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Board 216: Areas of Improvement and Difficulty with Lab Report Writing in the Lower-Division Engineering Laboratory Courses across Three Universities

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Areas of Improvement and Difficulty with Lab Report Writing in Lower-Division Engineering Laboratory Courses Across Three Universities.

Abstract

Engineering undergraduates often mention hands-on laboratory courses as the most exciting learning experience in college. At the same time, they frequently point out that lab report writing is one of the most difficult tasks. Indeed, writing requires an extensive time investment for students, from developing ideas to proofreading before submission. Although engineering educators and writing educators offer impactful instructions in academic writing, engineering undergraduates seem to struggle when they are assigned to write in their major classes. This paper aims to investigate the areas of writing competencies where students improve or struggle in lower-division engineering laboratory courses. We collected and analyzed lab report samples from sixty-four students (n = 64) in a total of seven sophomore-level civil, electrical, and mechanical engineering courses at three different universities, consisting of a polytechnic university, a liberal art-focused private university, and a branch campus of research-one land grant university in the academic years of 2019-2020 and 2020-2021. The analysis results from the lab sample assessment, using nine lab report writing outcomes, indicate that 30% or 19 out of 64 students could write their early lab reports at a satisfactory level; however, 70% or 45 out of 64 of students did not receive satisfactory grades in their early lab reports. These students are classified as the "needs improvement" group. The 45 students in the needs improvement group struggled with all nine outcomes; most notably, they had the lowest average scores in outcomes 5 (lab data interpretation), 6 (productive conclusions), and 7 (development of ideas), which often require evaluation and synthesis in Bloom's Taxonomy. This group of students' later lab report samples were assessed to investigate areas of change over the lab course periods. Lab instructions positively impacted students' writing, showing marginally improved average scores in all nine outcomes. The largest improvement was observed in lab data interpretation, followed by lab data analysis and lab data presentation. Even with the improvement in their late labs, the engineering undergraduates in the needs improvement group still struggle with addressing technical audience expectations, lab data interpretation, effective conclusion writing, and idea development, even with instructions and productive feedback from the lab instructors and/or teaching assistants.

1. Introduction

Engineering undergraduates often said the hands-on engineering laboratories were one of the best experiences in the engineering curriculum; however, writing lab reports was considered one of the worst experiences. Writing is known as a difficult task but a foundational skill in engineering education. As the ABET outcome 3 stated, engineering graduates should be able to communicate effectively with a range of audiences [1]. Most US engineering laboratory courses assign lab reports to improve students' written communication skills and knowledge of writing in the context of engineering. Indeed, engineering lab reports possess fundamental characteristics of professional forms in engineering literacy. However, engineering undergraduates consistently face many challenges in producing satisfactory quality engineering lab reports [2-10].

Writing is a complex task for students to combine multiple aspects of literacy at once. Often, undergraduates learn those aspects in their first-year composition courses. First-year composition instructors in the US schools mostly use writing outcomes in the academic settings identified by writing program administrators: 1) rhetorical knowledge as "the ability to analyze contexts and audiences and then to act on that analysis in comprehending and creating texts," 2) critical thinking, reading, and composing as "the ability to analyze, synthesize, interpret, and evaluate ideas, information, situations, and texts," and 3) processes as the ability to use "multiple strategies, or composing processes, to conceptualize, develop, and finalize projects" with the knowledge of conventions [11]. Due to the multiple aspects mostly related to students' cognitive and linguistic processes, writing is considered to be a burdensome and time-consuming task for undergraduates [12-15].

The difficulty of writing becomes more obvious to engineering undergraduates in engineering lab courses. According to the survey results from StClair et al. [16], many engineering undergraduates felt that the writing skills they had learned in prior courses were helpful limitedly when writing lab reports. They declared that the aspects of laboratory reports are unique from other types of writing in college. A focus group study [17] indicated similarities and differences between writing assignments in first-year composition and engineering laboratory courses. The similarities include writing for an audience with a purpose in mind, employing rhetorical appeals, and using evidence as support, while the differences are in how these elements were employed in the context of engineering labs. It is obvious that engineering undergraduates struggle when they apply their prior writing knowledge and skills learned in humanities or sciences to engineering, which is a distinct discipline.

This study focuses on engineering undergraduates who struggle in lab report writing for their entry-level engineering laboratory courses, primarily offered in the 2nd year of the four-year plans. The 2nd year or sophomore engineering lab courses can be the students' first experience writing a discipline-specific genre for a technical audience. This study aims to investigate the areas of improvement and difficulties with lab report writing in lower-division engineering laboratory courses across three universities: an urban, commuter, public research university; an urban, private, teaching-focused university; and a rural, public, teaching-focused university. The direct assessment of students' (n = 64) lab report samples was performed to produce a quantitative analysis using the engineering lab writing outcomes established by the engineering-writing faculty's collaborative research work [17]. A rhetorical analysis, the other direct assessment, was conducted with selected lab report samples to provide a qualitative analysis.

2. Methods of Approach

2.1 Student lab report sample collection

We recruited student volunteers in the six sophomore-level civil, electrical, and mechanical engineering courses at three different universities, consisting of a polytechnic university, a liberal arts-focused private university, and a branch campus of a research-one land grant university in the academic years of 2019-2020 and 2020-2021. The student volunteers signed their consent, which was approved by each institution's internal review board (IRB). A total of sixty-four students (n = 64) participated in providing their lab report samples. We collected their early reports to investigate areas of learning where students could complete tasks with their prior writing knowledge and initial guidance. Their late reports were also collected to study areas of learning where students could improve tasks with interventions such as appropriate feedback or instructions from lab instructors. The comparisons between students' early and late lab reports can provide areas of struggle where students could not improve.

2.2 Student lab report sample evaluation process and instrument

All the sample lab reports were assessed using the nine engineering lab report writing outcomes developed by the authors[Ref]. A panel consisting of the five engineering faculty evaluated all the samples. The extensive norming session for the developed rubric (need improvement = 1, satisfactory = 2, exemplary = 3) was conducted before the full-scale evaluation. Individual panelists carefully read one sample to provide 1 to 3 for each lab report writing outcome. One sample was assessed by two panelists.

Table 1. Lab report writing outcomes [17]: 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.	Introduction
2) Present experimentation processes accurately and concisely.	Methods
3) Illustrate lab data using the appropriate graphic/table forms.	Results
4) Analyze lab data using appropriate methods (statistical, comparative, uncertainty, etc.).	Results and Discussion
5) Interpret lab data using factual and quantitative evidence (primary and/or secondary sources).	Results and Discussion
6) Provide an effective conclusion that summarizes the laboratory's purpose, process, and key findings, and makes appropriate recommendations	Conclusion
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 Classification of two groups: Satisfactory vs. Needs improvement

The scores of the lab report samples from the early labs were used to group the students into two categories: satisfactory versus needs improvement. The satisfactory group is the students who resulted in 2 or better in their early lab report samples' grand average, which is the average of scores in nine outcomes from the two panelists. The needs improvement group can be defined as the students who received less than 2 in their early lab reports' grand average. Out of 64 students, 19 students, or approximately 30% of students, were in the satisfactory group, while 45 students, or approximately 70% of students, were in the needs improvement group. Figure 1 presents each group's average scores of lab report writing outcomes and the grand averages. It clearly shows the satisfactory group students' samples received 2 or better on average from all the outcomes except outcome 1: addressing technical audience expectations, which is an average of 1.98. The highest-scored outcome was outcome 8: demonstrating appropriate genre conventions. The reports written by this group can be considered high-quality or well-written reports to satisfy the panelists' expectations on lab report writing.

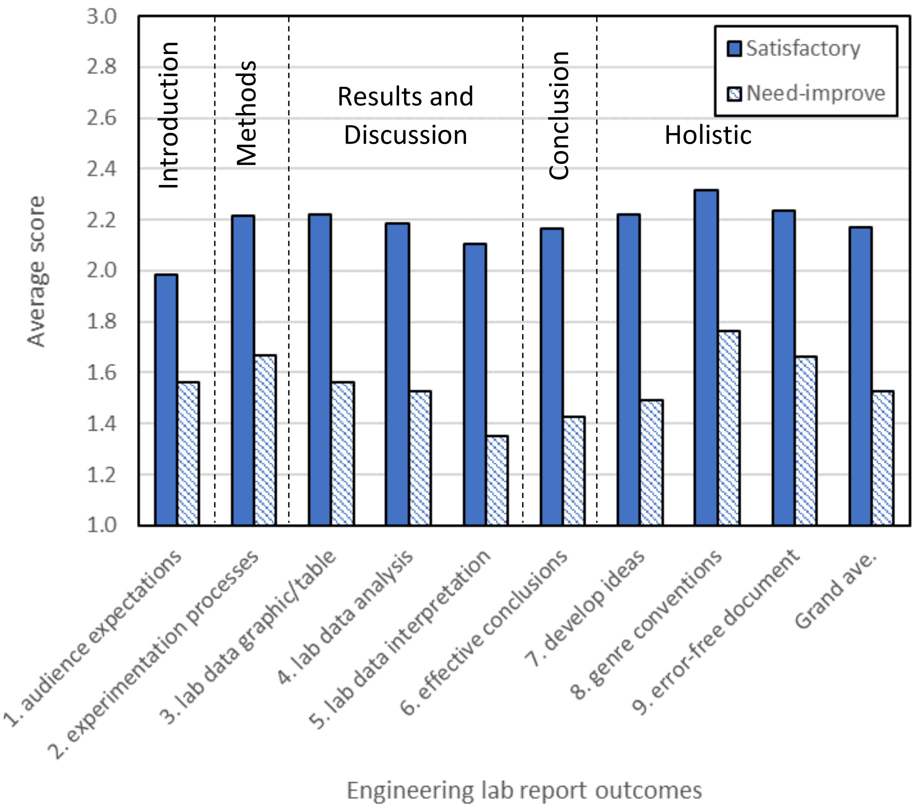

Figure 1. Average scores of the nine lab report writing outcomes and grand averages of the early lab report samples for the satisfactory and the needs improvement groups.

Figure 1 also shows the needs improvement group (n = 45)'s average scores in the nine outcomes and a grand average of 1.52. None of the outcomes reached 2 or a satisfactory score. The highest three scored outcomes included outcomes 8 (an average of 1.76), 2 (an average of 1.67), and 9 (an average of 1.66). The scores from the needs improvement group in demonstrating lab report genre convention, writing experimental processes, and providing an error-free document were better than those in other writing outcomes. The worst three scored outcomes included outcomes 5 (an average of 1.34), 6 (an average of 1.42), and 7 (an average of 1.49). This group of students struggled to interpret lab data, provide a productive conclusion, and develop ideas in their early lab reports.

3.2 Qualitative analysis results of the early lab report samples from the two groups

Out of 64 students, 19 students were able to write lab reports for their early labs that were deemed satisfactory by the panelists. The panelists felt that the lab report samples from these 19 students displayed the typical qualities expected of engineering lab reports. These reports have an introduction-body-conclusion structure, and the body contains methods, results, and discussion sections typically required for the engineering lab report genre. The introduction section provides the purpose, context, and background information to address the technical audience's expectations. The methods section includes accurately and concisely listed experimentation processes. The results and discussion sections contain lab data presentation using the appropriate graphic/table forms, lab data analysis using appropriate methods, and lab data interpretation using factual and quantitative evidence. The conclusion section summarizes the laboratory's purpose, process, and key findings, and makes appropriate recommendations. These reports holistically possess effective reasoning and productive patterns of organization, appropriate genre conventions, and error-free documentation.

A representative of this satisfactory group, Victor (pseudonym), includes a report from a binary adder and subtractor circuit lab, the early lab in a sophomore-level digital circuit course. In his lab report, Victor demonstrates an ability to adapt to the genre, audience, and purpose of the assignment: he writes to an audience of fellow engineers who want to understand his experimental findings and possibly replicate his procedures. Overall, he writes without using first or second person pronouns and provides thorough detail so that a reader can understand his report without reading the laboratory assignment that prompted it.

For example, demonstrating familiarity with the technical report genre, he includes an introduction that provides the technical background and the objective of the lab, as demonstrated in the following quotation:

> The binary adder and subtractor circuits are designed to perform addition and subtraction operations of a set of binary numbers. The binary addition operation is made up of an addend and augend, while the binary subtraction operation is made up of a minuend and a subtrahend. The binary adder and subtractor circuit along with two integrated switches and an integrated light bar allowed two four-bit binary values to be specified using the

> integrated switches and the result of the binary addition or subtraction to be projected as four-bit binary value on the LED bar. The purpose of the experiment was to demonstrate how the addition and subtraction of binary numbers can be done using a circuit, 4-bit adder chip, and the two's complement of number values. The goal of the laboratory experiment included the familiarization of binary addition and subtraction and the two's complement of four-digit binary numbers. The laboratory experiment also included the familiarization of the implementation of schematic diagrams, and the requirements needed to troubleshoot difficulties in the construction and implementation of schematic diagrams.

Victor's methods section highlights the necessary steps from the lab so the readers can repeat the lab activities by reading the section. This section is written as a numbered list using the scientific passive voice. Each numbered step reports on what was done; an engineer could reproduce these steps, but they are distinct from a set of user instructions.

This student's results/discussion section begins with presenting the data in table form. The table has a well-constructed title, and it is used to explain the inputs and outputs used in the lab. He included the table's source in italics on the bottom. This table is readable outside the context of the lab assignment.

Completed Table (Binary Subtractor Circuit)

Decimal Minuend A	Decimal Subtrahend B	Decimal Difference D = A-B	Calculated Binary Minuend A (4 bits)	Calculated Binary Subtrahend B (4bits)	Predicted Binary Difference D (4 bits)	Observed Binary Difference D (4 bits)
5	2	3	0101	0010	0011	0011
5	-2	7	0101	1110	0111	0111
-5	3	-8	1011	0011	1000	1000
-5	-3	-2	1011	1101	1110	1110

Source: Dr. John Lynch, Lab 1, Table 2

In addition to well-formatted tables, Victor's results/discussion section includes an overview of the lab data, the practical aspect of the lab work, and the problem-solving during the lab.

> The data observed from the binary adder and subtractor suggests that not only can circuits before both binary addition and subtraction and do so accurately, but it also demonstrates how technology can be implemented and made to simplify a task that could become tedious over time. Both of the constructed circuits in the experiment quickly and accurately performed addition and subtraction of two binary numbers respectively. One problem that was encountered during experimentation was in the design of the circuit on the solderless breadboard, a ground line was not attached to a pin corresponding the highest pin number on the 74LS283 4-bit adder chip. The problem was solved through troubleshooting of the binary subtractor schematic.

Victor includes multiple examples of lab activities in the results/discussion section. This information provides how he achieved the binary codes, which are the main deliverable of the lab.

> *Example of binary addition with two's complement:*
>
> 5+(-2) = 3
>
> Decimal 2 in Binary: 0010
>
> Inverse: 1101
>
> Inverse +1 = 1110
>
> Decimal -2 in Binary = 1110
>
> 0101+1110 = 0011

His lab report wraps up with a long conclusion. He detailed the troubleshooting process here; however, it contains the lab objective and the summary of the lab processes and significant results.

> The laboratory experiment demonstrated the steps and materials required to successfully construct and use binary adder and subtractor circuits. The observations and calculations made in the laboratory experiment demonstrated that both manual and circuit addition and subtraction are effective and accurate when it comes to adding and subtracting 4-bit binary numbers. The laboratory experiment showed that circuits can be utilized to simplify and decrease the time needed to perform each individual binary addition and subtraction calculation. The experiment went as planned except for an issue encountered with the construction of the circuit, the binary subtractor circuit did not work as expected as the results for the subtraction of negative binary values produced incorrect binary values. The problem was found after troubleshooting of the schematic to be caused by the lack of a ground connection on pin ten of the74LS240 octal inverting buffer chip. The laboratory experiment also demonstrated how a solderless breadboard jumper wires, 5-pin 10 K ohm resistors, 10-pin 330-ohm resistor, tactile push-button switches, 74LS283 4-bit adder chip, 74LS240 octal inverting buffer chip, and a 10-segment LED bar can be used in an experimental setting to observe binary addition and subtraction, alongside the two's compliment.

The needs improvement group's lab samples do not yet possess the expected characteristics of engineering lab reports. A representative of this group, Michael (pseudonym), includes a report from a logical circuits lab, the first lab in a sophomore-level digital circuit course. Throughout the report, this student writes as if he is providing answers to questions asked by a teacher instead of reporting on procedures to a fellow engineer. This report doesn't have subheadings and is overall missing important context.

He begins with an introductory paragraph that introduces the lab objective and overall lab processes, but it is mostly a repeat of the lab handout content. The introduction also uses first person language as if reporting on group work to a teacher instead of writing in formal style to a professional colleague:

> This lab was to demonstrate logical And, Or, and Not gates when used in logical circuits. During this lab our team constructed 3 different circuits to learn the outcomes of different current configurations that led the different outputs of the logic gates. The first two experiments were just to prove that the logic gates acted in accordance to their truth tables, and the third experiment was to see the delay of the logic gates as they change their state.

After the introductory paragraph, his report includes paragraphs related to the experimental processes with many distracting grammatical and style errors, such as verb tense and number inconsistency. The student also uses second-person language and imperative verbs ("connect two of your wires") to describe procedures. This is a typical genre feature of a set of instructions, but not in a report, suggesting the student is unclear about the purpose of this section or the report genre in general.

> To set up the first experiment our team place a 74LS32 logical OR gate into our breadboard such that none of the prongs were in the same line, to do this our breadboard had an indent meant for placing such logic gates. Then connect the power source to the breadboard into the power lines. then connect the power to the logic gate power and connect it's ground prong to where your negative or ground end is, schematics for these logic gates componentes are available on the internet. connect two of your wires to ground and connect them to the inputs of the same logic gate, and connect a wire from your multimeter to the logic gate output. next connect the multimeter to ground and the output and configure it to measure voltage now you have set up a logical OR gate circuit in logical 0,0 move the two input wires between ground and power to change their logic value. Record your output voltage with above 1V being a 1 and below being 0.

Michael reports the results and discussion after introducing experimental processes with the data tables and images; however, the report doesn't contain any explanation about the data tables and images. The following data table example does not follow the conventions for the table in engineering lab reports (for example, table number and title, axes labels, and legend). Again, this suggests a student writing to a teacher that already knows the context instead of writing to a professional colleague who needs the entire context.

Timing table to for the third circuit shown here

Michael wraps up his report with the following conclusion paragraph. It states the overview of the experimental work completed during the lab. This doesn't contain any meaningful technical knowledge drawn from the lab activities. The conclusion continues to use first-person language and contains distracting errors that affect clarity.

> From that data collected in the first two experiments my team has concluded that the logic circuits were identical to their truth tables, and from the third experiment the team has measured and demonstrated that these logic gates have a transition time between their high and low outputs. though this my team has proven that these logic gates are correct and can proceed to use them in further experiments, understanding how they work and an idea of what they should be in a given circumstance.

Other samples in the needs improvement group show similar patterns. Students in this group might struggle to understand the engineering lab report genre expectations from the instructional materials given for the first lab. The rhetorical features of their reports suggest they don't have a clear grasp of the intended audience or purpose of a typical lab report.

3.3 Areas of improvement in lab report writing for the needs improvement group

Students in the needs improvement group (n = 45) could not demonstrate satisfactory-level lab reports in their early labs. Lab instructors of the six participating lab courses might provide appropriate interventions, such as feedback, to improve their lab report quality. Out of 45 students, only six students received satisfactory scores (2 or higher) in their late labs. The majority of students (39 out of 45) in this group wrote lab reports with less than 2 in their late labs.

This doesn't mean students in this group failed to improve their lab report quality. Figure 2 compares the average outcome scores of the early labs with the late labs. Note that the average scores improve across all lab report writing outcomes, and the percent improvement ranges from 4% (outcome 8) to 27% (outcome 5). The largest improvement was observed in lab data interpretation, which had the worst average score in the early labs. Outcome 4 has the second highest improvement, while the third largest improvement is observed in outcome 3. These three outcomes are related to lab report's results and discussion section, which is the most significant section in the report format. Students are expected to present the lab data, describe the findings from their lab data analysis, and interpret the findings by connecting them to engineering principles. Improved scores in outcomes 3 to 5 might mean that the interventions by the lab instructors impacted undergraduates' learning in lab data presentation using graphic/table forms, lab data analysis, and lab data interpretation.

Although this is a positive sign of lab report quality improvement from the students who originally struggled in their lab writing, outcomes of 1, 5, 6, and 7 are still far below the satisfactory rating. Outcome 1 was not improved much. Outcome 6 is the worst.

This indicated that the engineering undergraduates still struggle with addressing technical audience expectations, lab data interpretation, effective conclusion writing, and idea development, even with instructions and productive feedback from the lab instructors and/or teaching assistants.

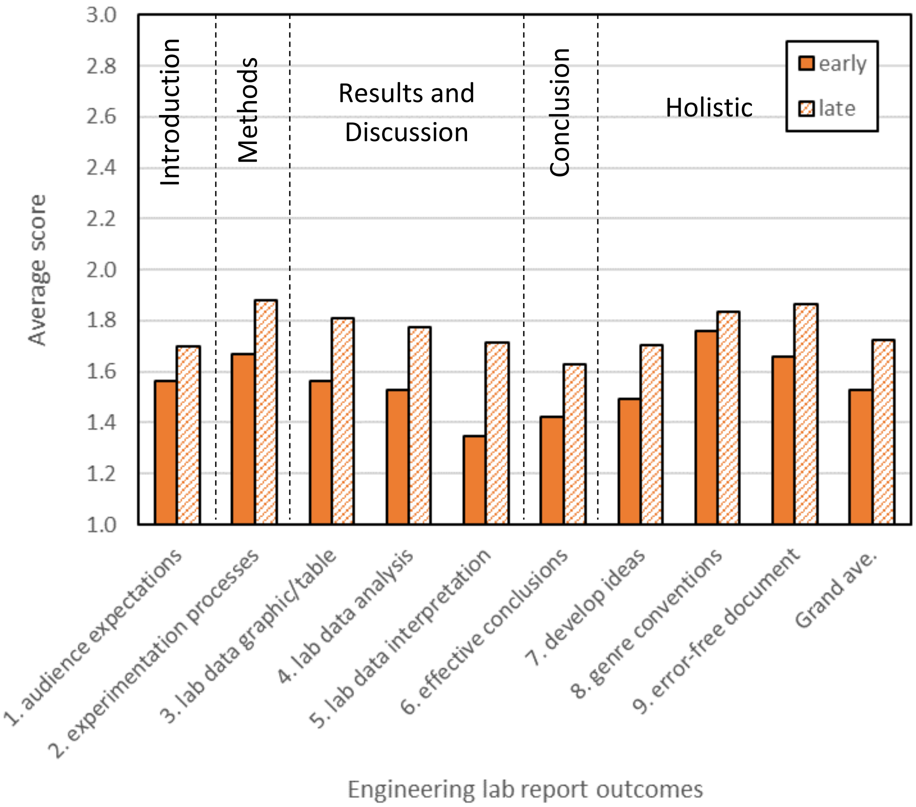

Figure 2. Average scores of the nine lab report writing outcomes and grand averages of the early and late lab report samples for the needs improvement group.

Michael's report sample in his last lab of the sophomore-level digital circuit course shows improved areas in lab report writing. His report includes sub-headings, such as Introduction, Materials, Procedure, Results, Discussion, and Conclusion. However, his introduction section still describes the overview of the lab activities.

> This lab tasks teams with specifications of a circuit that we are to optimize and build based on the description given. To do this, teams will have to work under cost constraints to show that they know how to create equivalent circuits with different parts while keeping costs in mind to create a cost effective solution.

The sample's procedure section becomes significantly shorter in his last lab; however, its grammatical mistakes are minimal. Compared to the procedure section of the previous lab, the student has stopped using second-person pronouns and imperative verbs, which is an improvement, but only one sentence of this section reports in the past tense on what the team actually did. The other three sentences are either indicative or an inappropriately conversational use of the modal verb “would”.

> The first step to this lab is to create the truth table and karnaugh map to be able to find the formulas that help in formulating a solution. Then would be selecting the most cost effective bridges to implement. After making a decision, my team chose to use a NOR – OR implementation as these components are cheaper than the rest. The last step would be conversion from And-OR to NOR - OR, and then implementation.

Michael’s data presentation style is unchanged; however, he included a short discussion about the lab data in this report.

These are our conditions and truth table used to derive the K-map

Sp<=45<=45 d Limit (mp>65)	a	b		a	b	c	d	f	g	SP DL	SPD
45	0	0		0	0	0	0	0	0	45	<=45
55	0	1		0	0	0	1	1	0	45	45< x <=55
65	1	0		0	0	1	0	1	1	45	55< x <=65
Unus<=45d	1	1		0	0	1	1	1	1	45	>65
				0	1	0	0	0	0	55	<=45

> This demonstration helps in teaching the concept of circuit conversion, along with giving a circumstance when you would be asked to work with different componentes to cut costs. This is an example of how to conceptualize this process and how to implement it, along with proving it.

The report wraps up with the following conclusion section which continues to contain distracting errors.

> This lab is the demonstration of circuit equivalence and demonstrates a team’s ability to convert circuits from one form to another. In a semi realistic circumstance As our team has proven out ability work circuits

As shown in the case of Michael’s first and last lab report samples, many students in the need for improvement group could show a marginal improvement in their lab reports’ quality. Michael obviously improved in outcomes 8 (conventions) and 9 (error-free documenting). It is clear that he continued to struggle with other outcomes.

4. Conclusion

This paper investigates the areas of improvement and difficulty in lab report writing from lower-division engineering laboratory courses. Lab reports in early and late labs from sixty-four students (n = 64) in a total of seven sophomore-level civil, electrical, and mechanical engineering courses at three different universities were collected and evaluated using engineering lab writing outcomes. A rhetorical analysis of two students' lab reports was conducted to compare the aspects of improvement and difficulty qualitatively.

The analysis results indicate that 30% of a total of 64 students could write their first lab reports at a satisfactory level. The lab report samples of this satisfactory group (n = 19) received average satisfactory-level scores from all the outcomes, except the outcome with slightly lower than the satisfactory level. A sample report from the satisfactory group proves a student in the group could demonstrate the ability of audience awareness, control lab report conventions, and deliver detailed technical information from the lab.

70% of the participating students did not receive satisfactory grades in their reports in the early labs. Although the needs improvement group (n = 45) could not meet the satisfactory scores in any writing outcomes, they struggled the most in outcomes 5 (lab data interpretation), 6 (productive conclusion), and 7 (idea development), which often require evaluation and creation in Bloom’s Taxonomy. We could find the improvement of the needs improvement group’s lab reports in their later labs. The average scores of all nine outcomes improved from the early lab to the late lab by 4% to 27%. The greatest improvement was observed in outcomes 3 (lab data presentation), 4 (lab data analysis) and 5 (lab data interpretation). The interventions by the lab instructors could impact undergraduates’ learning in these areas. However, the needs improvement group’ late lab report average scores were less than the satisfactory level across all nine outcomes. The four lowest-scored outcomes of 1, 5, 6, and 7 indicated that the engineering undergraduates still struggle with addressing technical audience expectations, lab data interpretation, effective conclusion writing, and idea development even with instructions and productive feedback from the lab instructors and/or teaching assistants. This suggests additional pedagogical interventions are necessary to ensure all students are reaching a satisfactory level of achievement in lab report writing.

5. Acknowledgement

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