Consistency in Instruction and Assessment of Student Engineering Laboratories

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Abstract

Consistency in instruction and grade assessment is an important area of focus in higher education due to the high volume of students that take the same course with varying instructors. Eliminating the discrepancies between grades and course objectives is crucial to a healthy learning environment and improving student satisfaction with the university's curriculum. [regional university]'s Mechanical Engineering department requires undergraduate students to take a junior level laboratory/lecture course, Experimental Measurement and Techniques (EMT). The purpose of this course is to familiarize students with uncertainty, sensors, and hands on use of various types of lab equipment. The lab portion of the class contains a six-week rotation where students participate in experiments that utilize thermal, pressure, electrical, and light sensors to gather data and perform post-lab analysis. To standardize the instruction of the lab attendant, standard operating procedures (SOP's) were created to ensure that the methodology and results were consistent between semesters and instructors. The SOP's contain instructional notes and results to better familiarize new instructors with the labs and procedures so that students are getting the most consistent lab instruction possible compared to their previous peers. To see how the assessments varied, data was taken from two different instructors over four semesters that utilized the same six-week rotation. The first instructor did not have the SOP's developed while the second instructor performed the rotation with and without the SOP's. All three of the second instructor's semesters were impacted by COVID-19. The various changes and responses to the pandemic led to some interesting statistics on student performance.

Keywords

Consistency, Instruction, Standard Operating Procedure

Introduction

Consistency in education is a topic that is often overlooked as an important parameter for educational improvement. Universities with large enrollments often have various instructors teaching the same course at the same time to handle the student load. Due to instructor/teaching assistant (TA) turnover year to year, lack of consistency in the instruction of a course between semesters is a point of concern. Devasagayam, a researcher at Siena College, states that "an issue that deems special attention in assurance of learning outcomes is related to consistency across courses, and more specifically, across multiple sections of the same course taught by different professors"[1]. The Accreditation Board for Engineering and Technology (ABET) lists curriculum as one of the most important factors in education. Their objective states that a consistent curriculum with continuous improvement is of utmost importance[2]. Hicks and Diefes-Dux, engineering professors at Purdue, published research on grading consistency which states that

"Differences in instructors' grading practices can have a considerable effect on student success"[3]. There is a clear connection amongst researchers that the grading consistency is an extremely important topic.

Laboratory courses add the additional factor of maintaining consistency in equipment proficiency among instructors and students. To maintain a consistent curriculum, tools like Standard Operating Procedures (SOPs) can be implemented to provide a rubric for instructors and students to follow for equipment and procedures in the laboratory. SOPs allow instructors the freedom to educate in their own style while ensuring educational objectives are met consistently semester-to-semester. The SOPs given to students set a clear objective and methodology which is important in the development of student knowledge. D. Royce Sadler emphasizes the importance of task criteria and feedback when it comes to their ability to learn new material[4]. Wiggins and McTighe's "backwards design" method is widely used to improve educational methods[5]. The instructors, as a collective, began by defining goals and objectives, then created the assessments, designed the learning experience (events, activities, etc.); and then gathered student feedback. The new course design and administrative method was introduced into their A&P course at the University of Connecticut which contained over 1000 students per semester with 60 laboratory sections and 30 TAs. The new laboratories and examinations were designed to be objective oriented with clear rubrics for instructors and students. All the laboratories had an identical setup and SOP template for lab fluidity. If there were any student inconsistencies or issues in the course, exams included, the inconsistencies were found and addressed. The study showed that at the end of the semester, the scores between different sections nearly matched each other in percentages. Large engineering courses provide a difficult challenge. Enszer and Buckley installed new rubrics into their engineering course and implemented "spot-checking" where they periodically evaluated the TAs to keep up standards throughout the semester[6]. This course contained roughly 700 students and 30 TAs. Statistics on two different semesters. Enszer found that the deviation in grading outliers was greatly reduced with the use of their rubric changes and algorithm into their introduction course. Their conclusion that a grading "algorithm" greatly increases consistency across instructors.

A laboratory course at [regional university] was used as the test course for implementing SOPs. Experimental Measurements and Techniques (EMT) contains a six-week rotation of lab procedures and post lab assignments. The labs cover a wide variety of topics: industrial sensors, strain of materials, strain loading orientations, digital temperature sensors, analog temperature gauges, and pressure calibration. SOPs for laboratories should include all the students steps as well as notes for the instructor to mention in the lab to help students understand the importance of the equipment and the purpose of the lab. The SOP also contains the post-lab questions and point breakdown so that students have a clear understanding of what is expected of them. To improve the fluidity and student experience, constant changes based on student feedback and results are done to ensure that the pre-defined course objectives are being met. This does not mean that changes are made to make coursework easier or harder. However, it is important that students are getting consistent, quality instruction across teachers and semesters.

Methods

In Summer 2021, SOPs were created for the equipment and procedures in the junior-level course, Experimental Measurements and Techniques (EMT). The SOPs contain information such as lab manager contact information, purpose of the SOP, the experiment description, safety literature, storage requirements, and emergency procedures. This information was not provided in the initial lab procedure handouts. Providing this information in conjunction with the lab procedures ensures that instructors/teaching assistants have all relevant information for the equipment and procedure in the same location. The benefit of this type of setup is discussed in Chen's instructional curriculum revision at the University of Connecticut based on Wiggins and McTighe's "backwards design."[5] The analysis concluded that identical SOP templates creates a fluidity between labs.

Two versions of the SOPs were created: an instructor and student version. The student version includes the procedure and post-lab assignment questions. One of the three main components to consistent internal structure of a course is alignment according to Carnegie Mellon University[7]. In this sense, alignment is when the objectives articulate the knowledge and skills instructors want students to learn by the end of the course. When scaled down to an individual assignment level, this means that it is imperative that students understand what it is the assignment is trying to get them to understand prior to receiving a grade on it. In the student version of the SOPs, objectives for the procedure and post-lab assignment were clearly outlined. For the student version of the SOP, the step-by-step procedure went relatively unchanged from the original lab handout with slight format changes. Some of the steps were condensed to make the procedure slightly less bloated.

The instructor version includes some important additions in the form of "Instructor Notes." This includes information about each lab procedure's specific requirements or unusual procedure issues that may arise. This also allows for TAs to have specific instructions to students that can benefit their understanding of the lab. For instance, the strain loading lab contains three different loading arrangements: tension, bending, and torsion. Students taking EMT have either already had mechanics of materials or are in the process of taking it. There has been a consistent lack of understanding of calculating stress using mechanics of materials methods as well as how the strain gauge is working internally. To improve student understanding, the instructor SOP contains some notes to inform students how the strain gauge accounts for bending or torsion. The theory behind how the strain gauge arrangement processes the results is also provided. The temperature analog lab contains another good example of how instructor notes can benefit the TA. The NTC temperature sensor is wildly inaccurate in certain data ranges due to the nature of the device. The instructor notes give the TA the reason behind this and allows them to hint to the students what is occurring and encourages them to develop their own understanding of the phenomena and to research it further during their post-lab analysis. If a TA had never performed the lab as an undergraduate at [regional university], they would have never understood the reasoning without performing the experiment themselves and completing the post-lab assignment. These notes are intended to make it much easier to understand the lab while grading so new TAs don't

have to spend as much time reviewing old, graded work. This could lead to a large issue if old work was lost, or the university switched grading systems.

The last large addition to the SOPs were the post-lab results and point breakdown for the instructor version. This was to give the TA proper background on what student results should look like prior to leaving lab. Before the introduction of the SOP, the TA had no experimental data averages to see what the data should look like. If there was an instrument error, there was no way of knowing until the students turned in their post-lab. To fix this, the instructor version contains the tables of data that the student values should generally fall under. The strain-loading lab has a good example of how a TA might not be prepared to catch a small detail that throws off analysis significantly. Due to all the lab equipment being German-made, the given modulus of elasticity is written with the European formatting of numbers where a comma and period are switched. Students were getting the magnitudes of stress and strain significantly wrong. The old procedure and grading examples contained no information or mention of this being a potential issue. After this small issue was found during the SOP semester, this is now included as an instructor note in all SOPs for the lab.

The first step in evaluating the effectiveness of the SOPs was to compare grades from the same procedures across semesters with no SOPs and a semester with. The authors expected to see higher grades from the SOP semester learning objectives and expectations were clearly laid out for the students in a consistent manner. Four semesters worth of grades were analyzed. The first semester analyzed was the Spring of 2020 under “TA 1.” The entirety of that six-week lab rotation was done in person, prior to the COVID-19 pandemic. The lab schedule was different as mentioned earlier which allowed students to spend longer period with the equipment and not rush through any procedures. “TA 2” was the responsible lab assistant for three semesters. Semesters 1 (Fall 2020) and 2 (Spring 2021) were under the original lab handouts, and Semester 3 (Fall 2021) utilized the SOPs. It should be noted that Semester 1 was the first semester back on campus after the onset of the COVID-19 pandemic. The grades averages for each of the six procedures were compared across the four semesters to evaluate consistency in student comprehension.

Results and Discussion

The averages for each semester are shown below in Table 1. The grades for all six procedures from every group were averaged together to get one value for the entire semester.

Table 1: Average Grades Over Four Semesters

	Average Performance	Number of Students
TA 1	93.42%	96
TA 2 - Sem. 1	94.21%	93
TA 2 – Sem. 2	91.32%	96
TA 3 – Sem. 3 (SOPs)	88.97%	102

The expected average for these assignments is between 85% and 95% due to the nature of the laboratory. All of the averages fall in this range, but the trend of the data does not align with the

hypothesis of the authors. In fact, the downward trend in grades across Semesters 2-4 was slightly concerning. The averages for each of the six procedures from each semester are shown in Figure 1.

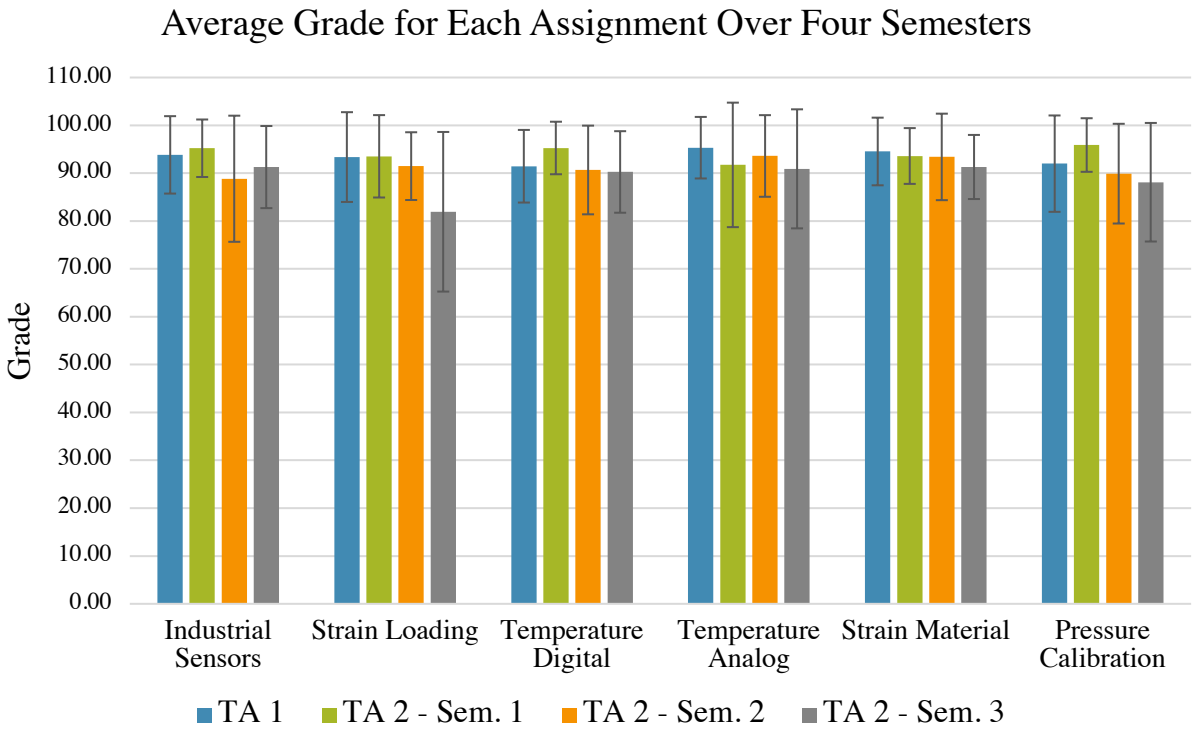

Figure 1: Average Grade for Each Assignment Over Four Semesters

For TA 2, a downward trend in grades was seen for four of the six assignments. Additionally, all but one assignments were lower between the first and second semester for TA 2.

The strain loading post-lab grades show an interesting trend as grades are consistently decreasing with a significant drop off at the last semester as seen in Figure 1. This lab requires students' knowledge of circuits as well as mechanics of material and can lead to an increase in questions compared to the other labs. This lab largely sees issues during the mechanics of materials portion of calculations in the post-lab as well as the professionalism of the submission when it comes to showing the results. This is a trend that is seen consistently in the submissions of students as the COVID-19 pandemic semesters have gone on.

To see if there were any significant outliers within the strain loading assignment, Chauvenet's criterion was performed to see if significant improvements in the grade would occur[8]. The average after Chauvenet's criterion was 84.364 as opposed to an 81.94. This only eliminated one group's submission. There is still a high standard deviation in this lab for the fourth semester. To improve this, the SOP can be altered to include more information on the mechanics of materials equations and their relevance in comparison with the unbalance method as well as professionalism of showing results. Students most significant issues were not including their work or showing proper plots. A fundamental misunderstanding of the equations is still there, however, so the lecture portion pertaining to this topic could also be addressed.

This data is especially revealing in showing that the transition between TAs during the COVID-19 semester resulted in significantly higher averages relative to the overall grade distribution. At the time, the uncertainty of grading and lack of interaction in classes could have led to less confidence in grade deductions. The students during the Fall 2020 semester most likely benefitted from fully in person pre-requisite classes as opposed to the students in the Spring 2020 and Fall 2021 classes.

Overall, no clear conclusions could be made about the effectiveness of the SOPs in improving student comprehension and performance on the post-lab assignments. However, the effects of the COVID-19 pandemic add an additional variable to the performance of students, and based on these results, they seem to contribute significantly.

Conclusion and Future Work

The need for standardizing and creating consistent course curriculum in laboratories is well documented in other studies[1,6]. Standard Operating Procedures (SOPs) were developed for a laboratory course (Experimental Measurements and Techniques, EMT) in the mechanical engineering department at [regional university] in order to help with instructor/teaching assistant proficiency and student success. The results of the lab rotation grades in EMT did not show the positive trend in grade averages as desired when implementing the SOPs. The trend shows a decline in the overall grades across multiple semesters, even without SOPs; however, this decline is believed to be due to ulterior factors out of the control of the EMT course instructor. COVID-19 is believed to be a large issue in the pre-requisite professionalism and knowledge that students are supposed to have by the time they are junior-level mechanical engineers. There is a clear decline in the standard since the grades of the course have gone down while implementing better tools and giving more resources to aid the students than they had previously. This was shown by a continued decrease in grades even with the implemented SOPs. More study needs to be done on the use of the SOPs while also adjusting and adding more information to improve the lab experience and give students the proper education they need to succeed post-graduation. Future work is two-fold. First, an evaluation of assignment averages each semester will continue to see how the averages change as we move farther from the peak of the COVID-19 pandemic. Second, a new TA for EMT will start in Spring 2022. The effectiveness of the SOPs in helping new TAs learn how to effectively instruct students through the procedures can be assessed at this time. Additionally, assessment of instructor/TA ability through help of the SOPs will take place for two other laboratory courses in the department. Additionally, the results of this work show the potential to track student performance in the semesters following the peak of the COVID-19 pandemic. The decline in scores must be corrected to ensure the proficiency of engineering graduates.

References

1. Devasagayam PR, Mahaffey TR. Effecting Consistency Across Curriculum: A Case Study. *Contemporary Issues in Education Research (CIER)*. 2011;1(1). doi:10.19030/cier.v1i1.1207
2. Criteria for Accrediting Engineering Programs, 2019 – 2020. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/#GC3
3. Hicks N, Diefes-Dux H. Grader Consistency in using Standards-based Rubrics. In: *2017 ASEE Annual Conference & Exposition Proceedings*. ASEE Conferences. doi:10.18260/1-2--28416
4. Sadler DR. *Formative Assessment and the Design of Instructional Systems*. Vol 18.; 1989.
5. Wiggins G, Mctighe J. *Understanding by Design Chapter 1. What Is Backward Design?*
6. Enszer J, Buckley J. Algorithm for Consistent Grading in an Introduction to Engineering Course. In: *2020 ASEE Virtual Annual Conference Content Access Proceedings*. ASEE Conferences. doi:10.18260/1-2--34100
7. Eberly Center CMU. Learning Objectives.
8. Lin L. *Cleaning Data the Chauvenet Way*.

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Alta Knizley has been part of mechanical engineering faculty at MSU since 2012. Her research areas of interest include energy sustainability and engineering education. Special interests include K-12 STEM outreach and minority and female leadership and recruitment in mechanical engineering. Currently, she works as an Assistant Clinical Professor and teaches courses within the thermal/fluids and analysis areas of the mechanical engineering curriculum at Mississippi State. Alta serves as the Teaching Director, and in this role she oversees ABET assessment, instructional consistency, and overall teaching management needs for the department.