2017

# Increasing Engagement in Materials Laboratory with Backward Design and Quadcopters

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Paper ID #17633

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## Abstract

This paper describes a laboratory experiment that was designed to increase student engagement and enhance student development in a materials laboratory. The laboratory module described is part of a broader effort to enhance the mechanical engineering laboratory curriculum to incorporate modern pedagogical methods and to improve student outcomes using backward design.

The new laboratory modules encourage students to work in small groups, develop team skills, and learn about basic measurement methods. The first module is a simple cantilever beam mounted with a strain gage. Students develop an understanding of the correlation between bending stress and strain. While doing so, they also determine a calibration factor for the beam in order to use the beam as a load cell to measure the weight of an object. For the second module, students are provided an instrumented beam with a known calibration factor and are asked to determine the amount of lift produced by a small quadcopter.

To assess the effectiveness of the laboratory experiment, a student survey was designed and the experiments were observed by an education expert. The results indicate the new laboratory modules have been successful in increasing student engagement and meeting learning objectives.

## Introduction

This paper describes a set of laboratory modules designed to improve student engagement and team skills in the sophomore year. The materials laboratory modules are part of a larger effort by several mechanical engineering faculty to enhance the entire laboratory curriculum and scaffold professional development with technical skills. The laboratory curriculum enhancement includes two facets:

1. Modernize and improve the technical skills acquired by students in the laboratory courses.
2. Thoughtfully incorporate developmental skills (soft skills like teamwork and communication) that are important for engineers.

The project uses evidence based instructional methods with an emphasis on backward design. The pedagogical methods are used to create new laboratory modules that use specific learning objectives with open-ended laboratory methods to create experiences where each student "cooks without a recipe." Prior work by the research team describes a successful experiment that scaffolds a low-cost experimental module through the entire mechanical engineering curriculum and provides additional context about the project goals [1]. The institutional change model has been used in a similar way to embed design projects in the curriculum [2].

An important goal for this laboratory module was to increase student comfort with measurements using strain gauges. In the older curriculum the students had some exposure to strain gauges, but only in a demonstration capacity without user interaction or application context. The faculty team identified this area as a possible weakness in laboratory education.

## Background

Backward design is a pedagogical tool where the instructor starts with a list of learning objectives and works backward to determine activities and assessment that will support them. Backward design has been used by the research teams to enhance other laboratory courses in mechanical engineering [1]. Duis et al. used a similar approach to modify laboratory curriculum in chemistry [3]. The technique has been used more widely in traditional classrooms [4]–[7]. In this project we used backward design to build student skills in professional development and technical areas. We used a list of learning outcomes developed by Kuh [8] that employers consider essential, specifically: Self-direction, timeliness, cogent writing, critical thinking, adaptability, quantitative reasoning, social responsibility, teamwork and collaboration.

Active learning is a pedagogical method to engage students more directly in learning, typically using small groups and minimizing lecture. Active learning has been used in laboratory classrooms, but is not often cited in engineering labs because they tend to be more active by nature. Sokoloff et al. used active methods to enhance physics laboratories [9]. Kontra et al. confirm that interacting with physical items improves learning [10]. One important feature of this project was the focus on making sure each student is active in learning. To facilitate this the project team designed small, inexpensive equipment that would allow students to work in small groups interactively rather than gathering around one large device.

Other evidence-based instruction methods, pedagogical methods verified by research, have been used in engineering laboratories. Many researchers found that the evidence based approaches were appreciated by the students, particularly minority students [11], [12]. Most prior investigations focused on one laboratory class, while this effort is part of a larger attempt to enhance the laboratory design across a four-year engineering curriculum.

In the larger researcher effort to adjust the curriculum with new modules has the following features [1]:

1. Specific student learning objectives (technical and developmental)
2. Structure that encourages self-direction and critical reasoning rather than recipe reading
3. Interaction with modern equipment and tools that students are more likely to encounter in industry (programming, modern instruments, calibration, data acquisition, etc.)
4. Designed to be inexpensive and easy to implement by other universities

This paper discusses two new modules developed and implemented in the materials laboratory and the results as determined by a trained observer and student survey.

## Learning Objectives

This project used backward design for the curriculum development, based on several outcomes planned for the different laboratory courses. The new modules facilitated both technical and developmental outcomes for students.

The research team developed the following objectives as key elements of the materials laboratory that the new modules were designed to facilitate.

Technical objectives:

- Experimentally, determine stress in a part by measuring strain (understand relationship between stress and strain in linear elastic materials).
- Be able to calibrate a load cell and use the load cell to measure force
- Understand the role of calibration in measurement

Developmental objectives:

- Negotiate and resolve conflict independently within the group.
- Ability to communicate experimental data graphically and use graphical data

## Module Development – Bending Module

The bending module is a new experimental module that has been developed to help students achieve the technical and developmental learning objectives. The module is also designed to expose students to measurement and instrumentation using strain gauges in a hands-on way that the previous laboratory experiments did not do.

The module consists of a small fixture to hold strain-gaged cantilever beams. The prototype fixture holds three different beams of differing materials: mild steel, 6061 aluminum, and polycarbonate test specimens, each of the same dimensions. There is a stop to prevent the test specimens from plastically deforming when a load is applied. Each specimen has a strain gauge mounted on top aligned with the beam axis. Loads are applied by hanging small weights at the end of the beam. The bending module is shown in Figure 1.

The module has been designed to allow small teams of students to interact with the system in a very hands-on way. Students bend each different material by hand and observe how strain changes real-time. Strain measurements may be recorded using LabVIEW or other data acquisition tools and analyzed.

The technical objectives are achieved as follows:

*Experimentally, determine stress in a part by measuring strain (understand relationship between stress and strain in linear elastic materials):* A laboratory handout was developed to allow students to calculate the bending stress in the beams based on an applied load (most of the students have not yet completed strength of materials course). Students put various loads on the beam (50g, 100g, 200g, 500g) and record the corresponding strain values. They calculate stress based on beam bending theory (σ=Mc/I) and compare that with the experimentally determined value from the strain measurements (σ=Eε).

*Be able to calibrate a load cell and use the load cell to measure force:* Using the strain data collected for various loads on the beam, the students create a calibration curve (appropriate for calibration, plotting the weight as a function of strain) and then determine the calibration factor for each beam (they use linear regression to determine the slope of the weight-strain curve). They then hang a new weight on the beam (such as 300g), and multiply the corresponding strain reading by the calibration factor. The result should correspond to the applied load; thus demonstrating to the students the principles of calibrated load cells.

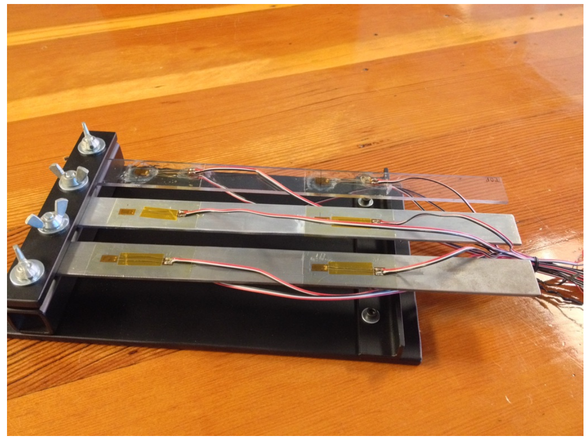


**Figure 1.** Bending module fixture. Three materials for students to test are shown with strain gauges mounted on the upper surface.

**Module Development – Quadcopter**

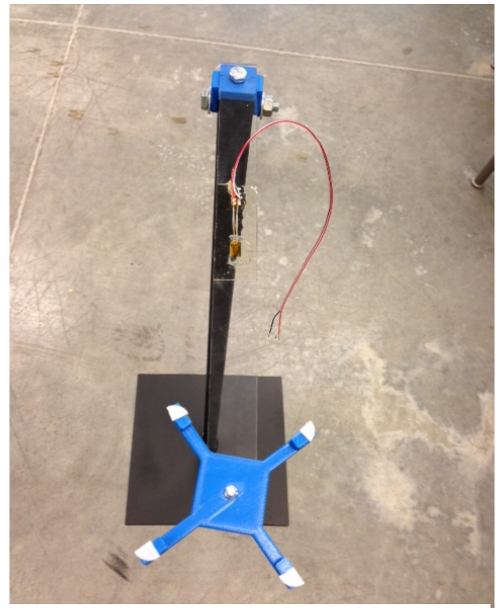
The quadcopter module is a new experimental module that has been developed to improve the interactivity of education about load cell calibration, lift, and the relationships between acceleration and velocity as well as MATLAB and LabVIEW coding. This multi-laboratory module is meant to enhance students' cognition with repeated exposure to the same laboratory system through the curriculum.

The quadcopter mount uses Velcro® tabs to hold the quadcopter in place, and is located high off the ground so ground effect does not affect the flow patterns or lift created by the rotors. The quadcopter stand is shown in Figure 2.

*Understand the role of calibration in measurement*: The quadcopter module is used in the materials laboratory to develop deeper understanding of calibration and measurement. This module was developed to help students appreciate the importance of calibration in developing confidence in measured values. After calibrating the beam in the bending module and using it to measure a load of *known* weight, students use the quadcopter module to measure *unknown* force: the lift produced by a quadcopter. Students are given a calibration factor for this load cell and confirm it by measuring the strain produced by known weights. They then attach a quadcopter to the stand and determine its weight based on the strain reading. They "power on" the copter and measure the lifting force. Due to the dynamic nature of the quadcopter lifting force, the quadcopter oscillates slightly. This requires students to wait, allowing the oscillation to diminish.

The two modules (bending and quadcopter) were also designed to achieve the developmental objectives. These will be discussed next.

*Negotiate and resolve conflict independently within the group:* During this laboratory, students are provided handouts and basic direction from the instructor in order to achieve the technical objectives. However, the information provided is minimal, thus the students must work as a team in order to determine how to achieve all objectives fully. The instructor is available to answer questions and to provide guidance when asked, but ultimately, the students must work together in order to succeed.



*Ability to communicate experimental data graphically and use graphical data*: The authors believe that the calibration process the students use in the bending module provides a unique experience in that it requires students to both create a graph based on data they collect as well as use that graph in an engineering context. "Adequacy" of the calibration graph is not arbitrarily judged by an instructor, but rather in a very meaningful way by the students themselves. If the weight measurement they obtain from the load cell does not agree with the "known" weight of the object, they know immediately that there is something wrong with the calibration curve and/or their interpretation of it.

Table 1. Summary of components and costs associated with the bending module. Existing strain indicators in the laboratory were also used, about $2,000 each but common in materials laboratories.

| Component | Part Number/Serial Number | Cost per Module |
|---|---|---|
| Steel Base – Large Rectangular Tubes | 6527K364 | $15.94 |
| Steel Base – Medium Rectangular Tube | 6582K43 | $7.94 |
| Steel Base – Small Rectangular Tube | 6582K22 | $8.83 |
| Steel Base – Steel Bar | 8910K383 | $2.75 |
| Aluminum Bar | 9872T57 | $12.70 |
| 350Ω Strain Gage | SGD-5/350-LY13 | $7.50 |
| 3 X 350Ω precision resistors | 71-PTF56350R00BZEK | $2.92 |
| 2 X 10kΩ resistors | | |
| 2 X 1MΩ resistors | | |
| 0.1 µF Conductor | | |
| LM 324 Op amp | 595-LM324AN | $0.39 |
| | | |
| **Total** | | **$59.97** |

## Student Observation Assessment

As the first module implemented, the bending experiment was assessed in several ways. A faculty member trained in educational assessment attended the laboratory and posed several questions to the students during the experiment, including asking about the level of control they might notice over the experimental outcomes. Photos illustrating the engagement are shown in Figure 3.

The trained observer posed several questions to each of the six student teams of three to four students. Student responses are summarized below focused on "What do you feel you are getting from these particular lab experiences?"

- Group 1—"we are fumbling through these calibrators and have to do the thing multiple times if we want to get an accurate measure. That's probably what it's like in real life when you start something new."
- Group 2—"you have a lot of senses beyond just reading and listening and this is helping us process a lot more memories, even if it is frustrating."
- Group 3—"I'd never know how to use a caliper from reading about it. Hands-on is waaaaay better than just looking at a procedure, even if we have to keep trying to get it right."
- Group 4—"we were told how to use these tools and we saw a video and even though those were clear, I can't really say I understood it. Hands-on really helps us **understand** [emphasis is students] how something works, instead of just observe it. We're figuring a lot of these instruments out through plugging and chugging. That's trial and error to you."
- Group 5—"echoed other groups' appreciation of the value of hands-on (really getting something, not just memorizing). Plus noted that this lab **forces** [their emphasis] them to learn better communication and cooperation, We have to learn how to divide up tasks fairly, and to communicate our calculations clearly."
- Group 6—ditto the above, plus one member noted "I went into Engineering to have these hands-on experiences, to be more engaged, and this is definitely more engaging. It's more like how we learn. I'm going to retain this way better."
- A student questioned in line waiting for next set of materials offered "this is so helpful for me to actually SEE how the values change during the calibration. You can read calculated values, but it's a lot more valuable to figure it out on your own.

The trained observer also spoke with an instructor that is not on the research team who has worked on labs before about what she observes about the new experiments (not just demonstrations). She noted that "working in small groups mostly spurs them on to help each other out. There's a lot of trial and error. It usually takes more than one trial, and that could be frustrating. But mostly they treat that as a challenge to be solved and they stick with it." She also noted that "These labs are a combination of demonstration and actual experimenting. They really have to learn how to use these tools and figure out the calibration. That's not open-ended, like in an experiment, but it does take a lot of trial and error and I think it will help them stick to problems they deal with in real jobs out there."

**Figure 3.** Students engaged in testing strain on different weights and beams.

The trained observer also made several notes about the activities of students during the module.

**Student Engagement**

- Not a single cell phone was out unless it was engaged in a calculation.
- Sound level was at a productive murmur level, meaning that each member of the 3-4 person teams could hear one another by using an "18-inch voice." Although perhaps 12 people were talking at any given time, the sound was not out of hand and each person could be heard as needed.
- Groups divided tasks evenly, apparently. Evidence: each person I observed in the hour was engaged in a task, from physically handling the materials to conducting calculations and looking up values/definitions needed on handouts from instructor.

**Learning Environment**

- Instructors provided at most 10 minutes of direct instruction before lab activities commenced. Then both moved freely around room, answering questions and re-directing as needed.
- "Answers" were more in the form of questions that prodded students to draw from previously learned material to answer own question or providing enough scaffolding/re-framing of the question so that student came to reasonable conclusion.
- Most groups took at least three trials to correctly complete the calibration process.
- A rarity in group work—although it was possible to identify at least three students who functioned as project managers, no one appeared to be excluding their peers from decision making. Divisions of labor really did appear to be equitable in terms of time needed, and value added to overall objective.

## Survey Assessment

To assess how student's perceived the experimental module outcomes a survey was administered to students in the Spring of 2016 at the end of the semester. Forty-two students completed the survey in several sections with a total of 81 students, representing a 52% response rate. The survey asked the students to rank how they perceived each laboratory module in the course. To allow comparison, students were asked to evaluate all the laboratory modules in the course, although only one of the modules was tied to this research project.

An example question from the survey is shown below. An asterisk has been added to experiments that were designed to be open ended as part of this project.

*1. Rank the following laboratory experiments based on how much control you had over the laboratory experiment success (how open-ended was the lab)?*

| Laboratory Module | How much control did you have over the laboratory experiment success? Circle one. | | | | |
|---|---|---|---|---|---|
| | Very little control | | | | A great deal of control |
| Strain gage, force calibration* | 1 | 2 | 3 | 4 | 5 |
| Tensile test | 1 | 2 | 3 | 4 | 5 |
| Cold rolling copper | 1 | 2 | 3 | 4 | 5 |
| Precipitation heat treating of alum alloy | 1 | 2 | 3 | 4 | 5 |
| Hardenability of steel (Jominy test) | 1 | 2 | 3 | 4 | 5 |
| Microscopy | 1 | 2 | 3 | 4 | 5 |
| Ductile-to-Brittle Transition (Charpy Impact) | 1 | 2 | 3 | 4 | 5 |
| Independent Lab (such as corrosion, weathering, or creep) | 1 | 2 | 3 | 4 | 5 |

The results from this question are shown in Figure 4. Students reported feeling a great deal of control over the modified strain gauge lab. The average Likert score for all the laboratory modules was 3.65 with a strong distribution of a great deal for the strain gauge module, much more than most of the other experiments in the lab course.

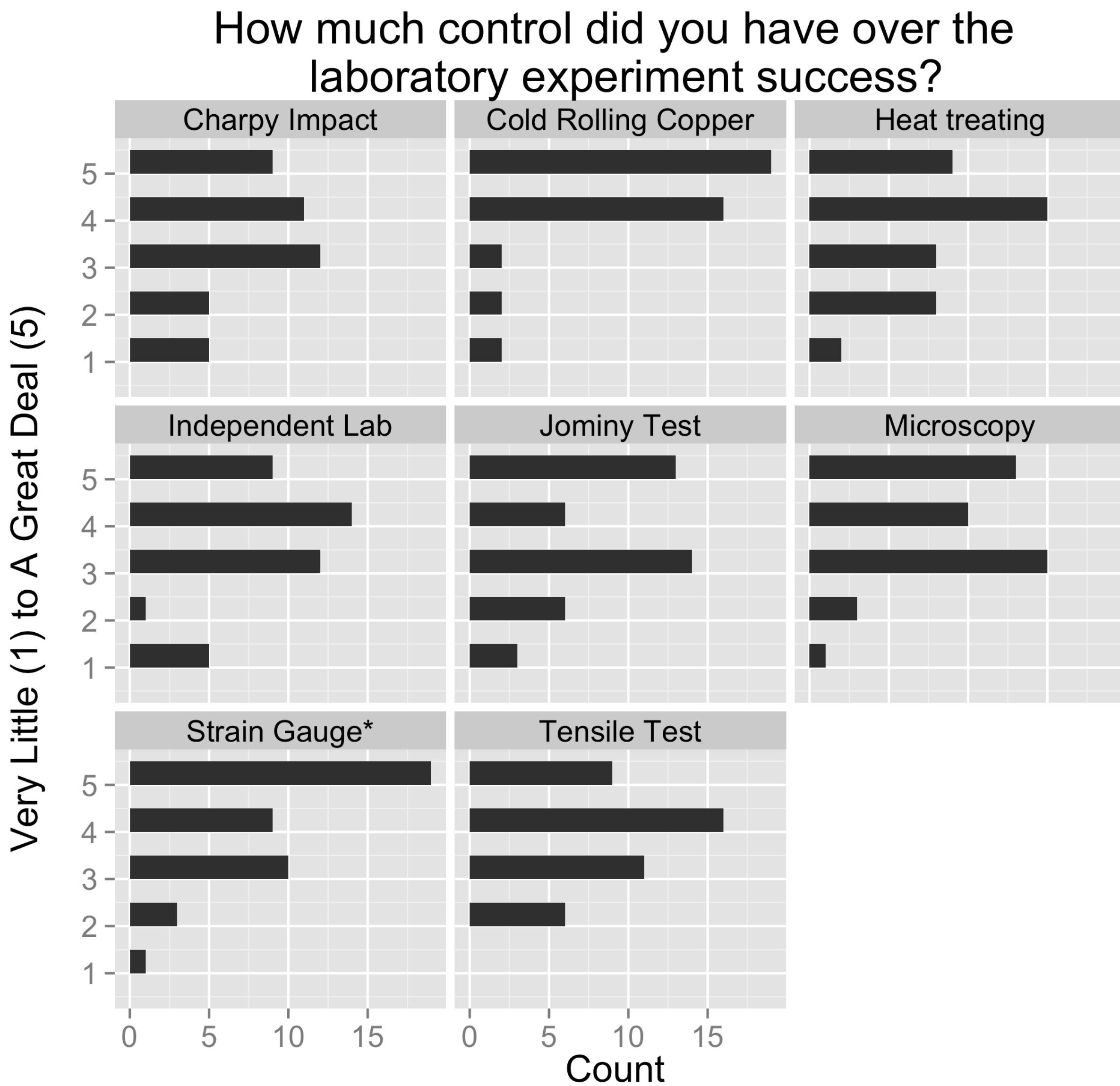



**Figure 4.** The student responses to the question, "How much control did you have over the laboratory experiment success?" separated based on laboratory module. The strain gauge module was modified as part of the project.

The students were also asked how invested they felt in each laboratory module. The overall average was 3.80, indicating the students felt invested in the lab modules in general. A summary of the responses by module is shown in Figure 5.

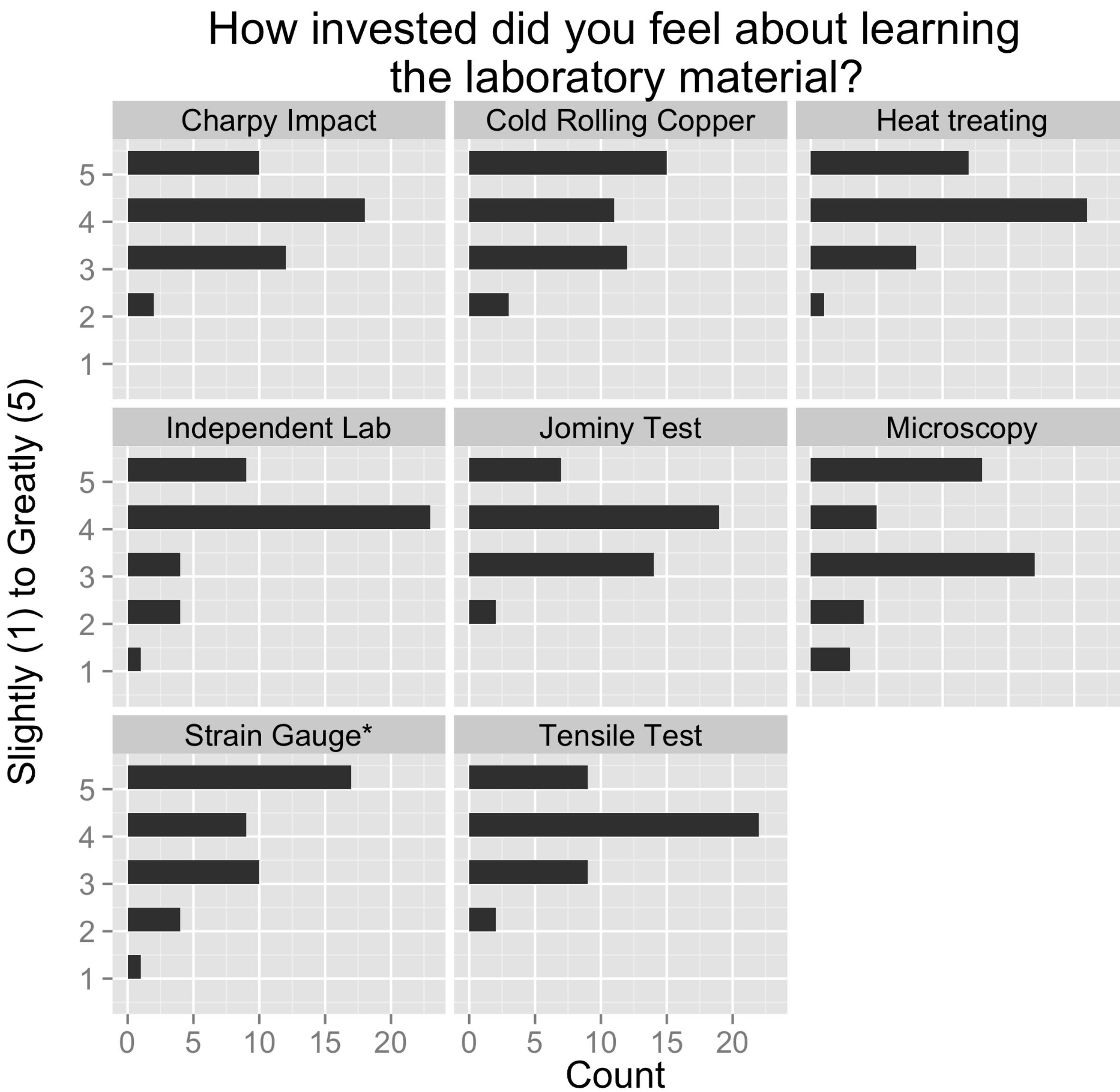



**Figure 5.** The student responses to the question, "How invested did you feel about learning the laboratory material?" separated based on laboratory module. The strain gauge module was modified as part of the project.

The students were then asked how competent they felt on each of the laboratory objectives that had been targeted by the design. Students reported strong confidence levels on all the learning objectives as shown by Figure 6, with most reporting 4 or 5 on the Likert scale for an average of 4.26. Students also overwhelmingly (89%) indicated their competence had increased as part of the laboratory class.

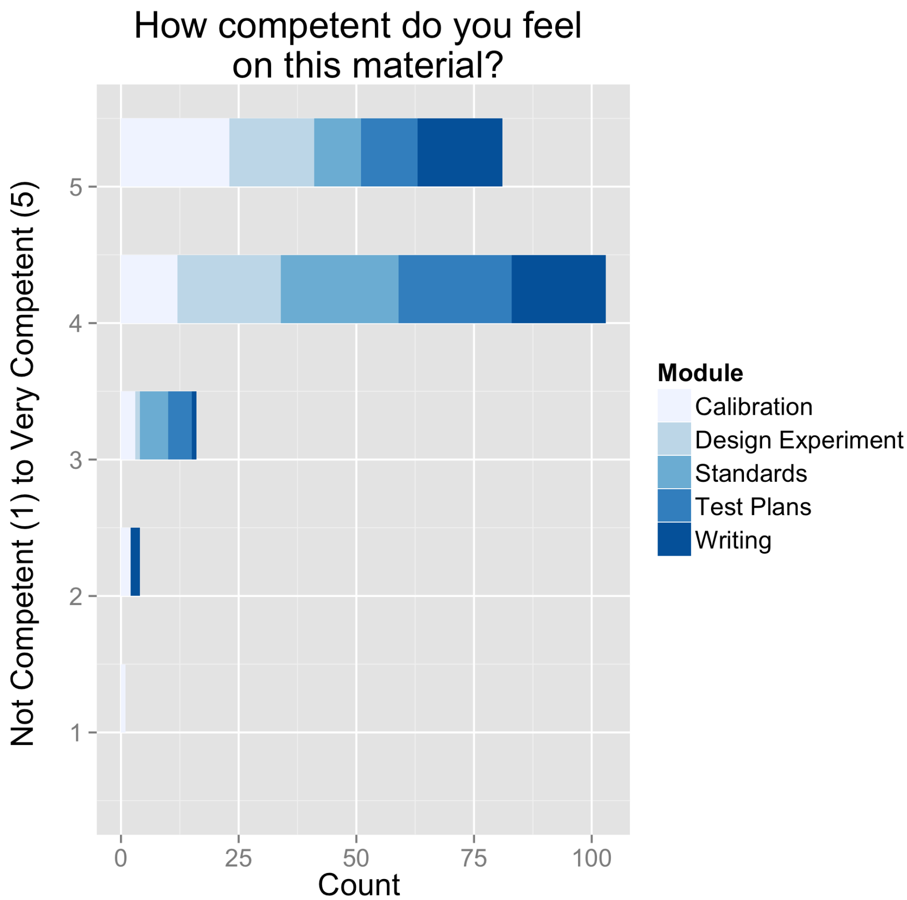



**Figure 6.** The student responses to the question, "How competent do you feel on this material?" separated based on the different learning objectives targeted by the project.

## Conclusions

An inexpensive set of laboratory modules have been created to enhance engineering student engagement through the full mechanical engineering curriculum. A set of strain-gage modules were developed and the modules were tested in a classroom setting.

Students reported they found the bending module engaging and appreciated the challenge of the calibration activity. The students self-reported high levels of competence with the learning objectives developed by the research team using backward design.

Future work will bring additional laboratory modules into laboratory and traditional courses. A full assessment of the first group of students to pass through the sequence of courses is planned to better understand if the consistency in the equipment benefits students. In future terms student self-assessment on learning objectives may be compared to performance on quiz material.

## Acknowledgements

Thanks to the W.M. Keck Foundation for funding this study. Thanks to the many undergraduate students who made this project and paper possible. Special thanks to Jared Rees and Jacob Amos for construction and technical support on this project. Will Delaney also made significant contributions to enhance the modules.

The survey methods described in this paper were reviewed and approved as exempt by the University of Portland IRB committee.

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