Writing a Laboratory Report for Senior Electrical Engineering Courses: Guidelines and Recommendations

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Abstract- Improving students’ soft skills is considered one of the important pillars of effective learning. Soft skills include various abilities such as communicating effectively using communication and writing skills. This paper focuses on the improvement of writing skills, particularly when writing a persuasive technical mini-project or laboratory report. The report should encompass all the factors that enhance levels of organizing and writing technical reports using the appropriate language and conventions. Improving the writing skills of students, especially electrical engineering students, falls under outcome ‘g’ of the Accreditation Board for Engineering and Technology (ABET) student outcomes. Hence, this paper introduces recommendations and guidelines for the structure of mini-projects or laboratory reports for senior (level 4 and level 5) electrical engineering courses. Moreover, it contains a discussion of a case study conducted over eight consecutive terms to assess student performance in three different courses using the suggested structure. In addition, the researcher discusses the results of a student questionnaire exploring students’ satisfaction with the proposed report structure.

Index Terms—Electric machines course, teaching electric machine, ABET, lab. report, communication skills, writing skills, electrical engineering, effective learning.

I. INTRODUCTION

HE electrical and Computer Engineering Department (ECE), College of Engineering, Sultan Qaboos University (SQU) achieved ABET accreditation in 2007. The ABET accreditation is renewed every six years. The department achieved the second cycle in 2013 and currently is working towards third cycle renewal in 2019 [1]. During the preparation of the required self-study report in 2012, the department’s Accreditation, Curriculum, and Timetabling Committee (ACTC) found that outcome g (ability to communicate effectively) [2] fell short of the required threshold. Thus, the committee created an ad-hoc committee to find suitable methods of improving students’ communication skills. One of the requirements is to improve students’ writing skills. Before applying the structure proposed in this paper to senior courses, laboratory reports consisted of forms with blank spaces for students to complete, which did not allow them the opportunity to improve their writing, presentation, and other skills. Thus, the ad-hoc committee commissioned the author to prepare appropriate recommendations and guidelines for writing professional mini-project or laboratory reports. The department intends to implement these recommendations and guidelines as departmental guidelines all instructors can use or modify according to their course needs, with the target of improving students’ writing skills. Therefore, the author focuses on the improvement of students’ communication skills, specifically their report-writing skills.

To this end, the author examines the benefits of using the proposed structure in section II and describes the proposed report structure in section III, which contains nine subsections. In addition, factors students should consider while completing reports appear in section IV. Finally, the author discusses a case study conducted over eight terms and students’ feedback in sections V and VI.

II. BENEFITS OF USING A PROFESSIONAL REPORT FORMAT

In engineering pedagogy, and specifically in electrical and computer engineering, the laboratory is an important tool for understanding theory. The laboratory assists students in improving their practical laboratory skills and in confirming the phenomena studied. Hence, the author believes in the saying “I hear and I forget, I see and I remember, and I do and I understand” [3]. However, this raises the question of how students can prove they understand the theory by confirming the practical work. The incontrovertible answer is that students need communication skills to explain their understanding, whether orally or in a written (report) format.

Numerous benefits are associated with students receiving training on writing laboratory reports by following guidelines and recommendations that cover various ABET outcomes, such as outcomes b, d, k, and g. For example, training improves individual skills, enhances teamwork, increases professional responsibility, enhances editing skills, improves search skills if a literature survey is needed, and expands language skills if the report is written in a language other than the mother tongue. In addition, it teaches data manipulation techniques, provides experience in analysing and interpreting results, improves software skills when simulation is used to confirm the practical results and theory, and offers training for answering open-ended questions and reaching conclusions that align with the laboratory objectives [4–8].

III. RECOMMENDED REPORT STRUCTURE

According to ABET outcome g, a professional report can be defined as a technical report which organizes information in a clear, logical sequence, conforming to prescribed guidelines, to make it easy for a reader to understand; it is relevant, focused, free of errors, and shows mastery of the chosen language’ [2]. Consequently, the report has a frame that contains the main points authors should cover and consider while writing. The typical professional mini-project or laboratory report can include up to 15 sections. These include a title page or cover page, a table of contents or outline, an objective or abstract, a nomenclature and abbreviations section (if necessary), an introduction that includes an overview of the background theory, and a list of equipment or components used. In addition, the report can...
contain sections outlining the design methodology, constraints (if any), procedure, results, analysis and discussion of results, answers to questions given in the laboratory manual (if any), experiment or project comments or observations, a conclusion, an appendix, and references [8—11]. Students should use these 15 items to create checklists they can use to ensure they have included all the necessary sections and information before submitting their reports.

A. Cover Page and Table of Contents

The cover page, a single page, should include the university logo followed by the university, college, and department name. In the upper half of the page, the experiment title and number should appear. In addition, it should include the course code, the course name, section number, and name(s) of the instructor(s). If it is a laboratory report, the title of the experiment should be copied from the laboratory manual, but if it is a mini-project report, the title should provide a concise indication of what was done (maximum two lines). The lower half of the page should contain the student(s) name(s) and ID number(s) as well as the date of the experiment and the due date of the report.

Finally, students must add a declaration to confirm that their manuscripts do not contain plagiarised content, and all students involved in the creation of the reports must sign these declarations. Alternatively, one student can sign on behalf of others as a part of professional responsibility, and this student must inform those who collaborated on the report that he or she will sign on their behalf. For example, the declaration used in the ECE Department at SQU reads, ‘I/We, _________, certify that I/we have neither given nor received any unauthorized aid in this work, and I/we indicated all references including those from the internet.’

The table of contents typically appears as the second page of a report. It should indicate report sections and the page numbers on which they appear. Although one can include subsections in the outline, it is not recommended to do so.

B. Abstract/Objective, Nomenclature, and Introduction

The abstract or objective section provides the first impression of the report. Therefore, authors should carefully choose words and phrases to attract the reader’s attention and motivate the person to read the body of the report. This short paragraph (not more than 250 words [7]) briefly describes the aim and outcomes of the mini-project or experiment in a concise statement that includes specific information. It seldom contains equations, figures, or references [7]. If a report includes numerous equations or design symbols, it is better to include a section listing the nomenclature and abbreviations after the abstract than to define each symbol in the text. This allows the reader to concentrate on the report material without the distraction of searching for symbols scattered throughout the text.

The introduction prepares the reader for the rest of the report. To avoid including irrelevant information, students should limit this section to a maximum of two A4 pages. It should include and justify the importance of the experiment or mini-project. Moreover, it should refer to the relevant theory and important previous studies if appropriate. In this case, laboratory manuals may not be sufficient. Thus, students should visit the library to search for information on the background or theory of the subject, or even literature surveys in textbooks or other reference materials. However, students should not copy information from laboratory manuals or other references. They must reference any information taken from other sources, as failure to cite sources leads to plagiarism. Furthermore, students may add equations and explanatory diagrams to cover the background theory. In addition, writing the introduction and abstract last facilitates the writing process, as these sections contain an overview and summary of the information presented in the body of the report.

C. Equipment or Components Used

The report must contain a list of components and equipment used. Equipment information should include the name of each piece of equipment and its function, which includes the range for measurement devices (e.g., one voltmeter to measure supply voltage [0–300 V] and load voltage [0–300 V]). Technical data or data sheets for equipment, components, or devices appear in the appendix section.

D. Design

Although laboratory experiments that follow steps outlined in specific laboratory manuals may not contain design problems, reports of activities that include designs, such as mini-projects, should include the design methodology. For some mini-projects, the design process is considered the main part of the report, thus students should ensure that they add design items. These include design requirements, constraints, limitations and assumptions, and trials and modifications as well as realistic constraints, the final design that meets the requirements with any constraints and limitations, design justification and verification, and, finally, the steps or components required to implement and test the functionality of the design [2], [11]. Fig. 1 shows the items students should include or highlight in the report for the design section.

![Fig. 1: Main items of the design section in laboratory or mini-project report](image)

E. Procedure

This section describes how to perform the experiment in a systematic manner to obtain the required results. Numbering the steps is preferred, as this allows the reader to easily duplicate the experiment. Students should redraw rather than scan figures such as electrical circuits, connections, and block diagrams and flowcharts that illustrate the information in the procedure section. Additionally, students should reference all images, whether scanned, copied, or adapted.

F. Results

This section contains the findings of the experiment. Most experiments yield numerical values or scope figures as results or raw data. It is preferred to present these data in either tables or graphs, or both. Students should distinguish between calculated and measured values where lines or curves can represent calculated or simulated data, but discrete points or marked lines or curves can represent
measured data or data calculated from measured values. They should identify these marking signs in the legend [9], [10]. Moreover, it is important to determine axis limits and major and minor ticks and to add a grid (if necessary), axis titles that include units in SI format, and a figure title (if necessary).

Figures should include captions when they illustrate practical results, such as scope results where voltage per division or time per division requires identification. In addition, students should number figures in the order they appear in the text. Similarly, tables should have titles, and students should number them in order throughout the text. Although results are introduced in either table or graph form, the author should discuss the results in the text to guide the reader in understanding the information presented in the figure before jumping to the analysis and discussion of results section. For values calculated from measured data, students should detail at least one complete sample of calculation. However, this depends mainly on experiment requirements, as students should add each calculated point for some experiments.

G. Analysis and Discussion of Results

This section is the most important part of the report. Here students describe, analyse, and interpret the results obtained and present an interpretation of the measured and calculated data. In addition, they draw comparisons between expected and experimental results, determine whether the experimental results align with the expected results, and provide reasons for deviations from the expected results. Furthermore, this part includes simulation results (if required) to confirm the results described in the preceding section. Students should discuss the output from simulations that support the practical results and provide justification if there are any deviations. If required, error analysis appears in this subsection, and from a design perspective, it confirms and adds design verification. This section enhances ABET outcome b, specifically the B4 performance indicator [2].

H. Comments and Observations

This section is optional, and its inclusion depends on instructors’ requirements. Nevertheless, it is beneficial to students. During experiments, students record their observation in logbooks. They should document any information provided by instructors or laboratory engineers that supports the experiment or enhances students’ technical knowledge of safety precautions, level checks, current monitoring, measurement boundaries, adjusting measurement tools, connection priority, and any abrupt change in any parameter and its effect on the experiment.

To clarify this section, students receive an annotated model depicting an Ohm’s law experiment. It lists all the report structure sections in one report to show the students what a professional report looks like. It includes several examples of experiment comments: During the experiment, the student notices that there is no output from the DC-source voltage unless the current knob is adjusted to ‘on’ mode. The laboratory engineer provides numerous voltimeters and ammeters for the experiment and explains which one the student should use and why. The measurement devices could be DC devices or AC devices, and the range selection is important. Students should add comments such as these, as they facilitate the revision of experiments before practical laboratory exams.

I. Conclusion, Appendix, and References

The conclusion section is a single paragraph that contains the author’s overall conclusions relating to the purpose of the study, the significance of the findings, outcomes, usefulness, and advantages or limitations. In addition, it describes the actions that should be taken based on the study results. Like the abstract, the conclusion typically does not contain equations, figures, or references [7].

The appendix section follows the conclusion and contains data sheets for components as well as additional calculations, software code, graphs, pictures, and tables that were not included in the main body of the report. Each item should be contained in a separate appendix where it should be referenced in the body of the report. For example, in an electrical machines report, the appendix includes the machines’ nameplate information, test-rig picture, data sheet for components, and any extra data for measurement devices.

For the reference section, students should use one format such as IEEE or IET. The format depends on the instructor’s requirements listed in the laboratory manual or mini-project statement. Furthermore, it is recommended that students use either Microsoft Word’s built-in referencing system or EndNote software coupled with a word processing program.

IV. POINTS TO CONSIDER

Students should consider several points, listed in this section, while writing reports [4–10]. This list can be modified according to the needs of instructors and the nature of specific courses.

- Students should write in their own words and should not copy from books, laboratory manuals, or the internet; if they use material from other sources, they must cite the sources.
- Before submitting reports, students must ensure that they have included all the required components and that their reports are grammatically correct and free from spelling mistakes.
- Students should avoid long sentences and be concise—one word or two words are better than long phrases. In addition, passive voice is preferred to the first person (‘I’ and ‘we’).
- Students must avoid contractions (e.g., by writing ‘is not’ rather than ‘isn’t’, and ‘do not’ rather than ‘don’t’).
- Students should check that all tables and graphs are labelled with a title (if required), are numbered, have captions, and are referenced in the text.
- Students should confirm formatting and font choices with their instructors, but it is recommended to use Times New Roman.
- Report pages should be numbered.
- Values should be in SI units.
- Students should sign the non-plagiarism declaration statement.
- Students should attend the laboratory with logbooks and record in them all details about the experiments they conduct.
- Pre-lab work should be completed before entering the laboratory and not during laboratory sessions.
- Students can begin with any section when writing their reports, but it is recommended to leave the abstract, introduction, and conclusion to the end, as these parts
• are easier to write when one has obtained an overview of the complete picture.

V. CASE STUDY

Starting Since the Fall 2012 semester, the above recommendations and guidelines and the annotated model of the laboratory report have been available as part of course outlines and online on the SQU E-Learning page of the author [12]. Students should follow these guidelines when submitting reports. After obtaining approval from the head of the ECE Department, the author evaluated a sample drawn from students who attended his classes and followed these guidelines and the recommended report structure when submitting their laboratory reports. The students attended the author’s classes between Fall 2012 and Spring 2016, for four different courses, namely Electrical Machines (ECCE4358), Electrical Machines I and II (ECCE4356 and ECCE4357), and Power Electronics and Drives (MCTE4210). During this period, the author taught ECCE4356 three times (Fall 2012, Spring 2013, and Fall 2013) and ECCE4357 eight times, which means the latter course is offered every term. It should be noted that ECCE4356 is a prerequisite for ECCE4357. Other courses were presented once during this period. The MCTE4210 course was offered for mechatronics rather than ECE students in Spring 2015. According to the new department degree plan, the ECCE4358 course was launched in Spring 2016, and it subsequently combines ECCE4356 and ECCE4357.

Each course requires the completion of four experiments per term, three of which count towards the final grade. A group of three or four students submits one report, and students distribute the work between themselves without any interference from the instructor to improve team management and group work skills. The time allocated for laboratory report submission is two weeks from the completion of the experiment. In all courses, laboratory reports represent 10% to 12% of the overall grade; other assessment components are homework, quizzes, a term project, a laboratory exam, a midterm exam, and a final exam. The laboratory report is graded out of 100 marks because reducing the total marks makes it difficult to highlight shortcomings in each section, while higher total marks provide the opportunity to deduct marks easily for uncompleted sections. For example, from the author’s experience, if a student earns 60 out of 100, it motivates the student to cover more aspects in the next report. Although this is equal to 6 out of 10, if the same report is marked with a total score of 10, the mark would be lower. Hence, increasing the marking scale has two advantages: firstly, it prevents students losing a large portion of marks and, secondly, it motivates students to make a greater effort to address shortcomings in the subsequent reports.

Fig. 2 shows the average mark per experiment per course in each term. The blue columns represent the ECCE4356 course, the red columns represent the ECCE4357 course, the orange column represents the MCTE4210 course, and the magenta column represents the ECCE4358 course. The black line indicates the average of the three experiments per course per term. In addition, the number in the white circle represents the total number of students registered for the course.

![Fig. 2: The lab. grades for different course for subsequent eight semesters versus average per course](image)

![Fig. 3: Average grades for each course versus overall average grade for all courses](image)
Fig. 3 shows the average variation for each course (black line in fig. 2) with respect to the average of all courses and considering all students. The average grade for 371 students registered in 13 courses from Fall 2012 to Spring 2016, which represents around 85 to 90 reports, is 8 out of 10, as shown by the orange line in fig. 3.

One can make several comments and observations from figs. 2 and 3:

- In most cases, student performance improved gradually from the first laboratory report of the term to the last.
- As ECCE4356 is a prerequisite for ECCE4357, students performed better in ECCE4357 than in ECCE4356.
- The averages of ECCE4356, MCTE4210, and ECCE4358 are lower than the average of ECCE4357 because these students learn the format while completing ECCE4356.
- The cohort level and student numbers affect the average grade. As the number of students rises above 35, the average decreases.
- For a period of eight terms, the average grade for all students is around 8 out of 10.
- From Fall 2012, the average of courses is far from the overall average; in contrast, from Spring 2013, there is a minor deviation from the overall mean for all courses except the non-ECE course.
- Although the students’ laboratory reports and writing skills improved, several shortcomings in their laboratory reports need to improve, including punctuation, formatting, report consistency during formulation, and lack of references. Therefore, students need to focus on the final presentation of their reports and enhance their introductions, specifically by expanding the background sections by adding more references. Similarly, there is a lack of emphasis on the explanation of results, and students need more training on how to interpret results and how to conduct valuable discussions based on the practical results combined with theoretical or simulation results.

VI. QUESTIONNAIRE COMPLETED BY STUDENTS

The case study discussed in section V indicates that students’ writing skills improved through writing laboratory reports, as the average mark is around 8. This shows that the students’ performance is acceptable, as they developed and achieved satisfactory performance in some sections. Moreover, some groups achieved exemplary work in certain sections of the laboratory report. These comments stem from the instructor’s point of view. However, students also should contribute to the evaluation process by indicating their satisfaction levels and stating whether they feel their writing skills improved. Thus, after obtaining approval from the head of the ECE Department at SQU, the author administered a formal questionnaire to ECCE4358 students about the laboratory report writing guidelines. The completed questionnaires were archived in the department.

The sample consists of 31 students. Table I contains the questions, which required students to respond with strongly disagree, disagree, neutral, agree, or strongly agree.

From first impressions, the students were satisfied with this laboratory report structure. Because one student did not answer Questions 4 to 9, some questions were answered by only 30 students. When examining the questionnaire responses in detail, as shown in Table I and fig. 4, the following can be observed: 24 students agreed that the laboratory report structure supports technical and theoretical aspects, and 26 students declared that the structure supports ABET course outcomes. Most students were satisfied with the laboratory report submission time; 20 students strongly agreed with the two-week deadline. Twenty-four students felt that their writing skills had improved due to the laboratory report structure, but 8 remained undecided. Moreover, as for teamwork and professional responsibility, the survey shows acceptable results.

The majority of students were happy with the grading system out of 100 instead of 10 marks; around 21 students were satisfied with the assessment method. Question 9 shows that about 7 students disagreed about the workload. This is because many components per course are used to assess the students. The average student registers for about 15 to 18 credits per term. Consequently, some students feel stressed as the midterm and final examinations approach. Furthermore, the responses to Question 10 are satisfactory because not all the students like to do extra work, such as simulations, without being required to do so; on the contrary, about 21 students wanted to support their results and discussions using simulation results.

The grading system combined with detailed feedback shows that approximately 24 students were motivated to improve subsequent reports, as clearly indicated by the responses to Question 11. In addition, the answer to Question 11 reflects the high response (agree and strongly agree) of Question 12.

Table I: Students Questionnaire about lab. report with recommended guidelines

<table>
<thead>
<tr>
<th>Question</th>
<th>Strongly disagree</th>
<th>disagree</th>
<th>neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lab. report items support technical and theoretical parts</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>17</td>
<td>7</td>
</tr>
<tr>
<td>2. Lab. report supports course outcomes</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>18</td>
<td>8</td>
</tr>
<tr>
<td>3. Time allocated for lab. report submission is convenient</td>
<td>0</td>
<td>1</td>
<td>8</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>4. Lab. report improves my writing skills</td>
<td>0</td>
<td>2</td>
<td>7</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>5. Lab. report improves my skills in working with a team.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>6. Lab. report increases my professional responsibility</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>7. Lab report grade (out of 100) is convenient</td>
<td>0</td>
<td>3</td>
<td>7</td>
<td>16</td>
<td>5</td>
</tr>
<tr>
<td>8. Lab. report assessment method is effective to evaluate my report</td>
<td>1</td>
<td>6</td>
<td>4</td>
<td>14</td>
<td>5</td>
</tr>
<tr>
<td>9. Per Person, the work load for lab. report is appropriate</td>
<td>1</td>
<td>6</td>
<td>4</td>
<td>14</td>
<td>5</td>
</tr>
<tr>
<td>10. Adding simulation results to the lab. report using MATLAB/SIMULINK for example increases my understanding for practical and theoretical parts</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td>11. My motivation to improve lab. report with peer assessment is increased</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>16</td>
<td>6</td>
</tr>
<tr>
<td>12. Instructor feedback helps in improving my subsequent lab. reports</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>13. I can learn from the other group’s report.</td>
<td>0</td>
<td>3</td>
<td>13</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>14. In general, I am satisfied with the lab. report as it improves my personal skills.</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>21</td>
<td>6</td>
</tr>
</tbody>
</table>
As for Question 13, the author considers the student response quite logical, as many students, when they receive their assessed reports, wait until the laboratory exam before reviewing others’ reports to note other groups’ shortcomings. Generally, 27 students were satisfied with this laboratory report structure. The pie chart in fig. 5 shows the percentage of the average for each response with respect to all responses (432 responses). This shows that 75% of the class falls under the ‘agree’ category, while 8.94% falls under the ‘disagree’ category.

CONCLUSION

Communication skills such as presentation and writing skills have become an important part of effective learning, especially in electrical engineering pedagogy. This paper highlights how students can improve their writing skills through mini-project or laboratory reports. The author introduces recommendations and guidelines for the report structure by explaining in detail what each section in the report should include. In addition, he describes a case study conducted over four courses (level 4) from Fall 2012 to Spring 2016. The results of the case study indicate that although students’ writing skills improved, they need to improve further, especially in areas such as formatting, punctuation, and writing the introduction. Students should not depend on only online references and their laboratory manuals but also should review textbooks, journals, and conference papers related to the mini-project or experiment topics. Moreover, during the marking process, the author noticed that the weakest point in the reports is that students still cannot interpret their findings and discuss the deviations from or alignment with theoretical or simulation results. These shortcomings would not have been discovered if the old report style, which involved filling in a form had continued to be used. Most of the students (75%) were satisfied with the recommended structure of laboratory reports, as it improved their soft skills, enhanced teamwork and professional responsibility, and broadened their understanding of the mini-project or experiment topics.

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REFERENCES

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