ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE
Paper ID #37300

The Status of Laboratory Education Focusing on Laboratory Report Assignment and Assessment in the Engineering Programs of a 4-Year Institution

Dave Kim (Professor and Mechanical Engineering Program Coordinator)

Dr. Dave Kim is Professor and Mechanical Engineering Program Coordinator in the School of Engineering and Computer Science at Washington State University Vancouver. His teaching and research have been in the areas of engineering materials, fracture mechanics, and manufacturing processes. In particular, he has been very active in pedagogical research in the area of writing pedagogy of engineering laboratory courses. Dr. Kim and his collaborators attracted close to $1M research grants to study writing transfer of engineering undergraduates. For the technical research, he has a long-standing involvement in research concerned with manufacturing of advanced composite materials (CFRP/titanium stack, GFRP, nanocomposites, etc.) for automotive, marine, and aerospace applications. His recent research efforts have also included the fatigue behavior of manufactured products, with the focus of fatigue strength improvement of aerospace, automotive, and rail structures. He has been the author or co-author of over 200 peer-reviewed papers in these areas.

John D Lynch

John Lynch received the BSEE degree from the University of Utah in 1979. He worked in the aerospace and computer industries in California and Oregon from 1979 to 2002. He was an instructor at the OGI School of Engineering at Oregon Health and Science University, where he received a Ph.D. in 2009. Since 2009 he has been a professor of electrical engineering and Washington State University Vancouver.

Pavel Pisarchuk

I'm a junior electrical engineering student at WSUV who hopes to use his skills in the industry to help make the world a better place!

Allegra A Bryant

Danielle Gedlick

Terry Sjolander

The Status of Laboratory Education Focusing on Laboratory Report Assignment and Assessment in the Engineering Programs of Washington State University Vancouver

Abstract:

Engineering undergraduate programs offer a variety of laboratory courses that aim to give students hands-on experience with engineering practices while also assigning lab report writing that builds communication skills within their major. This study aims to investigate how engineering programs of Washington State University Vancouver offer writing education in undergraduate lab courses. Among numerous electrical engineering and mechanical engineering course offerings at the university, nine undergraduate engineering lab courses were chosen for this study. To begin, the purpose, content, environment, and grading contribution of the chosen labs were surveyed. Then, the materials provided to students about lab report assignments were investigated using nine lab report writing outcomes defined in earlier studies. Finally, the provided evaluation criteria of the lab reports were studied using the same nine outcomes. The lab report writing outcomes used in the study include 1) address technical audience expectations, 2) present experimental processes, 3) illustrate lab data using appropriate graphic/table forms, 4) analyze lab data, 5) interpret lab data, 6) provide an effective conclusion, 7) develop ideas using effective reasoning and productive patterns, 8) demonstrate appropriate genre conventions, and 9) establish control of conventions for a technical audience. We concluded that, regardless of major or program level, the primary purpose and contents of the course materials were usually categorized as educational and experimental, respectively. The secondary purpose and contents were predominantly developmental and analytical. Additionally, we found that most courses explicitly addressed outcomes related to report organization, data presentation/analysis/interpretation, and writing conventions. However, the outcome related to developing ideas using effective reasoning and productive patterns was not proven to have been explicitly covered in any of the courses studied. Finally, we found that though many of the courses studied had explicitly addressed these outcomes, fewer courses directly assessed the nine outcomes. It can be interpreted that engineering students might struggle with the inconsistency between the assignment and the assessment in lab report writing.

1. Introduction

Engineering programs offer laboratory or lab courses to prepare students to conduct hands-on engineering practices in their curricula [1]. At the same time, engineering labs assign students to produce lab reports to help them communicate with a range of audiences effectively. Often, engineering programs use the lab courses to strengthen their education related to ABET's Student Learning Outcomes 3: An ability to communicate effectively with a range of audiences and 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.

Many engineering programs have made an effort to design lab education at the program level [2-3]. For example, the bio-engineering program of the University of Illinois at Urbana-Champaign investigated twenty-two ABET-accredited biomedical engineering programs to survey lab credit requirements and the instructors' practices about their laboratory and project-based courses to assess the landscape of lab courses in biomedical engineering programs [2]. The mechanical and aerospace engineering program at the University of Virginia offers the scaffolded lab sequence in mechanics over three lab courses in the program: 1) Mechanics Laboratory, 2) Thermal Fluids Laboratory, and 3) Aerospace or Mechanical Laboratory to offer seamless mechanics education from fundamental to advanced topics in various mechanics-based courses over time [3].

At the same time, engineering programs have made program-level efforts to improve students' writing in the discipline. Some engineering programs host writing or communication programs/centers directed by communication experts (e.g., Stanford, Virginia Tech), or integrate writing-intensive curricula (e.g., the Writing-Enriched Curriculum program at the University of Minnesota [4], Engineering communications program at Cornell [5]) into their engineering programs [6]. However, not all engineering programs offer such comprehensive, tailored writing instruction due to a lack of financial resources or time to allocate support. Mostly, US engineering programs rely on individual engineering instructors to help undergraduates' writing preparation within their engineering curricula [6].

Only a few studies investigated comprehensively how writing education has been offered in multiple engineering undergraduate labs. Gravé [7] reported 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) offered to the electrical engineering undergraduates at Elizabethtown College. Genau [8] studied the impact of strengthened technical communication education in introductory engineering materials courses. The collaborative efforts between engineering programs and writing programs have been reported [9,10], and most of the work was related to the standardization of writing assessment and professional development on writing education.

Although a few studies investigated the writing education of multiple labs, the knowledge of how an engineering program has offered writing education in their disciplinary undergraduate lab courses is still lacking. This study aims to investigate how engineering programs of Washington State University Vancouver, a branch campus in a land-grant research-one university, offer writing education in undergraduate lab courses. We have three objectives in this study. First, we surveyed the purpose, content, environment, and the contribution of the labs to overall course grades. Second, we investigated how the lab reports were assigned to students. Lastly, we studied how the lab reports were evaluated. We collected the instructional materials, such as course syllabus, lab handouts, or lab report assessments, given to the students from seven instructors in nine lab courses from both electrical and mechanical engineering programs.

The study results may contribute to engineering educators to visualize a school's engineering lab report writing education. Also, this study presents engineering lab instructors' writing pedagogies and preparedness for lab report assignments and assessment from the program level. It also suggests room for improvement in engineering lab report writing education.

2. Methods of Approach

2.1 Study Area

This study took place in the engineering programs (Electrical and Mechanical) at Washington State University Vancouver. According to the University catalog, the electrical engineering program offers seven required lab courses and six elective lab courses. The mechanical engineering program offers four required lab courses and two elective lab courses. Among those, this study focuses on the following nine lab courses, which are offered regularly and assign lab reports as evaluation tools.

Table 1. The engineering lab courses investigated in the study

Major			Term	Year of offering	Number of labs in the term
Electrical Engineering	214	Required	Fall	2019	12
	260	Required	Spring	2021	14
	327	Elective	Spring	2020	11
	411	Required	Fall	2021	13
	421	Elective	Fall	2019	5
	425	Elective	Fall	2020	6
Mechanical Engineering	309	Required	Fall	2019	6
	310	Required	Spring	2021	13
	402	Required	Fall	2019	9

The instructors for the lab courses include one full professor, two associate professors, two assistant professors, and two part-time adjunct professors from industry, which is close to the overall demographics in the engineering programs on campus. We focus on how engineering programs perform on lab report writing pedagogies; therefore, it is not studied how individual instructors' background impacts the lab course instructional materials.

2.2 Research instruments

This study refined or adapt the instruments from Refs [1,11] to characterize the purpose, content, and assessment of the labs offered to engineering students. Feisel and Rosa [1] claimed that engineering labs have three purposes: educational, developmental, and research. Table 2 shows how each purpose can be articulated in terms of main goals and unique features. Engineering labs can be classified lab contents in five groups including experimental, analytical, simulation, design, and programming. Each content's main goals and unique features are elaborated in Table 3. Table 4 is the lab report writing rubric drawn from the WPA (Writing Program Administrators) outcomes and ABET outcomes #3 and #6 [12]. The WPA outcomes are widely used in first-year college writing course instructors as their student outcomes, focusing on rhetorical knowledge, critical thinking, reading and composing, and processes [14]. They also emphasize the audience expectations and genre conventions of the discipline when the writing skills are applied to specific disciplines [14]. Most engineering lab reports follow the IMRDC format or introduction-methods-results-discussion-conclusion [11-13], the lab report writing rubrics are designed to connect with IMRDC.

Table 2. Lab's purpose refined from [1]	Main goal	Unique features
Educational	• Learn how to operate lab equipment/devices to collect data. • Analyze lab data to verify specific theories/principles covered in class.	• The introduction to the theories/principles covered in class needs to be included in the report. • The accuracy of the data collection/analysis is valued.
Developmental	• Conduct engineering design and/or realization of system/device/program to produce solutions that meet specified needs.	• Outcomes include design and/or realized system/device/program. • Lab deliverables are clearly defined.
Research	• Develop appropriate experimentation. • Analyze and interpret the lab data with outside sources to use new knowledge not taught in class.	• Referencing is required in the report. • An in-depth discussion using outside sources is required in the report. • Using engineering judgment to draw conclusions is valued.

Table 3. Lab's contents refined from [1]

	Main goals	Unique features
Experimental	• Develop the experimentations to collect empirical qualitative or quantitative data. • Use the theoretical concepts learned from the course and apply them directly to the procedure to test their consistency in practice.	• Includes following procedural instructions to collect data. • The report format follows IMRDC or introduction-methods-results-discussion-conclusion.
Analytical	• Make observations and judgments based on quantitative or qualitative work from elsewhere. • Conduct in-depth data analysis and interpret the findings.	• Uses the data that have not been collected by the student. • Requires in-depth analysis and discussion using outside sources.

Simulation	• Use special computer software to model systems and/or study their behavior. • Use the modeled systems to represent the current concepts and ideas that are being learned about in the course.	• Creates a simulation profile to be analyzed. • Uses simulation results to compare with experimental or expected data.
Design	• Involve the creation of a new system, product, or model. • Use engineering principles to help produce the design.	• Deliverables include the new system/product/model and/or their specifications. • Includes different design phases such as conceptual design, functional design, modeling, etc.
Programming	• Develop computer codes and algorithms to solve problems. (Python, Matlab, C++, etc.)	• Codes as a deliverable. • Coding software specified. • Can be used in the design of a system, product, or model.

Table 4. Lab report writing outcomes [11]: Lab report writing outcomes rubric (I = introduction; M = methods; R = results; D = discussion; C = conclusion).

Writers in early engineering lab courses are able to	**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 Analysis of the labs offered

We collected nine course syllabi, eighty-five lab handouts/manuals, nine lab assessment documents, eight other documents from seven lab instructors. We investigated the purpose, content, environment, grading contribution to each course, and instructional materials given to the students in nine lab courses in this study.

3.1.1 Lab's purpose

We used Table 2 as the instrument to assess the primary and secondary purposes of each lab. Table 6 shows the primary and secondary purposes of each lab course. The primary purpose is the driving force behind each lab; it is the intended understanding or outcome for the students. The secondary purpose is not the goal or interest of the lab but rather a support for student understanding. For example, MECH 309 Lab 1 Materials Identification: XRD (x-ray diffraction) and FTIR (Fourier-transform infrared spectroscopy) were educational because mainly the lab aimed to teach how to operate XRD and FTIR, collect the data from those instruments for analysis. Therefore, the lab's primary purpose is educational. However, the lab recommends reading outside sources to verify the accuracy and soundness of the XRD and FTIR data analysis results and interpret the data using engineering principles such as Bragg's law. This allowed students to conduct research; therefore, the secondary purpose of the lab should be research.

Table 6. Primary and secondary purposes of the labs offered in each lab course.

Course (Number of labs)	Primary Purpose:	Secondary Purpose:
ECE 214 (12)	12 Educational	12 Developmental
ECE 260 (14)	14 Educational	14 Developmental
ECE 327 (11)	11 Educational	11 Developmental
ECE 411 (13)	13 Educational	13 Developmental
ECE 421 (5)	5 Educational	2 Research, 3 Developmental
ECE 425 (6)	6 Educational	6 Developmental
MECH 309 (6)	3 Educational, 3 Research	3 Research, 3 Educational
MECH 310 (13)	13 Educational	4 Developmental, 2 Research, 7 N/A
MECH 402 (9)	9 Educational	2 Research, 1 Developmental, 6 N/A

Table 6 clearly shows that most of labs are given to educate engineering students to operate equipment and devices, develop the experimentations, collect empirical qualitative or quantitative data as the primary aim. As the secondary purpose is to support experimental labs, the majority of the labs are developmental so that the students can conduct engineering design and/or realization of system/device/program to produce solutions that meet specified needs within the primary purpose of experimentations.

3.1.2 Lab's content

We used Table 3 as the instrument to assess the primary and secondary contents of each lab and presented the number of contents used in each lab course in Table 7. The terms 'primary' and 'secondary' here are defined similarly to the definitions above. The primary contents make up the bulk of the lab experiment. For example, in many of the ECE lab experiments, such as in ECE 260, the primary contents were experimental, in that the labs were largely spent following hands-on experimental procedures and testing theoretical concepts learned from the course. The secondary contents are important components of the experiments but come after the primary goal of the lab. In ECE 260, most of the labs include simulation-based secondary contents, as PSpice was used to simulate results after the completion of the physical portion of the experiment, and these results were used to attest to the validity of experimental results. As shown in Table 7, most engineering labs have experimental contents as the primary; therefore, students mainly conduct hands-on experiments using equipment or devices to obtain empirical data during the labs. There are a few simulation or design labs. Analytical or programming labs are limited in the lab courses chosen for the study.

Table 7. Primary and secondary contents of labs in each lab course.

Course (Number of labs)	Primary Contents:	Secondary Contents:
ECE 214 (12)	12 Experimental	12 Design
ECE 260 (14)	14 Experimental	1 Analytical, 13 Simulation
ECE 327 (11)	5 Experimental, 4 Simulation, 2 Design	8 Analytical, 2 Experimental, 1 Simulation
ECE 411 (13)	13 Experimental	13 Analytical
ECE 421 (5)	5 Experimental	5 Simulation
ECE 425 (6)	6 Experimental	6 Analytical
MECH 309 (6)	5 Experimental, 1 Analytical	6 N/A
MECH 310 (13)	9 Experimental, 3 Simulation, 1 Design	3 Design, 1 Analytical, 9 N/A
MECH 402 (9)	9 Experimental	2 Design, 7 N/A

3.1.3 Lab's contribution to the class grade

Table 8 shows all of the engineering lab courses in the study are conjoint between lectures and labs. Lab portions range from 20% to 38% of class grades, which means the lecture portions (homework and exams) contribute the most to students' overall course grades. Each lab course offered from 5 to 14 labs during a 15-week term; therefore, individual lab reports are worth 2.0% to 5.5% of class grades.

Table 8. the percentage of the lab portion and individual lab report contributing to the lab course grade.

Course	% of the lab portion on class grade introduced in the course syllabus	Number of labs in each lab course	% of Individual lab reports on class grade
ECE 214	33 %	11	2.5 %
ECE 260	30 %	14	2.1 %
ECE 327	30 %	11	2.7 %
ECE 411	30 %	14	2.0 %
ECE 421	20 %	5	4.0 %
ECE 425	25 %	6	4.2 %
MECH 309	33 %	6	5.5 %
MECH 310	25 %	13	2.8 %
MECH 402	38 %	9	4.2 %

3.1.4 Instructional materials related to labs and lab report writing given to students

Table 9 summarizes the instructional materials given to the students for each lab course. Most lab courses used lab handouts written by the instructors so that students can learn the lab's background and procedures. Lab handouts also act as the lab report assignment specifying the submission deadline, necessary processes, or the expected contents of the lab report. Two electrical engineering lab courses used published lab manuals. Many instructors provide lab report grading materials such as rubrics applying to all labs. Three lab courses provided sample lab reports. It is noted that ECE 260 provided a special handout, entitled "How to Write a Lab Report," to introduce the fundamentals and genre expectations of engineering lab report writing.

Table 9. Types of instructional materials related to labs and lab report writing for each course.

	Individual lab handout/manual	Lab report assignment	Lab report assessment	Others
ECE 214	Written by the instructor, some content was leveraged.	Lab handout for individual labs.	Lab Report Cover Page with a rubric. Also, a document that teaches individuals to write a report in detail.	Schematics to build circuits for each lab assignment.
ECE 260	Lab manual "Experiments with Electric	ECE 260 Schedule of Lab Experiments	Rubric on Cover Sheet for all labs	How to Write a Lab Report (PPT presentation)

	Circuits" by Sid Antoch; Instructor's notes in some labs			Lab Report Writing Guide, ECE 260 Lab Manual Errata by the instructor
ECE 327	Written by the instructor	Lab handout for individual labs.	Rubric on the cover page and lab reporting guidelines at the bottom of each lab handout.	
ECE 411	Lab manual provided by the maker of the lab equipment	Not provided.	Laboratory Orientation - "Grading"	Safety for Power Lab, two example lab reports provided.
ECE 421	Written by the instructor.	Lab handouts for individual labs.	A grading rubric on the cover page shows all of the expectations for the lab report.	Two example lab reports are provided.
ECE 425	Written by the instructor.	Lab Assignment on individual lab Cover Sheets	Rubric on individual lab Cover Sheets	Lab Template "LAB REPORT FORMAT" document IEEE Referencing Guidelines in PDF
MECH 309	Written by the instructor	Lab handout for individual labs	Lab report grade guideline for all labs	A graded sample lab report (one average quality)
MECH 310	Written by the instructor	Lab handout for individual labs	Lab report grade guidelines for all labs	
MECH 402	Written by the instructor	Lab handout for individual labs	Lab Report Introduction document for all labs	

3.2 Analysis of lab report assignments

The majority of the lab courses provided students multiple lab instructional materials such as lab handouts or manuals, sample lab reports, lab report writing guidelines, and/or grading rubrics. We analyzed each lab course's lab instructional materials using the nine lab report writing outcomes in Table 4. Table 10 presents the mapping results to show the outcomes explicitly covered in each lab course.

Table 10. Mapping results of explicitly covered lab report writing outcomes in each lab course's assignments.

Course	Outcome 1	Outcome 2	Outcome 3	Outcome 4	Outcome 5	Outcome 6	Outcome 7	Outcome 8	Outcome 9	Number of explicitly covered outcomes in each course
ECE 214	x	x	x	x	x	x		x	x	8
ECE 260	x	x	x	x	x	x		x	x	8
ECE 327		x	x	x					x	4
ECE 411								x		1
ECE 421	x	x	x	x		x		x	x	7
ECE 425		x	x	x	x	x		x		6
Number of outcomes explicitly covered in each ECE course	3	5	5	5	3	4	0	5	4	
MECH 309		x	x		x	x		x		5
MECH 310	x	x	x		x	x		x	x	7
MECH 402			x	x	x			x		4
Number of outcomes explicitly covered in each MECH course	1	2	3	1	3	2	0	3	1	

Our observations of how each lab report writing outcome is assigned to the students are discussed below.

- *Outcome 1: Address technical audience expectations.* Only four out of nine lab courses had this outcome explicitly covered in the assignments. For example, ECE 214 explicitly covers this outcome in the "How to Write a Lab Report" document, which states that a lab report introduction should include the objective (what the lab is about), the motivation (why the lab is being done), and an introduction to any relevant technical background information, engineering principles, and scientific theories to "the technical audience."

- *Outcome 2: Present experimentation processes.* Most lab courses (seven out of nine) covered this outcome. For example, MECH 310 explicitly covers this outcome in the

“Lab Report Format” document, which states that the experimental procedures should “elaborate on steps performed in the lab, define equipment and/or materials used,” and “give all necessary equations.” Another good example is ECE 260. Students of this course are provided with a lab report writing guide, which states that a methods section “must provide a clear outline of what was actually done during the lab. Pictures of experimental setup or workpieces can be included. After reading this section, the reader should be able to completely reproduce the experiment to verify the results. Don’t simply copy the lab handouts.”

- *Outcome 3: Illustrate lab data using the appropriate graphic/table forms.* Most lab courses covered this outcome, with only one course not providing explicit instruction. ECE 260 explicitly covers outcome 3 in the “How to write a lab report” PowerPoint, where the “Results: Data Tables,” and “Results: Figures and Graphs” slides give examples and instructions on including graphic and tabular forms of data. ECE 425 also explicitly instructs students on expectations when illustrating lab data. The given “LAB REPORT FORMAT” document states: “Data should be reported in a clear and organized way. Include tables with numbers (such as Table 1). You can then refer to these tables in the discussion section by their numbers. Any numbers entered into the data table must be complete with units. Graphs and figures should also include numbers with descriptive titles. Both axes on a graph should be labeled with specific units of measure.” The three MECH courses covered also include instructions that students should illustrate lab data using appropriate plots.

- *Outcome 4: Analyze lab data using appropriate methods.* This outcome is covered in six out of the eight courses. Specifically, the course ECE 260 covered this outcome very well; the “Discussion / Analysis” section of the “How to write a lab report” PowerPoint slides available at the beginning of the term, state, “Interpret and contextualize the lab results. What does the data show? Does this support your hypothesis If discrepancies exist, then possible reasons should be discussed? Possible sources of erroneous or unexpected may be discussed. Make logical appeals using the lab results to lead the audience to the conclusion.”. MECH 402 also explicitly covers this outcome in labs 1 and 2 of the course, specifically mentioning that students must analyze their collected data. In labs 1 to 6, the lab handouts explicitly ask students to discuss uncertainties and differences found during the experiment.

- *Outcome 5: Interpret lab data using factual and quantitative evidence*. A good example of this outcome being covered is in MECH 402, in which all lab handouts explicitly state that the lab data should be interpreted and compared to theoretical/empirical equations. The syllabus from this course also explicitly states that students should interpret the collected thermal system data as a primary source. Also, labs 6, 7, and 8 explicitly state that the collected data needs to be compared with the data described in the literature. Another course that covered this outcome well was ECE 214 which explicitly included this outcome in the “Discussion and Conclusions” section of the lab report rubric found on the cover page handout. The "How to write a lab report" document also states that one should "discuss and interpret the results …" in the Discussion/Analysis section of the document.

- *Outcome 6: Provide an effective conclusion*. 6 of the 9 lab courses considered explicitly covered outcome 6. MECH 310 provides a good example, explicitly stating in the lab report guide that the conclusion should include a "summary of key results, evaluate results and comment on their accuracy, provide advice for future labs, if necessary." Another example is present in ECE 260, where conclusion writing is covered in lab report handouts and the given "Lab report writing guide" as: "Briefly recap the lab topic and objectives. Provides a summary of, and draws conclusions from, the key findings made from the results and discussion sections. What happened in the experiment? What does your data tell you about the experiment? What did you learn from completing this experiment? Descriptions of the key findings need to be a direct response to the lab objectives. May suggest improvements to the lab and further investigation/future work."

- *Outcome 7: Develop ideas using effective reasoning and productive patterns of organization.* None of the courses considered include explicit instruction relating to outcome 7. This outcome includes consideration of writing techniques learned in writing courses before and during university, such as cause-effect and compare-contrast. This suggests that this outcome may be difficult to include in the instruction of lab report writing in these lab courses and assumed instead to have already been a learned component of the lab report genre.

- *Outcome 8: Demonstrate appropriate genre conventions.* Most lab courses covered this outcome, with only one lab course not providing explicit instructions. MECH 309 offers a good demonstration by providing students with a "Lab Report Format Guide" that states a formal lab report should include an introduction, experimental procedures, results and discussion, conclusion, references, and an appendix (as needed). Additionally, the document requires students to use proper font size, appropriate spacing, page numbers, and clearly labeled and formatted pictures, graphs, and diagrams.

- *Outcome 9: Establish solid and consistent control of conventions for a technical audience (grammar, tone, mechanics, citation style, etc.)* In lab report writing it is important to follow a format that helps the author present their data efficiently and appropriately. This particular outcome was covered in five of the nine courses studied. An example of this is in ECE 214 which explicitly includes "Professional Presentation (Overall quality of report, grammar, spelling, neatness, organization, etc.)". in the lab report rubric found on the cover page. Another example is MECH 310 which explicitly states that lab reports are written using third person, past tense, active voice, etc., in Lab 2, 7, 9, and 10. The citation style is also explicitly stated in the Lab Report Format Guide.

As a whole, most of the courses covered the 9 desired outcomes of lab report writing but there were areas of concern that could be improved upon to help current and future students present their findings more professionally and efficiently.

ECE 411 is an outlier in that only Outcome 8 (appropriate genre conventions) is included in lab assignments. This is likely because all ECE 411's labs are assigned from a lab manual provided by the manufacturer of the equipment used by the students in the lab. The instructor provides minimal additional guidance.

3.3 Analysis of lab report assessments

Each lab course's lab instructional materials were analyzed to investigate how the student lab reports are evaluated. As in Section 3.2, we use the nine lab report writing outcomes in Table 4 for the analysis. Table 11 presents the mapping results to show the number of outcomes explicitly covered in each lab course's lab report assessment.

Table 11. Mapping results of explicitly covered lab report writing outcomes in each lab course's assessments.

Course	Outcome 1	Outcome 2	Outcome 3	Outcome 4	Outcome 5	Outcome 6	Outcome 7	Outcome 8	Outcome 9	Number of explicitly covered outcomes in each course
ECE 214	x	x	x	x	x	x		x	x	8
ECE 260	x	x	x	x	x	x		x	x	8
ECE 327			x	x				x		3
ECE 411										0
ECE 421		x	x	x				x	x	5
ECE 425		x	x	x	x	x				5
Number of outcomes explicitly covered in each ECE course	2	4	5	5	3	3	0	4	3	
MECH 309		x				x		x	x	4
MECH 310	x	x				x		x	x	5
MECH 402		x	x	x		x				4
Number of outcomes explicitly covered in each MECH course	1	3	1	1	0	3	0	2	2	

Comparing Tables 10 and 11, the outcomes covered in the assignments overlapped those covered in the assessments by 84%. For example, the courses included outcome 4 (analyze lab data) were identical between the lab report assignments and assessment. Thus the students in those lab courses were well guided to include lab data analysis results in their lab reports and knew that outcome would be evaluated. In contrast, six courses included outcome 5 (interpret lab data) in lab report assignments, but only three of those courses included the lab data analysis in the lab report assessment.

How each lab report writing outcome was evaluated is introduced in the following:

- *Outcome 1: Address technical audience expectations*. Few lab courses (three of nine) explicitly assessed this outcome. However, ECE 214 contains a good example of explicit assessment of this outcome in the "Lab Cover Sheet" document in the form of the assessment rubric on the front of the page. The document shows that the Title/Introduction/Purpose is worth 4/25 available points per lab report, meaning it is worth 16% of the total lab report grade.

- *Outcome 2: Present experimentation processes*. Most lab courses (seven of nine) directly assessed this outcome. In the "Lab Report Guide" document for MECH 309 students, the "Experimental Procedures" section was worth 10/80 available points per lab report, or 12.5% of the overall lab report grade. Another course that directly assessed outcome 2 was ECE 425; in the "Lab Cover Sheet" document, the description of the "Procedure and Experimental Data" portion of each experiment was worth 40 out of 100 available points, making it worth 40% of the lab report grade.

- *Outcome 3: Illustrate lab data using the appropriate graphic/table forms.* six of the nine courses considered explicitly assessed this outcome. For example, MECH 402's "Lab Report Introduction" document states that "collected data in tables" is worth 3 points and "results presented using plots and/or tables" is worth 5 points, making Outcome 3 worth 8 points of the total 23 points in each lab report. This can be worth 47% of the lab report grade.

- *Outcome 4: Analyze lab data using appropriate methods*. Six out of the nine courses had an evaluation for the analysis of laboratory data in some form, meaning, it either was a standalone subject that students would be graded for or it would be included or combined with another subject for grading. For example, in ECE 214, the analysis would be included with the "Discussion and Conclusions" section of the grading rubric. It would also be graded as a part of this section which was worth 6 out of 25 total points which would be 24% of the report grade. Another course that covered this evaluation well was ECE 421 which explicitly stated that students must "Correlate Measured and Calculated Data" in the lab report rubric. This section involved analyzing the collected lab data and making comparisons to the theoretical data. The section was noted to be worth 10 out of 80 total points of the lab report which is 12.5%.

- *Outcome 5: Interpret lab data using factual and quantitative evidence*. For assessments of the interpretation of lab data, only three of the nine courses evaluated it through a section that combines the outcome with other outcomes. One of the more prominent courses for this assessment was ECE 425 which included a "Discussion and Conclusions" section in the rubric of each experiment, worth 30 points of the total 100, or 30% of each lab report's grade.

- *Outcome 6: Provide an effective conclusion*. The majority (six of nine) of the lab courses considered directly assessed this outcome. For example, the ECE 214 rubric states that this section would be worth 6 out of 25 total points, which would be 24% of the report grade.

- *Outcome 7: Develop ideas using effective reasoning and productive patterns of organization*. None of the courses considered directly assess this outcome. As stated above, this outcome is not directly assigned by any of the lab courses included in this study and is therefore also not assessed by any of these courses.

- *Outcome 8: Demonstrate appropriate genre conventions*. Five out of the nine lab courses explicitly assessed outcome 8. Of the courses that covered this outcome, MECH 310 provides a good example of this in the "Lab Report Format" document, which states that "Format and Grammar" and "Referencing" contributes 10 points to the individual lab report score of 80 points, meaning that outcome eight is worth 12.5% of the lab report score.

- *Outcome 9: Establish solid and consistent control of conventions for a technical audience (grammar, tone, mechanics, citation style, etc.)* Five of the nine courses covered this outcome. The best example was found in ECE 214 which explicitly stated in the rubric that students must have "Professional Presentation (Overall quality of the report, grammar, spelling, neatness, organization, etc.)". The evaluation of this outcome was worth 3 out of the 25 total points, or approximately 12% of the report grade. This also means that this section alone, from one report, would be worth 0.3% of the overall course grade. Some courses also might explicitly state the importance of this outcome but they do not explicitly evaluate it. An example is ECE 327 which explicitly states in all of the lab report guides that "Your analysis should be written in prose..." and "The report should have section headings to help organize your information," but there was no grade on the rubric that was specifically assigned to having conventions.

Again, ECE 411 was an outlier. ECE 411's labs are assigned from a lab manual provided by the manufacturer of the equipment used by the students in the lab which offers no guidance for how to report lab results beyond collecting specified data. The instructor provides no rubric or other information about how students' lab reports are evaluated.

3.4 Discussion

The analysis results can provide the current status of the lab report writing education in the two engineering programs. As shown in Tables 10 and 11, the lab report writing outcomes 2, 3, 4, 8, and 9 are covered in most lab courses. They are well aligned with ABET outcomes. ABET outcome 6. "an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions" are related to the lab report writing outcomes 2, 3, 4. The lab report writing outcomes 8 and 9 are aligned with ABET outcome 3 "an ability to communicate effectively with a range of audiences." Most lab instructors might use the components of ABET outcomes 3 and 6 when writing their lab assignments and assessment. However, outcomes 1, 5, and 6 are covered only a few lab courses. The lab report writing outcome 1 is mainly related to the introduction section of a lab report focusing on technical audience expectations. Not many instructors specified what they expect students to write in the introduction on their assignments and assessments. This may be due to a lack of understanding technical audience and their expectations in the lab report genre. The lab report writing outcomes 5 and 6 are related to ABET outcome 3; however, some lab courses in the 2nd year courses do not include them. Some instructors might believe they are beyond the scope of the labs. It is noted that outcome 7 is rarely covered in the lab courses. Developing ideas using effective reasoning and productive patterns of organization (cause-effect, compare-contrast, etc.) is required for engineering undergraduates to demonstrate before graduation[11]; however, they may not be confident to assign and assess the outcome, or it may be beyond the scope of the labs.

The results of this study suggest that lab report writing instruction and evaluation can be improved in some courses to better align with ABET and WPA outcomes. For example, in ECE 411 the equipment manufacturer's lab manuals just deliver the lab contents and do not have any pedagogical components focusing on lab report writing or assessment. Our results allow us to give productive feedback to the course instructor. Future work could include writing additional lab materials to supplement the published lab manuals for lab report writing and assessment.

This study is part of the engineering programs' continuous improvement in supporting student learning. The authors will share the analysis results with engineering faculty during the closing-the-loop meetings at the end of the academic year. Plans to update the lab instructions and assessments will be discussed during the meetings.

4. Conclusion

This article presents an insightful investigation of how engineering programs offer writing education in mechanical and electrical engineering undergraduate lab courses by examining the lab documentation provided to students in these programs. The purpose of this was to understand a school's engineering lab report writing education, understand the assignment and assessment methods of engineering lab instructors, and suggest ways of improving lab report writing education using the qualitative and quantitative information collected throughout this study.

The conclusions drawn from the study are the following:

1. Overwhelmingly, and regardless of major or year, the primary purpose and contents of the engineering lab course materials were categorized as educational and experimental, respectively. The secondary purpose and contents were predominantly developmental and analytical, respectively.
2. The lab report instructional materials analysis showed that most courses explicitly addressed the illustration, analysis, and interpretation of lab data, the presentation of experimentation processes, and the demonstration of appropriate genre conventions (outcomes 3, 4, 5, 2, and 8, respectively). One outcome that was not covered in any course was the development of ideas using effective reasoning and productive patterns of organization (outcome 7).
3. The lab report instructional materials analysis showed that even though most courses explicitly addressed many of the desired outcomes, fewer courses explicitly assessed the outcomes. For example, six courses assigned lab data interpretation (outcome 5) in lab reports; however, only three courses assessed the outcome. It is also found that one course did not assess any of the nine outcomes. Of the outcomes explicitly assessed in the lab instruction materials, outcomes 2, 3, 4, 6, and 8 were the most frequently covered in both programs. It means that engineering instructors emphasize the importance of displaying, interpreting, and analyzing data, and demonstrating appropriate conventions for the engineering genre through lab report writing education.
4. The results of this study suggest that lab report writing instruction and evaluation can be improved in some courses to better align with ABET and WPA outcomes. The analysis results will be used to improve writing education continuously in the two engineering programs' lab courses.

5. Acknowledgement

This work was supported by the National Science Foundation under Grant DUE #1914593.

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