and presentation.
- Reference would be an easy place to get full marks, if students paid attention, did any self-study, and took notes.

## Results and Interpretation

A total of 103 students turned in the report. The scores are summarized in Figure 3. The stacked bar represents the score for each rubric item. The mean of total score was 54 out of maximum possible 100, and the standard deviation was 13.2. Please note that the grading standard was set



**Figure 3: Lab Report Scores in Stacked Bar**

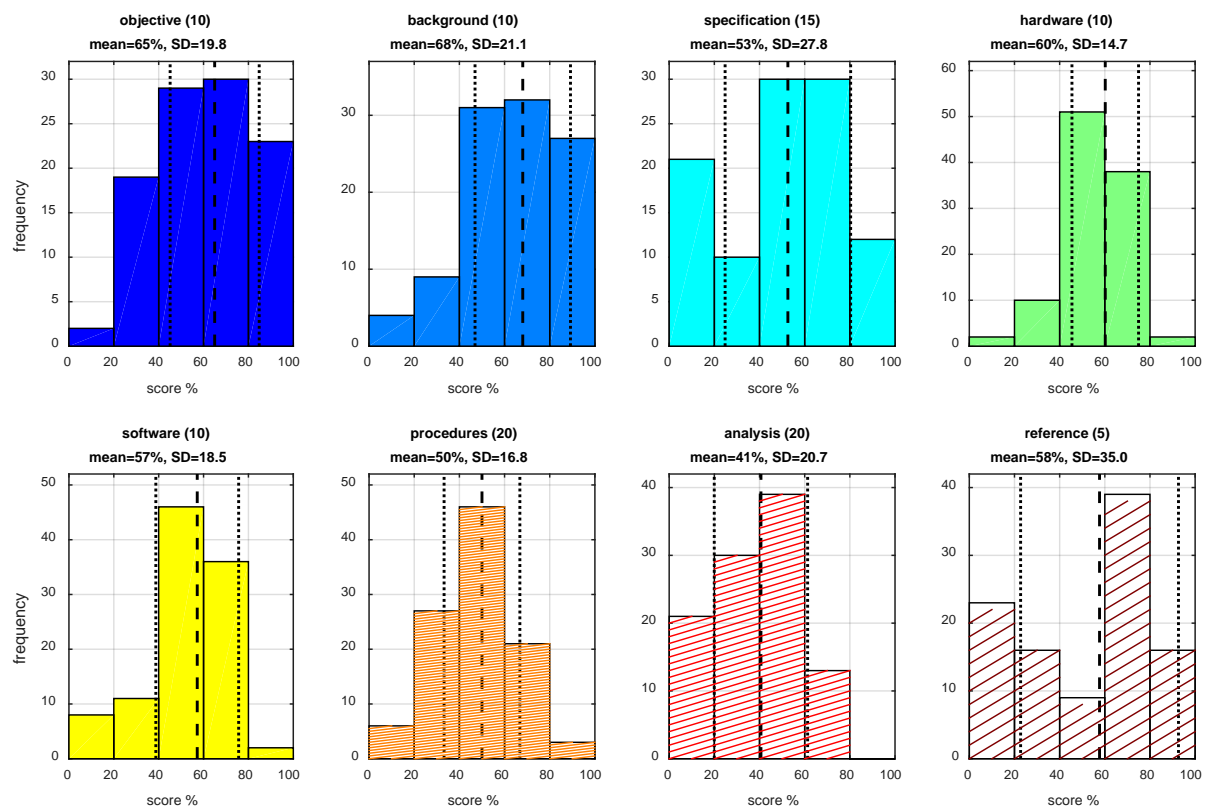
higher than the instructor's usual standard in order to avoid saturation of scores.

Figure 4 shows score distribution histogram for each rubric item.

Comparing rubric items, we can see that students performed best in the first two items: Background (mean 68%) and Objective (mean 65%), which suggests that they were able to follow the scenario and understood the main objectives fairly well.

Average performance was observed in Hardware (mean 60%) and Software (mean 57%), as well as Reference (mean 58%). Interestingly, the histogram for Reference revealed two peaks in the score distribution. We observed some students just did not cite any reference or listed only one or two sources with incomplete information. Many others did just fine in this item.

Students performed poorly in Analysis (mean 41%), Procedures (mean 50%), and Specifications (mean 53%). In Analysis, a good number of students could not devise a working algorithm or had trouble describing/demonstrating calculation steps in written form. A common deficiency was that they showed a screenshot of a spreadsheet, just table of numbers and an unlabeled plot, without any explanation of calculation steps or formula used. It also looked like a number of



**Figure 4: Score Distribution Histogram for Each Rubric Item**

students just ran out of time and turned in unfinished work. Some students actually communicated to the instructor that they were extremely busy toward the end of the semester due to exams and projects for other courses; they needed to manage time and priorities, and this report was apparently considered as relatively small return for the time investment.

In Procedures, a common weakness was that many students just rephrased the general experimental design suggested by the instructor more or less, and did not elaborate on specific details of procedures. Those who did not describe calibration procedures lost points, too.

In Specifications, two peaks are observed. Generally, the students who understood the difference between “problem definition” and their “solution” were in the upper cluster, while those who confused the two fell into the lower cluster. A common pattern was that they wrote down the “specifications” of the devices and components that they happened to use instead of addressing the “specifications” of the overall project. Even though this potential confusion of “problem definition” and “a solution” had been pointed out and clarified in the lecture, it seems that many students did not catch it.

## **Discussion and Other Observations**

To clear the confusion among students about the difference between the specifications of the overall problem and the specifications of solution (hardware and software), one simple idea is to change the wording; the “specifications” of the overall project can be consistently worded as “requirements” for better clarity. Also, earlier and throughout the semester, the difference should be pointed out using various examples, including each lab activity.

The overall organization and time management around the final project should be adjusted. It may be a good idea to introduce the project earlier in the semester, and spend smaller blocks of time on it in the lectures but more frequently throughout the semester, almost as if to help students draft the technical report one section at a time. It would be better if the students could finish data collection earlier and just focus on writing the report near the final’s week. That would probably reduce the cases of unfinished work.

Regarding data analysis and presentation, we believe that the students needed more guidance in general. In future, we will simplify the process required for data reduction, and will show example calculations in Excel and MATLAB in a more easily relatable form. Interestingly, some students expressed general dislike for computer programming (LabVIEW and MATLAB), while some others were delighted about it.

Grading the reports turned out to be a very time-consuming undertaking for the instructor, and it may not be sustainable without radical change or some clever technique, considering ever increasing enrollment. Some form of peer grading system, possibly using online management system, e.g. Blackboard Learn, may be worth exploring.

Almost all students seemed to appreciate the task-based format and the concept of open-endedness apparently, but in practice it appears that a good number of students, consciously or not, expected (or wished) that the instructor defined the problem tightly for them, and provided a step-by-step “to-do” list, so to speak. Some students had an attitude like “tell me what to do, and I will do it.” Some students seemed to shut down when the instructor’s general suggestion was that it is up to them to think of the specific tasks to do because that is part of experimental design process.

Another perspective we observed in some students was that they wished to just learn how to use specific tools (sensors, instruments, computer program, etc.) so they could apply them in future project. That doesn’t sound unreasonable at all, but when we listened to them carefully, their viewpoint was somewhat misaligned with the instructor’s thinking that, primarily, students should *learn how to learn* to be able to use new tools, equipment, or whatever they may see in their career. Similarly, the overall course was not intended to be a tool-specific skills workshop; the idea was to help students learn a basic form of experimental design process, so that they have a prototype or a template, so to speak, on which to continue building their expertise in whichever field they may be working in future. This message may not have reached some students.

It appeared that some students could not or did not want to tolerate the ambiguity of the open-ended project set up as presented by the instructor. They seemed to think that, in a “good” classroom, the instructor should present a well-defined problem to students, along with the correct solution and explanation. They want to see the same problem in an exam or a “project”, and then they would demonstrate that they could solve it. This misalignment of expectations between some students and the instructor can be a source of frustration.

To reduce this misalignment, our plan is to give students what they want: examples of problem and answer, but not in the way they would think. We wish to raise the dimension of the problem, so to speak. Instead of providing a set of procedures (a recipe) and assessing if students can follow them to produce correct-looking data plots, we would like to present examples of problem and answer, or rather, case studies of “task” and solutions. We can change the presentation of existing lab activities so that they look like case studies, i.e. example attempts to define a problem and solve it. After a few case studies, students would hopefully feel natural when they get a chance to create their own “recipe”. As we move forward, we should be able to try a new project every semester, and accumulate more and more case studies.

## **Conclusion**

We implemented a pilot version of a task-based, open-ended project in our Measurements and Instrumentation course using MEMS accelerometers, where the task was to quantify “bandwidth” of the elbow flexion/extension. This was accomplished without spending large amount of money. We made time for the new project by streamlining and compressing existing lab activities that

had been mostly carried over from the previous year. In the lecture part of the course, we emphasized the connection of textbook concepts to lab activities.

Students were able to understand the task-based project format fairly well, at least conceptually, and seemed to enjoy the hands-on activities. However, we observed confusion and frustration regarding the ambiguity of open-ended process; some students wished or expected the instructor to demonstrate the “correct” solution or step-by-step procedures. Some other students seemed to enjoy the ambiguity as they could explore more freely, have fun, and still get good grades.

Many students would have benefitted from additional guidance in overall design process, including clear distinction between problem definition and solutions, as well as data analysis and presentation. By improving overall course organization and time management, we hope to guide students naturally and gradually to the framework of task-based, open-ended design process, where there are many possible solutions. To begin with, we will present existing lab activities as case studies of open-ended design process. Meanwhile, we are seeking practical and scalable method to grade group work and technical reports.

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