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Investigating Engineering Laboratory Course Assignments and Assessments across Four Institutions and a Case Study on Their Impact on Students' Lab Report Writing

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Abstract

This paper aims to investigate how engineering lab courses intervene with students in terms of written course materials. The instruments used for the study include Feisel and Rosa's philosophical-based lab learning objectives and engineering lab report writing outcomes (1 through 9). The participating lab courses include seven engineering lab courses across four institutions. The laboratory courses cover the majority of Feisel and Rosa's learning objectives for lab assignments. The most typical assignment method is to provide lab report guidelines in individual lab assignments or for the entire lab course; however, some labs offer templates with blanks, so students simply fill those in for lab reports. We mapped lab assignments and assessments with the engineering lab report writing outcomes. Most labs focus on audience expectations, experimentation processes, high-quality tables/graphs, lab data analysis, and organization. After surveying all the lab courses, we conducted a case study to investigate how lab instructors' lab report assignments affect students' lab report quality in the two lab courses (EE 221 with n = 12 and CE 212 with n = 12), showing distinct characteristics in their lab assignment and assessment. EE 221 did not provide the instructor's expectations or any guidelines but required fill-in-the-blanks-type lab reports. In the EE 221 student samples, none of the outcomes reach a satisfactory level. In contrast, CE 212 provided the instructor's expectations for the labs and lab reports explicitly through handouts and guidelines. CE 212 student samples show that most outcomes reach the satisfactory level. It is concluded that engineering lab courses offered a variety of materials with a wide range of lab objectives and outcomes. Those materials could impact the students' lab report writing extensively.

1. Introduction

Most engineering programs include laboratory courses in their curricula to offer hands-on experience with disciplinary concepts and methods used in engineering practices. Most engineering laboratory instructors assign lab reports to prepare engineering undergraduates to be effective communicators with a range of audiences [1-3]. Lab reports also provide students to review the necessary technical information and present their lab data while also giving them career-specific equipment and practical laboratory skills [4]. Despite the importance of labs and lab report writing in engineering programs, the expectations, instructions, and preparations provided to students vary wildly [1]. There are some studies about how lab reports are assigned to engineering students. Gravé [5] assigned the different formats and requirements of report writing in a sequence of four scientific/technical labs (Physics 1, Physics 2, Circuit Analysis, and Control Systems Labs). For example, a "notebook" report helping engineering students establish their lab report writing routines and a 2-page "formal" report focusing on the lab process and the results were assigned in Physics 1 and 2 courses. Then, a 4-page formal report, requiring technical background to experimental result analysis, was assigned in the Circuit Analysis course; however, the report's requirements were relaxed to provide autonomy to the students in the Control Systems course, the last course in the sequence. Rhudy [6] assigned short writing in the five dynamic systems lab projects, and the lab report assignments included a one-page report, abstract with 150-300 words, technical email, and graphical abstract. Walk [7] applied low-stakes writing assignments consisting of abstract writing, one-sentence summaries, headlines, directed paraphrasing, definitions, application cards, editorials, online discussion groups, letter writing, personal response exercise, journals, poems, and memory matrix, in the EET365W lab course. The student cumulative average assignment scores were improved through the low-stakes assignments in a Learning through Writing context. There have also been multiple collaborative efforts between writing programs and engineering programs to standardize engineering lab report instructions [8-10].

Despite a few published works examining the writing education of engineering labs, it is not well understood how lab reports are assigned and assessed in engineering undergraduate programs. This paper aims to investigate assignment and assessment materials given to engineering students in lab courses across four institutions. We focus on which instructional materials were provided for a lab report assignment, how those materials aligned with the corresponding assignment, and what differences exist among lab courses. The instructional materials include rubrics, objectives, lab report guidelines, and assignment-specific information. Instructional materials were collected from the participating lab instructors from mechanical, civil, electrical, and general engineering courses. In doing these comparisons, this paper aims to highlight the probable issues of certain instructional strategies and provide suggestions for improvement. We added a case study to compare two distinct lab courses in terms of assignment and assessment methods. This will provide helpful insight into effective instructional strategies to improve students' lab report writing.

2. Methods of Approach

2.1 Participating Engineering Lab Courses

The participating lab courses include seven engineering lab courses across four institutions consisting of a 2-year community college (Clark College in WA), a public polytechnic institution (Oregon Institute of Technology in OR), a branch campus of a public R1 institution (Washington State University Vancouver in WA), and an independently governed Catholic institution (the University of Portland in OR). We included courses from three engineering disciplines (civil, electrical, and mechanical) with one general engineering curriculum. All courses are 2nd year engineering labs, except MECH 309, which is offered in the 3rd year. CE 376 is offered in the 2nd year.

Table 1 provides information regarding the major of the courses being analyzed, along with the name of the course, the institution, the term and year in which it was offered, and the number of laboratories that were present throughout each course. As shown in Table 1, samples of multiple years were collected in ECE 214, EGR 270, and MECH 309.

Table 1. Participating engineering laboratory courses in the study

Major	Course	Topic	Institution, Semester/Quarter	Term	Year	Number of Labs
General Engineering	ENGR 240	Numerical computing	2-year community college, Quarter (Clark College)	Spring	2021	9
Civil Engineering	CE 212	Civil engineering materials	4-year public polytechnic college, Quarter (Oregon Institute of Technology)	Fall	2019	7
	CE 376	Environmental engineering	4-year private college, Semester (University of Portland)	Spring	2021	4
Electrical Engineering	EE 221	Circuits	4-year public polytechnic college, Quarter (Oregon Institute of Technology)	Fall	2019	8
				Fall	2020	8
	ECE 214	Logic Circuits	4-year public college, Semester (Washington State University Vancouver)	Fall	2019	11
				Fall	2020	10
				Fall	2021	10
Mechanical Engineering	EGR 270	Materials	4-year private college, Semester (University of Portland)	Spring	2020	6
				Spring	2021	7
	MECH 309	Engineering materials	4-year public college, Semester (Washington State University Vancouver)	Fall	2019	6
				Fall	2020	9
				Fall	2021	9

2.2 Sample Collection and Evaluation

Samples from the instructors in the seven lab courses were collected after having their consent, which was approved by each institution's internal review board (IRB). The samples included any materials given to the students in those courses related to the labs; therefore, we collected course syllabi, lab manuals, lab handouts, and/or lab report writing guidelines.

We also collected student lab report samples from the participating lab courses. The students, who signed the consent to participate in this research project, submitted two lab report samples, one in an early lab and one in a late lab. Four engineering professors had extensive norming sessions using the rubric based on nine lab report writing outcomes in Table 3 before evaluating student lab report samples. The rubric with three levels (need improvement, satisfactory, exemplary) is in the Appendix. One lab report sample was evaluated by two raters. When the average ratings of the two raters disagreed by more than 1 point, a negotiation session was conducted between the two raters.

3. Research Instruments

3.1 Lab's learning objectives

Learning objectives are the cornerstone when designing an efficient learning system in class. Feisel and Rosa introduced thirteen learning objectives within an educational laboratory in the engineering field [1], as shown in Table 2.

Table 2. Philosophical Basis of Learning Objectives Within an Educational Laboratory [1]

Philosophical basis	Learning Objective within an Educational Laboratory
Objective 1: Instrumentation	Apply appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities
Objective 2: Models	Identify the strengths and limitations of theoretical models as predictors of real-world behaviors. This may include evaluating whether a theory adequately describes a physical event and establishing or validating a relationship between measured data and underlying physical principles
Objective 3: Experiment	Devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterize an engineering material, component, or system
Objective 4: Data Analysis	Demonstrate the ability to collect, analyze, and interpret data, and to form and support conclusions. Make order-of-magnitude judgments and use measurement unit systems and conversions
Objective 5: Design	Design, build, or assemble a part, product, or system, including using specific methodologies, equipment, or materials; meeting client requirements; developing system specifications from requirements; and testing and debugging a prototype, system, or process using appropriate tools to satisfy requirements
Objective 6: Learn from Failure	Identify unsuccessful outcomes due to faulty equipment, parts, code, construction, process, or design, and then re-engineer effective solutions
Objective 7: Creativity.	Demonstrate appropriate levels of independent thought, creativity, and capability in real-world problem solving
Objective 8: Psychomotor	Demonstrate competence in the selection, modification, and operation of appropriate engineering tools and resources
Objective 9: Safety	Identify health, safety, and environmental issues related to technological processes and activities, and deal with them responsibly
Objective 10: Communication	Communicate effectively about laboratory work with a specific audience, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports

Objective 11: Teamwork	Work effectively in teams, including individual and joint accountability; assign roles, responsibilities, and tasks; monitor progress; meet deadlines; and integrate individual contributions into a final deliverable
Objective 12: Ethics in the Laboratory	Behave with the highest ethical standards, including reporting information objectively and interacting with integrity
Objective 13: Sensory Awareness	Use the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems

3.2 Lab report writing outcomes

All the participating courses assign lab reports to the students. Instructors use lab reports to evaluate students' performances in the labs. Kim et al. [11] introduced nine lab report writing outcomes based on ABET [12] and WPA [13] outcomes, as shown in Table 3.

Table 3. Lab report writing outcomes [11] (I = introduction; M = methods; R = results; D = discussion; C = conclusion).

Writers in early engineering lab courses can:	**Mostly related to**
1) Address technical audience expectations by providing the purpose, context, and background information, incorporating secondary sources as appropriate.	I
2) Present experimentation processes accurately and concisely.	M
3) Illustrate lab data using the appropriate graphic/table forms.	R
4) Analyze lab data using appropriate methods (statistical, comparative, uncertainty, etc.).	RD
5) Interpret lab data using factual and quantitative evidence (primary and/or secondary sources).	RD
6) Provide an effective conclusion that summarizes the laboratory's purpose, process, and key findings, and makes appropriate recommendations.	C
7) Develop ideas using effective reasoning and productive patterns of organization (cause-effect, compare-contrast, etc.).	IMRDC
8) Demonstrate appropriate genre conventions, including organizational structure and format (i.e., introduction, body, conclusion, appendix, etc.).	IMRDC
9) Establish solid and consistent control of conventions for a technical audience (grammar, tone, mechanics, citation style, etc.).	IMRDC

3. Results and Discussion

3.1 Weight of labs and one lab in course evaluation

The seven participating courses offer labs; however, the labs take a portion of each course when evaluating students' achievement. Table 4 presents information regarding the percentage of the course grade that consisted of completing labs and or writing lab reports, the number of labs present throughout each course, and the individual weight of each lab in %. For example, ENGR

240 is a mix of lectures and labs; their ratio in the student evaluation is 83% and 27%, respectively. There are nine labs in ENGR 240; therefore, each lab takes 3% of the total grade. Out of the seven courses, CE376 and EGR 270 take more than 50% of the total grade from the labs, and the others have around 30%. Individual labs weigh from 3% to 15% of students' lab course grades. Note that EE221 did not have any information about lab evaluation in the course materials.

Table 4. Percentage of the course grade(s) consisting of laboratory experiments

Course	**Weight of labs in the course grading (%)**	**Number of labs**	**Individual lab weight to total course grading (%)**
ENGR 240 (2021)	27%	9	3%
CE 212 (2019)	30%	7	4%
CE 376 (2021)	60%	4	15%
EE 221 (2019, 2020)	Not available	8	Not available
ECE 214 (2019)	33%	11	3%
ECE 214 (2020, 2021)	30%	10	3%
EGR 270 (2020)	75%	6	13%
EGR 270 (2021)	70%	7	10%
MECH 309 (2019)	33%	6	6%
MECH 309 (2020, 2021)	33%	9	4%

3.2 Analysis results of the assignments

3.2.1 Lab's learning objectives in the assignment

Table 5 related the educational lab learning objectives in Table 2 with the expectations provided in the syllabus, laboratory experiment instructions, and/or manuals for each course. Most courses included learning objectives 1, 2, 3, 4, 8, 10, and 12. All the labs in this study are introductory engineering labs offered at the beginning of students' programs of study. Often, they are the students' first engineering lab courses; therefore, instructors want to focus on instrumentation, models, experiment, data analysis, psychomotor, communication, and ethics in these courses. The data also shows that most courses devoted less focus to learning objectives 6, 9, 11, and 13, which are learning from failure, creativity, teamwork, and sensory awareness. The learning objectives in these categories may be related to the evaluation or creation of knowledge, which position in the two highest levels in Bloom's Taxonomy [14]. We also learned that only 50% of the lab courses focus on teamwork. This means many introductory labs require individual work so all students can gain standardized skill sets in experiments or engineering practices.

Table 5. Objectives 1-6 present in the course lab assignments

	Educational Lab Learning Objectives [1]: 1. Instrumentation; 2. Models; 3. Experiment; 4. Data Analysis; 5. Design; 6. Learn from Failure; 7: Creativity; 8. Psychomotor; 9. Safety; 10. Communication; 11. Teamwork; 12. Ethics in the Laboratory; 13. Sensory Awareness												
Course	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
ENGR 240 (2021)				O						O		O	
CE 212 (2019)	O	O	O	O	O	O	O	O	O	O	O	O	O
CE 376 (2021)	O	O	O	O	O		O		O	O	O	O	O
EE 221 (2019, 2020)	O	O	O	O	O	O		O			O		O
ECE 214 (2019, 2020, 2021)	O	O	O	O	O	O	O	O		O		O	
EGR 270 (2020)	O	O	O	O			O	O	O	O	O	O	O
EGR 270 (2021)	O	O	O	O	O	O	O	O	O	O	O	O	O
MECH 309 (2019)	O	O	O	O	O			O	O	O	O	O	O
MECH 309 (2020)	O	O	O	O	O	O		O	O	O		O	
MECH 309 (2021)	O	O	O	O				O	O	O		O	O
% of lab courses covered	92 %	92 %	92 %	100 %	75 %	58 %	50 %	83 %	58 %	92 %	50 %	92 %	58 %

3.2.2 Lab report format/content guidelines in the assignment

Although all the lab courses offer various types of lab activities, they commonly require the students to write lab reports, which are used for student evaluation. All the instructors provided lab assignments in the form of handouts or manuals. They provided guidelines for the desired lab report format and/or contents in the following four styles:

- *Style 1: Given by filling in the blank on an individual lab assignment*. Instructors provided lab handouts as fill-in-the-blank documents for labs, which would provide detailed instructions regarding the expectations of each experiment. Students were asked to submit the lab handouts after filling in the blanks.
- *Style 2: Given by report guideline introduced in individual lab assignments*. Instructors provided lab report writing guidelines in each lab. Often, the guidelines include the genre (e.g., memorandum, email, technical report, etc.) and technical contents, which are preferred in the lab report.
- *Style 3: Given one guideline covering all the labs*. Only one guideline was provided to the students; therefore, one guideline could be applied to all the labs in class. Often the guidelines indicated information about lab report evaluation, desired contents, and formats.
- *Style 4: Not specified explicitly*. There was no lab report writing guideline provided to the students. Lab handouts or manuals only contained information about the lab's technical background and procedures.

The table below provides the frequencies of which type of lab report format/content guidelines are used in the lab course assignments. For example, ENGR 240 provided individual lab writing guidelines for all nine labs or 100% of the labs. CE 212 assigned fill-in-the-blank styles for the first two labs, separate report writing guidelines for the following two labs, and provided a generalized lab report writing guideline for the rest.

Table 6. Format of course lab materials

Course	**Fill-in-the blank**	**Report writing guidelines for individual labs**	**One report writing guidelines for multiple labs**	**Not specified explicitly**
ENGR 240 (2021)	0%	0%	100%	0%
CE 212 (2019)	30%	30%	40%	0%
CE 376 (2021)	0%	50%	50%	0%
EE 221 (2019, 2020)	88%	0%	0%	13%
ECE 214 (2019, 2020, 2021)	0%	50%	50%	0%
EGR 270 (2020)	50%	0%	50%	0%
EGR 270 (2021)	50%	50%	0%	0%
MECH 309 (2019)	0%	25%	75%	0%
MECH 309 (2020)	0%	0%	89%	11%
MECH 309 (2021)	13%	88%	0%	0%

Overall, the data shows that one guideline for all the labs was most used for lab assignments within the data sample. The second most popular way was to provide individual laboratory guidelines, which allowed for the assessment of specific learning outcomes provided for each lab. EE 221 heavily relied on the fill-in-the-blank style, while CE 212 used a mix of three styles.

Two of the seven participating courses changed their lab report writing guidelines yearly. EGR 270 and MECH 309 provided lab report writing guidelines for individual labs in 2021. Before 2021, both courses offered one lab report writing guideline for multiple labs. The instructors of these two courses made an effort to individualize their lab report writing assignments for each lab in 2021.

3.3 Analysis results of the assessment

Table 7 relates the lab report writing outcomes in Table 3 with the expectations provided in the lab assignments, manuals, and/or lab report writing guidelines for each course. The table indicates the outcomes covered in most labs, covered in some labs, and not covered. All the lab courses included Outcome 2 (Present experimentation processes accurately and concisely), Outcome 3 (Illustrate lab data using the appropriate graphic/table forms), Outcome 4 (Analyze lab data using appropriate methods), Outcome 6 (Provide an effective conclusion that summarizes the laboratory's purpose, process, and key findings, and makes appropriate recommendations), and Outcome 8 (Demonstrate appropriate genre conventions, including organizational structure and format) in their evaluation. These five outcomes can be considered fundamental student outcomes in lab report writing. The student lab report writing outcomes most neglected in the lab assignments were 7 and 9. The data shows that overall, Outcome 7 (Develop ideas using effective reasoning and productive patterns of organization) had the lowest instance among the courses, making up only less than half of the courses in the data set. Four lab courses did not include Outcome 9 (Establish solid and consistent control of conventions for a technical audience) in their evaluation. Note that outcomes 7 and 9 are commonly focused on lower-division college writing courses, and they are related to the WPA outcomes (invention and convention) [13].

Table 7. Lab report writing outcomes [11] (1. Audience expectation; 2. Experimental processes; 3. Figure/table; 4. Data analysis; 5. Data interpretation; 6. Conclusion; 7. Productive patterns; 8. Organization; 9. Error-free) present in course lab assignments

	Lab report writing outcomes (● covered in most labs; ○ covered in some labs; × not covered; - no evidence from the samples)								
Course	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
ENGR 240 (2021)	●	●	●	●	●	●	×	●	●
CE 212 (2019)	●	●	●	●	●	●	○	○	×
CE 376 (2021)	●	●	●	●	●	●	●	●	×
EE 221 (2019, 2020)	-	-	-	-	-	-	-	-	-
ECE 214 (2019, 2020, 2021)	●	●	●	○	×	●	×	●	●
EGR 270 (2020)	○	●	●	●	●	○	●	●	●
EGR 270 (2021)	●	●	●	○	●	●	○	●	●
MECH 309 (2019)	●	●	●	●	●	●	×	●	×
MECH 309 (2020)	●	●	●	●	●	●	×	●	●
MECH 309 (2021)	●	●	●	●	●	●	○	●	●

4. A case study: student sample comparisons between two courses (CE 212 vs. EE 221).

This case study investigates how lab instructors' lab report assignments affect students' lab report quality. Out of the seven participating lab courses, CE 212 and EE 221 showed distinct characteristics in their lab assignment and assessment. Tables 6 to 8, show the instructor's expectations for the labs and lab reports in CE 212 and EE 221. CE 212 assignments covered all thirteen learning objectives and had a range of writing guidelines (i.e., fill-in-the-blank, report writing guidelines for individual labs, and report writing guidelines for multiple labs). CE 212 instructor provided assessment rubrics covering eight lab report writing outcomes. In contrast, the EE 221 instructor provided minimal instruction about the expectations for the labs and lab reports. EE221 labs only covered nine educational outcomes, while all the lab reports were in fill-in-the-blank formats. Lab report assessment instruments were not provided in EE221.

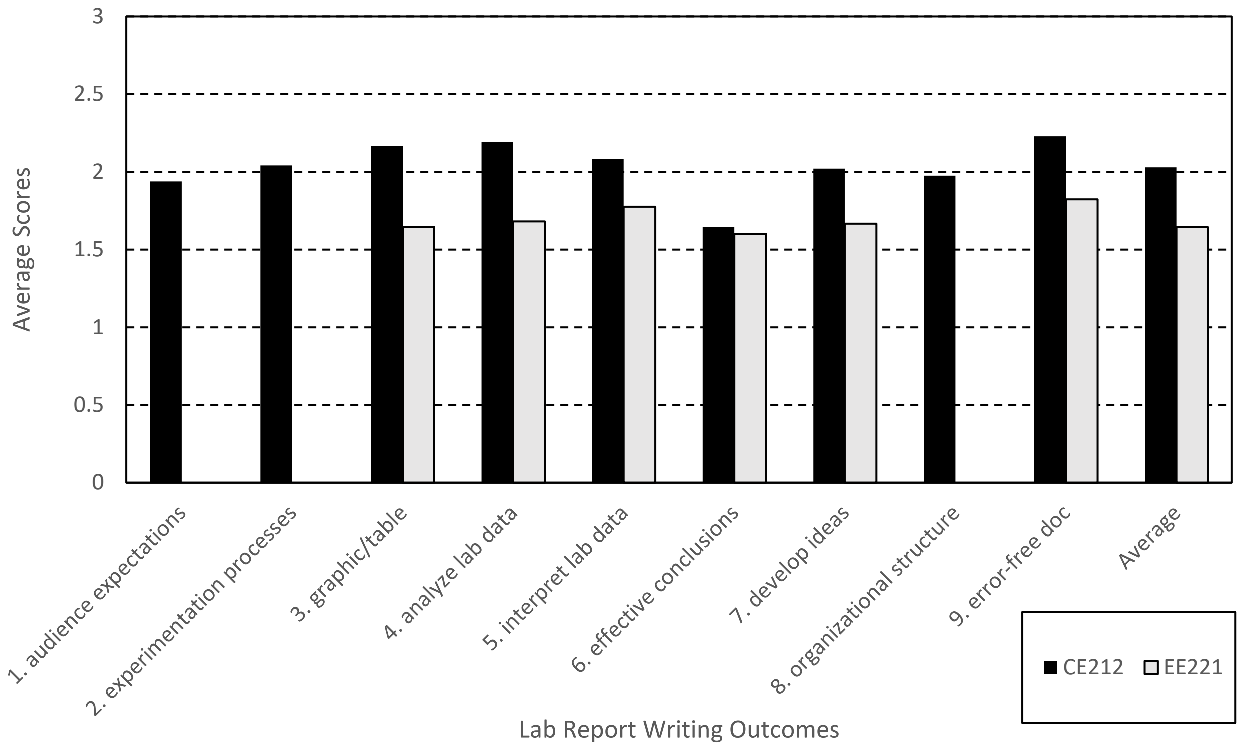

Figure 1. Student lab report sample evaluation results (Scores: 3 = exemplary, 2 = satisfactory, 1 = need improvement)

Figure 1 presents the grand average scores for the nine lab report writing outcomes CE 212 student samples show that outcomes 2, 3, 4, 5, 7, and 9 reach the satisfactory level or 2 out of 3. Outcomes 1 and 8 are close to 2. Outcome 6 (effective conclusion) is the lowest at 1.6. EE 221's lab report templates did not require writing an introduction or experimentation processes; therefore, no scores were assigned in outcomes 1 and 2. Also, the lab report format was fill-in-the-blank, which did not allow raters to assess outcome 8 (organizational structure). The average scores of EE 221 student samples range from 1.6 (outcome 6) to 1.8 (outcome 9). Note that none of the outcomes reach a satisfactory level. The comparison between CE 212 and EE 221 student lab report samples suggests that students can write lab reports to meet the instructor's expectations when the lab report assignment and assessment provide enough information about those.

If not presented to students clearly, achieving the desired outcomes will be difficult, as students would likely have to infer the course outcomes by themselves. Overall, students may find achieving all course outcomes and objectives difficult due to inconsistencies and information that is completely absent.

The lab report sample from Jeffery (pseudonym) is representative of CE 212 lab report samples that demonstrate a satisfactory level of lab report quality. Figure 2 (a) presents that Jeffery could present lab data using the appropriate table form after computing sample properties and % difference. He also wrote the lab data analysis results with the requirement (3000 psi) and the lab data (3616 psi) along with the lab data interpretation. In contrast, the lab report sample from Michael (pseudonym), which is representative of EE 221 lab report samples, shows a lack of writing competency. Figure 2 (b) presents that Michael simply filled in the blank to answer question number 15. He recorded the node voltages; however, he did not write his verification results. The only sentence he wrote was, "LED does light up," which was the main result of the lab activity. Michael's lab write-up did not demonstrate lab data presentation, analysis, and interpretation. The fill-in-the-blank format of EE 221 might limit Michael from presenting lab data using an appropriate figure/table, describing lab data analysis results, and interpreting lab results using outside sources.

Results: The concrete was intended to have a 1-2 inch slump and withstand 3000 psi, but it instead had a 0 inch slump and withstood 3616 psi (Table 2). After reaching the maximum 3616 psi, the concrete sample demonstrated a "good" break. It cracked more through the middle instead of one section and there was some aggregate failure.

Table 2: Portland Cement Concrete Strength

Desired Compressive Strength (psi)	Measured Compressive Strength (psi)	% Difference
3000	3616	120.5 %

(a) A portion of the result section from a CE 212 lab report sample by Jeffery (pseudonym)

15. Build and test your circuit. Record your node voltages, and verify that they agree with your calculated and simulated values -- and also that you can light up your LED!

$V_c = -15V$

$V_+ = 15v$

$V_- = -15v$

$V_C = 9v$

led does light up

(b) A portion of the result section from a EE 221 lab report sample by Michael (pseudonym)

Figure 2. Student sample comparison between CE 212 and EE 221.

Although this case study correlates the effect of lab instructors' lab report assignments on students' lab report quality, it has limitations. These two lab courses are offered in two different majors in the same school. Therefore, the overall quality of the two student groups may be different. Also, the two lab instructors' teaching goals and objectives for lab report writing should be distinct. Indeed, their teaching background was also very different. Finally, we only investigated a small sample size (a total of n=24); therefore, this case study needs to be expanded to a larger scale.

5. Conclusion

This paper focused on the objectives, outcomes, lab material formats, and overall lab report materials of engineering labs provided to undergraduates across four universities. We also investigate the effect of the assignments and assessments on students' lab writing outcomes via a case study comparing two lab courses.

Out of every course studied, all but a single course covered Feisel and Rosa's philosophical-based lab learning objectives related to instrumentation, models, experiment, creativity, safety, communication, and ethics in the laboratory in at least one assignment. Objectives related to teamwork and sensory awareness were much less often addressed than the other objectives. Half of the studied classes had no assignments that covered objectives related to learning from failure in any capacity. Across each class, most of the covered objectives were spread evenly; however, courses such as ECE 214 covered its objectives very consistently.

As for the lab report writing outcomes, most courses were very consistent in which outcomes were present and addressed. All the lab courses included writing outcomes related to the presentation of experimentation processes, illustration of lab data, lab data analysis, effective conclusion writing, and demonstration of appropriate organizational structure and format.

Many lab courses offered one lab report writing guideline, including assessment rubrics, to aid students in understanding the instructor's expectations and writing high-quality lab reports. Some lab courses provided lab report writing guidelines, assessment rubrics, or instructions on individual labs. A few labs relied on the fill-in-the-blank style, which often limits students writing.

In CE 212, which provided the instructor's expectations for the labs and lab reports clearly by instructional materials, the average writing outcome scores of students samples could reach the satisfactory level. However, students in EE221 received fill-the-blank type templates only, and all of their average writing outcome scores were below the satisfactory level. Providing instructors' expectations and writing knowledge through multiple instructional materials can enhance engineering undergraduates' lab report writing outcomes.

6. Acknowledgment

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8. Appendix: Engineering lab report evaluation rubric

Writers in early engineering lab courses are able to:	**Mostly related to**	**HIGH-Exemplary (3)**	**MED-Satisfactory (2)**	**LOW-Need Improve (1)**
			H-M (2.5)	**M-L (1.5)**
1) Address technical audience expectations by providing the purpose, context, and background information, incorporating secondary sources as appropriate.	I	Analyze the technical audience's expectations and the context for the lab report. Provide purpose, context, and technical background proficiently.	The writer's understanding of the context and audience supports a generally successful report. Attention to purpose, context, and technical background are generally appropriate, with some lapses.	Little to no awareness of the audience's needs and the context. The purpose, context, and technical background provided are too basic or inadequate.
2) Present experimentation processes accurately and concisely.	M	Lab processes presented are accurate and concise so that the writer can repeat the lab with the description. Graphics, such as photographs, are used effectively.	The presentation of the lab processes is accurate; however, it is highly wordy or unnecessarily detailed. Graphics, such as photographs, are used but lack clarity.	The writer cannot repeat the lab with the presentation. The lab processes are highly concise, simple, or not well organized.
3) Illustrate lab data using the appropriate graphic/table forms.	R	The writer uses effective strategies to use graphic/table forms when communicating lab data/results. Graphic/table forms are stand-alone and professional. They contain all required features to follow standard conventions and include useful captions. Figures, tables, and illustrations are correctly and usefully labeled.	When communicating lab data/results, strategies using graphic/table forms were generally appropriate, with lapses. Graphic/table forms are generally appropriate; however, they contain minor errors. Figures, tables, and illustrative materials are labeled.	The writer fails to use effective graphic/table forms when communicating lab data/results. Graphic/table forms contain little or no required features. Multiple errors are found in the graphics/tables. Figures, tables, and illustrative materials are not labeled.

4) Analyze lab data using appropriate methods (statistical, comparative, uncertainty, etc.).	RD	The writer analyzes lab data using appropriate methods (statistical, comparative, uncertainty, etc.) professionally. The writer draws significant technical knowledge from an in-depth analysis consistent with the complexity of the experimentation.	Lab data analysis is generally appropriate; however, the analysis methods have some lapses, or the analysis results of lab data are not well aligned with the complexity of the experimentation.	The writer fails to analyze lab data. The writer's lab data analysis is limited, and the data analysis methods have significant errors. Sometimes, the writer may "let the data do the talking."
5) Interpret lab data using factual and quantitative evidence (primary and/or secondary sources).	RD	The writer interprets lab data using factual and quantitative evidence appropriately. The writer addresses existing knowledge (engineering principles or outside reference data/information as the secondary sources) to connect the in-depth lab data analysis (the lab data as the primary sources).	The writer interprets lab data using secondary sources; however, the writer's explanation about the meaning of lab data is appropriate with some lapses. The writer addresses existing knowledge to connect the in-depth lab data analysis; however, it is limited.	The writer fails to interpret the lab data. The writer's explanation about the meaning of lab data is wrong or not based on factual and/or quantitative evidence.
6) Provide an effective conclusion that summarizes the laboratory's purpose, process, and key findings, and makes appropriate recommendations	C	The writer draws meaningful conclusions and reflects on the experiment as a whole in ways that provide closure and bring the analysis to a satisfying ending.	The writer provides closure by summarizing the analysis but may draw limited or inconsistent conclusions from the analysis.	The writer fails to close the report. The conclusion is inconsistent with the report's purpose and other sections' contents (intro and body).
7) Develop ideas using effective reasoning and productive patterns of organization (claim-evidence-reasoning, cause-effect, compare-contrast, etc.).	IMRDC	The writer communicates ideas effectively through reasoning and productive patterns. The writer uses appropriate strategies (claim-evidence-reasoning, cause-effect, compare-contrast, advantages-disadvantages, problem-solution, etc.) to make arguments logically to the audience with a proper flow.	The writer communicates ideas through reasoning and productive patterns with some lapses. Paper generally has a well-constructed flow; however, it sometimes wanders from one idea to another.	The write fails to use reasoning and productive patterns to make arguments. No strategies are used when making arguments and/or describing factual evidence — disjointed connections of ideas within or across paragraphs.
8) Demonstrate appropriate genre conventions, including organizational structure and format (i.e., introduction, body, conclusion, appendix, etc.).	IMRDC	The writer provides a purposeful structure that clearly articulates the experiment's purpose as a whole document. The report has a well-structured introduction, body, and conclusion. Each of these three parts (intro, body, conclusion) well functions in one report.	The writer provides a structure (intro, body, and conclusion) generally appropriate for a lab report as a whole document. Generally, each part (intro, body, conclusion) relates to the primary purpose of the report.	The report's structure (intro, body, conclusion) may be inappropriate, incomplete, or missing. The writer made significant errors in the functions of these three parts (intro, body, conclusion).
9) Establish solid and consistent control of conventions for a technical audience (grammar, tone,	IMRDC	The writer provides an error-free document. Style, tone, tense, and voice are appropriate for a lab report. Errors in	Style, tone, tense, and voice are generally appropriate, with some lapses. Errors in mechanics and grammar	Choices of style, diction, tone, tense, and voice are inconsistent with or inappropriate for a lab report. The

mechanics, citation style, etc.).		mechanics and grammar are minimal and highly infrequent. The report employs a syntax and diction appropriate to the lab report genre. The citations of source material are clear and consistent, and the citation style is appropriate.	are generally minor but may be sufficiently frequent to distract a reader. The writer's diction and syntax are sometimes effective. Source citations are uniformly included but may be incomplete. Figures, tables, and other illustrative materials are generally well-formatted and labeled.	writer's stylistic choices may seem random. Errors are frequent and seriously detract from meaning or prevent the reader from adequately understanding the writer's meaning. The writer omits some citations for sources and may inconsistently label tables, figures, and other visual material.