Purpose:

This guide is intended to provide the basic information about technical communication conventions, formats, and style. This guide also contains advice about common writing errors, writing in a diverse community, and developing a stronger writing vocabulary.
Additional Resources

*OSU Writing Center*
The Writing Center at the Center for the Study and Teaching of Writing offers free help with writing at any stage of the writing process for any member of the university community. Schedule an appointment here: https://cstw.osu.edu/writing-center

*APA Formatting Guide*
https://owl.english.purdue.edu/owl/resource/560/01/

*Purdue University Online Writing Lab (OWL)*
The Online Writing Lab (OWL) at Purdue University houses writing resources and instructional material, and we provide these as a free service of the Writing Lab at Purdue. Students, members of the community, and users worldwide will find information to assist with many writing projects. https://owl.english.purdue.edu/owl/
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Introduction

Technical Communication Overview

“Technical Communication” is a broad category that includes numerous ways of sharing information about specialized subjects. Some examples include user guides for software, product specifications, patents, assembly instructions, technical diagrams and illustrations, and websites about medical products. The most important principle of technical communication is that the information be presented in a way that is clearly organized, audience-appropriate, and easily understood.

This guide will introduce you to the general principles of technical communication and offer specific advice for completing the assignments in this class (including grading rubrics and sample documents).

Technical Communication in Engineering 1181/1182

The primary purpose of working in the laboratory is to build knowledge and solve problems by collecting data and testing hypotheses.

In addition to completing the labs themselves, you will be asked to produce documents which:

- record your process
- document and analyze data
- provide conclusions which explain the significance of your results

Progression of Assignments

The communication assignments in this class will help you to build skills progressively; they will be relatively simple in the beginning, but will become more detailed and complex as the course progresses. These assignments can be broken down into four basic types, which will be described in detail later.

Figure 1: Progression of Assignments
Evaluation of Assignments

You will work in teams to complete lab experiments and after-communication assignments. Some will have a team component AND an individual component, while others are completely team assignments.

For each assignment a sample document and grading rubric will be provided. (You will have a chance to practice grading sample assignments in class.)

Technical Communication Style

STYLE OVERVIEW
Above all, technical communication is concise and clear.

Use 3rd person and past tense
- The preferred style in engineering is 3rd person and typically past tense because the writer is reporting activity that already happened. Present tense is acceptable when writing about a topic rather than, for example, a previous procedure, lab, research process, or results of an experiment or test.

Avoid the use of any first or second person pronouns
- The focus of technical documents is on the activity, process, procedure, results, etc., rather than on the person who completed that work. Revise your sentences to avoid using first person pronouns such as I, we, us, our, you.

Avoid emotional statements
- Incorrect: “the process ran beautifully for five minutes.”
- Correct: “the process ran for five minutes.”

Use passive voice deliberately
- When a person could be identified, use passive to avoid that usage:
  - Incorrect: “We noticed that the meter registered the greatest change at…”
  - Correct: “It was noticed that the meter registered the greatest change at…”
    - “This lab team noticed that the…”

To provide the most precise information also use technical terms and jargon pertinent to the lab procedure and topic.
WRITING CONCISE SENTENCES

Use short sentences
Readers of technical communication have only limited time to read and process your message. To save the reader’s time, develop short to medium length sentences. Avoid constructing complicated sentences. For complex messages, split thoughts into short to medium sentences and use parallel structure (you can find more detailed information in the “Appendix: Writing Strong Sentences: Using Parallel Structure” section, see the Table of Contents for the exact page number).

Replace Wordy Phrases with a Single Word

- Make an adjustment adjust
- Make a decision decide
- Provide assistance assist
- At the present time now
- Due to the fact that because
- In order to to
- In the near future soon
- Prior to the start of before
- Until such time as until
- In the event that if
- Do not hesitate (omit—just invite an action)

Tighten Writing Style

Example: Keep this information on file for future reference.
Better: File this information.

Example: Ideally, it would be best to put the billing ticket just below the monitor and above the keyboard.
Better: Place the billing ticket between the monitor and the keyboard.

Example: We need to act on the suggestions that the supervisors offer us.
Better: We need to act on the supervisor’s suggestions.

Example: There are three reasons for the success of the project.
Better: Three reasons explain the project’s success.
VARYING SENTENCE STRUCTURE
Guidelines for sentence structure:
1. Edit sentences for conciseness.
2. When sentence topics are complicated or full of numbers, keep sentences short.
3. Group words in medium-length sentences into chunks that the reader can process quickly and that show the relationship between ideas.
4. When a sentence is long, keep the subject and verb close together.
5. It is acceptable to use bullets to break up listed thoughts.

Original Text
Movements resulting from termination, layoffs, and leaves, recalls, and reinstatements, transfers in, transfers out, promotions in, promotions out, and promotions within are presently documented through the Payroll authorization form.

Revised with varied structure
The Payroll Authorization Form documents the following movements:
- Termination
- Layoffs and leaves
- Recalls and reinstatements
- Transfers in and out
- Promotions in, out and within

Revising
When you’re finished writing your document, the writing process isn’t over yet! You must double-check your document to verify that your message is clear, correct and complete.

Here are a few guidelines to make the editing process more effective:
1. Plan your drafting and polishing time so that you can put the document away for 24 hours. If the document still makes sense after you leave it for a day, your ideas may be ordered neatly and the document may be well-written.
2. When checking for spelling and grammatical errors, don’t always trust your word processor’s spell check feature. Spell check is a good way to catch some errors but many are not identified by word processors. Make sure to carefully read through your document to find as many spelling and grammatical errors as you can.
3. Having someone else read your document can be a great way to make sure your ideas make sense and flow well. The person should have enough knowledge of the subject that they can understand the paper. If you can find someone suitable, peer review is one of the best ways to double-check a document.
Format Details

General

See the example documents. Below are some details:

- Use single spacing
- Separate paragraphs with 1 blank space
- Do not indent paragraphs
- Align paragraphs on left only
- Use 1-inch margins
- Number pages at bottom centered or bottom right
- Figures should be labeled and numbered below the figure, aligned to the center of the figure, while also referenced within the text
- Tables should be labeled and numbered above the figure, aligned to the center of the table, while also referenced within the text
- Both Figures and Tables should be center aligned to the page (when alone) or formatted similarly with multiple items
- Use appropriate significant figures and units, within text and figures & tables (with a maximum of 4 decimal places)

Font Details

- Use Calibri or Cambria
- Use 11 point
  - Main text
  - Equations
  - Exec. Sum & Memo header information
- Use 14 point
  - Section Headers
  - “Memo” in Memo header
- Figures & Tables
  - Use 11 point, *italicized* for captions
  - Use 11 point for data within tables
- Lab Report Title Page
  - Use 26 point for Title
  - Use 20 point for other information
Equations & Sample Calculations

Sample calculations are used to provide the reader with step-by-step examples of values obtained from data analysis.

- Sample calculations should be given in the appendix and referenced within the document.
- Within the body of the document, only the formula should be given, along with definitions of the variables, including units.
- Use the Word Equation Editor for all equations, found under the Insert tab.
  - See Microsoft’s online support page for help
  - Use built in structures, in many combinations and layers, to create equations.
    - Fractions \( \frac{x}{y} \)
    - Scripts \( e^x, e^y \)
      - Superscripts
      - Subscripts
      - Combinations of superscripts and subscripts
    - Radicals \( \sqrt{x} \)
    - Integrals \( \int_1^2 x \, dx \)
    - Large Operators \( \sum_0^3 y \)
    - Brackets \( \left[ (y + x) / (w + z) \right] \)
  - Use the Symbols tool (adjacent to the Equation Editor) to add common symbols.
- As seen on the next page, all equations should be numbered. Numbering should continue in the appendix.

Equations should be centered, with a single space before and after a set of equations. If equations are grouped, the spacing can be 1.5. If the equation has a specific name, it can be listed on the left. The units should be displayed as in equation 1. If the unit symbols are explained, it could be shown as in equation 2. For example, if Ohm’s Law was used in the documentation, the equation could be displayed

**Ohm’s Law** \( V = I \times R \)  \( \text{(Volts)} = \text{(Amps)} \times \text{(Ohms)} \)

**Ohm’s Law** \( V = I \times R \)  \( V = (A) \times (\Omega) \)

Within the appendix, sample calculations should be given for any calculations made during the lab exercise and subsequent data analysis. Data can be presented in a table, in this case Table 1, with equations following (Equations 3-5). An example is below:

<table>
<thead>
<tr>
<th>Current (Amps, A)</th>
<th>Resistance (Ohms, Ω)</th>
<th>Voltage (Volts, V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>0.2</td>
<td>150</td>
<td>30</td>
</tr>
</tbody>
</table>

\[ V = I \times R \]
\[ V = 0.2 \, A \times 150 \, \Omega \]
\[ V = 30 \, V \]
Written Communications

Executive Summary Content

An executive summary is a short document that details the results of a laboratory experiment. It is a self-contained document, however it may appear as a stand-alone document or included within a longer report (you will use it as both in this course). The reader should be able to quickly read it and obtain important results and conclusions from an experiment.

Stand-alone

The length of text should not exceed one page. When used as a self-contained document, an additional 1-2 pages may be used for figures or tables.

Included with a Lab Report

When an executive summary is paired with a lab report, the summary should not include or reference tables and figures within the report. It is also acceptable to repeat information from the rest of the lab report, however the summary should not include any new information or conclusions that are not already stated elsewhere. For this reason, it is advisable to write the executive summary last and should be only 1 page in length.

General Details

- Purpose – What was the objective of the lab exercises? Though this is provided in the lab documents, the purpose should be restated in your own words. The purpose should be specific and focus on scientific principles.

- Background – What is the motivation behind performing this lab? In a sentence or two, explain why the purpose of the lab is important to the scientific community.

- Objectivity – Your summary must be free of bias, including your own interpretations and feelings. You should state results and content independent of your own influence.

- Observations / Analysis – What can you infer from your data? After presenting your results, describe trends and implications by referencing your figures and tables. These observations should tie back into the purpose of the lab experiment.

- Resolving Error – How can error be addressed? Briefly describe possible errors and discuss potential solutions.
- Scenario Recommendations – At the beginning of each lab procedure, a scenario and question are posed. You will provide recommendations based on the lab procedure.

- Conclusions – What ultimate knowledge has the lab given you? Be sure to state how these ideas compare to the lab objectives and results.
Lab Memo Content Overview

A lab memo will be more comprehensive compared to an executive summary. It is similar in that you can assume the reader is familiar with the background and procedure of a specific lab, but it will offer further expansion on results obtained, discussion questions, and general conclusions. Unlike an executive summary, there is no length stipulation, however it should still be shorter than a lab report (see Lab Report Contents Section for comparison). The sections included in a lab memo are:

- Header
- Introduction
- Results and Discussion
- Conclusion & Recommendations
- Appendix (where applicable)

Header
The header will be on the top of the first page only. See the example for contents and formatting.

Introduction
The introduction should be a short paragraph that contains the goals and objectives of the lab. It should also contain a high-level overview of the memo contents. Further expectations are provided below.

- Purpose – What was the objective of the lab exercises? Though this is provided in the lab documents, the purpose should be restated in your own words.
- Background – Why was the report created, to convey what information? The introduction sets the tone for the report and creates a roadmap for the remainder of the text as well as give some background information.

Results & Discussion
This section will contain the results of the laboratory activities and a brief discussion of those results, mostly pertaining to the specific questions within the lab documentation. The raw and processed data should be presented, including observations and analysis methods. This section should not contain specific information on the lab procedure (e.g. “Task 2 Data”). The discussion requires a careful, objective, and logical description of the significance of the experiment’s results through trend analysis, comparison to theory, and application to the purpose of the experiment. Discussion requires the most comprehension of the theory behind the experiment in order to give context to the results. Further expectations are provided on the next page.

- Objectivity – Your report must be free of bias, including your own interpretations and feelings. You should state results and content independent of your own influence.
- Data Placement – See Further Details Section
• Data Analysis – What is the data you obtained and what did you do with it? You should present both raw and processed observations from the experiment. It is important that there is enough descriptive text to guide the reader through the results and explain any assumptions or analysis performed in order to reach the results.

• Tables & Figures – See Further Details Section

• Comparison to Theory – How do your experimental results compare to the theoretical information provided in the background information? Compare your results, both in general and some specific examples, to the theory. You should provide quantitative reasoning and logically compare your results to what was expected.

• Potential Error – Why would your data not exactly match the theory? Potential errors should be mentioned whether or not it is believed that they affected the data. Systematic and human errors can occur and should be discussed why they happen and how they affect the data. Potential modifications should be suggested in the following section, Summary & Conclusion.

• Analysis – What can you infer from your data? After presenting your results, data should be described and presented in a way which shows the trends, or lack thereof, that are pertinent to the content of the document and the lab objectives.

Individual Content - Summary & Conclusion

This section will be done individually by each group member. It is expected that each section be formatted properly as seen in the example.

This is the last written section of the memo and should recap the entire document. It should answer the questions, “So what?” and “What’s next?” Keep in mind, if the Introduction and Summary sections are near identical, the reader will likely decide the paper is not worth reading. This section should contain no new data that is not already part of the other sections in the memo, but should pull together ideas from the entire document. Further expectations are provided below.

• Summary – The first paragraph or two should underscore the experiment and results. It should also highlight key points from the discussion.

• Conclusion – What ultimate knowledge has the lab given you? Be sure to state how these ideas compare to the lab objectives and results.

• Resolving Error – How can error be addressed? Error should be discussed in the Results & Discussion section. In this section, discuss potential solutions for all errors previously discussed.

• Background Recommendations – At the beginning of each lab procedure, a scenario and question are posed.
In the conclusion, you will provide your individual responses and recommendations based on the lab procedure.

Format and Language
Follow the link to the Format & Language Section.
Lab Report Content Overview

A lab report will be more comprehensive compared to a lab memo and will contain an executive summary. Executive summaries and memos afforded the opportunity to assume that the reader is familiar with the subject matter, but lab reports do not make this assumption. Within a lab report, data presentation, analysis, and explanation should be thorough and should make no assumptions about the reader’s knowledge of the laboratory background or experiment. Lab reports should be more formal in language and format than previous types of documentation and should include a title page, a table of contents, and a list of tables and figures. The sections included in a lab report are:

- Title Page
- Executive Summary
- Table of Contents
- Introduction
- Experimental Methodology
- Results
- Discussion
- Conclusion & Recommendations
- Appendix (where applicable)

Executive Summary

The first page after the title page will contain an executive summary. The same content guidelines and formatting rules apply as seen when using the executive summary as a self-contained document, including the one page length limit. Below are high-level details you will be graded on, however the executive summary should still be complete. See the section Executive Summary for further details.

- Background – What was the purpose of the lab exercise and what will this report tell the reader? Explain the goals of this exercise and why they are important to the scientific community. This does not need to be as detailed as it will be within the report itself, but it should be thorough.
- Results – What were the results of the exercise? Results presented within the executive summary should be clear and concise. The significant/final results are the most important.
- Background Recommendation – At the beginning of each lab procedure, a scenario and question are posed. You will provide recommendations based on the lab procedure.

Table of Contents

The table of contents contains the title and page number of each of the main sections (and subsections) of the lab report.
The table of contents should start on a new page and stand by itself. For this course, you will likely not need subsections, however it is acceptable to use them for the sake of clarity. See the example for formatting.

Introduction
The introduction should be a short paragraph that contains the goals and objectives of the lab. It should also contain an overview of the report contents. Keep in mind for this document you can expect your reader to be more familiar with the material. Further expectations are provided below.

- Purpose – What was the objective of the lab exercises? Though this is provided in the lab documents, the purpose should be restated in your own words.
- Roadmap – Why was the report created, to convey what information? The introduction sets the tone for the report and creates a roadmap for the remainder of the text.

Experimental Methodology
Within this section, the experimental procedure should be explained to the reader. It should contain the setup, equipment, and processes used to perform the experiment. The reader should be guided step by step through the experiment, with any unfamiliar processes explained along the way. Note that this is not merely a list of bullets or numbers, but should be in paragraph form. Again, the goal is to understand and be able to replicate the experiment. Thus, it is not necessary to explain in detail how common equipment, such as a voltmeter or strain gage, functions. It is, however, important to explain how and where such tools are used. Nearly every experimental methodology section will contain images. These images should be added to support the text, not the other way around. An image should be chosen because, in the process of writing, it becomes obvious that a picture would communicate some idea better than words will. A common mistake beginning writers make is to assemble a list of images and then build the text around them. This will result in disjointed, awkward text.

- Procedure – What activities were performed, in what order, and how? This presentation of procedure should be enough that the reader can replicate what was done during the lab, but should not copy from the lab documentation.
- Equipment – What was used and how? The reader will need to know what equipment will be needed in order to replicate the experiment and should know how to use it. This includes pictures or diagrams.

Results
This section will contain the results of the laboratory activities. The raw and processed data should be presented, including observations and analysis methods. This section should not
contain specific information on the lab procedure (e.g. “Task 2 Data”). Further expectations are provided below.

- **Objectivity** – Your report must be free of bias, including your own interpretations and feelings. You should state results and content independent of your own influence.
- **Observations** – What was noticed throughout the course of the experiment? Observations must be objective and relevant to what is being presented.
- **Data Placement** – See Further Details Section
- **Data Analysis** – What is the data you obtained and what did you do with it? You should present both raw and processed observations from the experiment. It is important that there is enough descriptive text to guide the reader through the results and explain any assumptions or analysis performed in order to reach the results.
- **Tables & Figures** – See Further Details Section

**Discussion**

This section will contain a discussion of the experiment results, mostly pertaining to the specific questions within the lab documentation. The discussion requires a careful, objective, and logical description of the significance of the experiment’s results through trend analysis, comparison to theory, and application to the purpose of the experiment. Discussion requires the most comprehension of the theory behind the experiment in order to give context to the results. Further expectations are provided below.

- **Analysis** – What can you infer from your data? After presenting your results, data should be described and presented in a way which shows the trends, or lack thereof, that are pertinent to the content of the document and the lab objectives.
- **Potential Error** – Why would your data not exactly match the theory? Potential errors should be mentioned whether or not it is believed that they affected the data. Systematic and human errors can occur and should be discussed why they happen and how they affect the data. Potential modifications should be suggested in the following section, Summary & Conclusion.
- **Comparison to Theory** – How do your experimental results compare to the theoretical information provided in the background information? Compare your results, both in general and some specific examples, to the theory. You should provide quantitative reasoning and logically compare your results to what was expected.

**Individual Content - Summary & Conclusion**

*This section will be done individually by each group member. It is expected that each section be formatted properly as seen in the example.*
This is the last written section of the report and should recap the entire document. It should answer the questions, “So what?” and “What’s next?” Keep in mind, if the Introduction and Summary sections are near identical, the reader will likely decide the paper is not worth reading. This section should contain no new data that is not already part of the other sections in the report, but should pull together ideas from the entire document. Further expectations are provided below.

- **Summary** – The first paragraph or two should underscore the experiment and results. It should also highlight key points from the discussion.

- **Conclusion** – What ultimate knowledge has the lab given you? Be sure to state how these ideas compare to the lab objectives and results.

- **Resolving Error** – How can error be addressed? Error should be discussed in the Results & Discussion section. In this section, discuss potential solutions for all errors previously discussed.

- **Background Recommendations** – At the beginning of each lab procedure, a scenario and question are posed. In the conclusion, you will provide your individual responses and recommendations based on the lab procedure.

**Format and Language**

Follow the link to the Format & Language Section.
Format and Language

Below are further details on formatting and language. Different document types may have slightly different specifications, see the rubric.

Format

Content Placement
- Content (Exec. Sum) – What information is relevant? In the executive summary, not all information from an experiment is necessary. The summary should be complete without too many details.
- Body Content – Is your document arranged appropriately? Your headers are the guideline for the document. This guide will help you arrange information logically from introduction to conclusion; the layout of the rubric should help you to know which section should go where.

Labels & References
- See Further Details Section for examples

General Format
- Errors – General errors relating to style and formatting are included here. (font, alignment, headings, etc)
- Citations – Lab reports usually require outside references. You should use APA style to reference all sources within your text and in a References Section.

Language

Structure
- Brevity – While you should be sure to fully explain and describe your findings, a lengthy document is not always better. Make your point without flashy or unnecessary words. See the section on Writing Concise Sentences.
- Clarity – Be clear in what you are saying. Being able to clearly and concisely state your results and observations will help to keep your report coherent.
- Flow – While your memo has different paragraphs and sections, they should not be completely divorced from each other. You should transition from one sentence to another, one paragraph to another, and one section to another. The reader should also not be able to tell when the author changes.

Wording
- Professionalism – Some degree of technical vocabulary and jargon is not a negative; however, keep your audience in mind. Memos are used in an office setting and you can assume with relative certainty that the reader knows what you are talking about. Reports, on the other hand, do not necessarily stay within the office and you cannot assume that the reader will understand your jargon.
- Tense/Person – Your memos and reports should always be in third person, past tense. Avoid using: I,
he, she, we, and us. Instead of using the word ‘us’, use ‘the group’ or ‘the team’. The lab exercise has already taken place, so you should use the past tense.

General
- Spelling/Grammar/Punctuation – Each member of the group should re-read and edit the document. Mistakes in spelling and grammar are common and easy points to prevent losing.

Further Details (Figures, Tables, Appendices)

The most objective way to present results is with data. Data is most easily viewed using figures and tables. The reader’s ability to find and understand data is a critical aspect of a lab document.

Data Placement
When utilizing figures and tables, they should be placed within the section to which they pertain. Raw and processed data is normally presented in the Results section. The presentation of data generally depends on the amount of data. Large tables can cause clutter and confusion, and should be kept in the appendix and referenced. Smaller amounts of data can be presented in the Results section.

Figures and tables aid in the comprehension of material, but they also require some sort of discussion. Figures and tables should be introduced before they appear and should be discussed as close to the reference as possible. If you must place the table or figure on the next page, you should reference its location. For example, if a table appears on page 3 of a document, “Table 4, provided on page 3, illustrates this trend,” can be used.

Tables & Figures
Ultimately, all data from the lab should be presented either in the results or appendix sections. Unless specifically stated within the lab documents, it is up to you to decide how many or which figures to include. While figures are a useful way to visually present data, too many can confuse a reader. If multiple or similar figures exist, they can be placed in the appendix and referenced.

Figure and table should also be appropriately sized. They should be large enough to easily be read and understood, but not excessively large and a waste of space. Often two figures or tables can be placed side-by-side.

Table Formatting
Each table should have a label above the table that contains a number and a title. Also, each table should be introduced in the text before it is seen. An introduction consists of a table number and description of the contents. If the table is on a different page or in the appendix, the page number should be included as well. For example, Table 1 on the next page illustrates how the output voltage and magnitude gain
decrease as the frequency increases. Your description should fit in with the remainder of the text.

*Table 1: Output Voltage and Magnitude Gain*

<table>
<thead>
<tr>
<th>Frequency (kHz)</th>
<th>PP signal Output Voltage</th>
<th>Magnitude Gain</th>
<th>Magnitude Gain in dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>4.53</td>
<td>9.06</td>
<td>19.1426</td>
</tr>
<tr>
<td>1</td>
<td>4.44</td>
<td>8.88</td>
<td>18.9683</td>
</tr>
<tr>
<td>2</td>
<td>4.22</td>
<td>8.44</td>
<td>18.5268</td>
</tr>
<tr>
<td>4</td>
<td>3.53</td>
<td>7.06</td>
<td>16.9761</td>
</tr>
<tr>
<td>6</td>
<td>2.78</td>
<td>5.56</td>
<td>14.9015</td>
</tr>
<tr>
<td>8</td>
<td>2.14</td>
<td>4.28</td>
<td>12.6289</td>
</tr>
<tr>
<td>10</td>
<td>1.66</td>
<td>3.32</td>
<td>10.4228</td>
</tr>
</tbody>
</table>

**Figure Formatting**

Figure labeling and referencing is almost identical to that of tables, except that figures are labeled below the figure. Each figure should be introduced before the figure is seen and should be properly labeled. For example, Figure 2 on the next page illustrates operator time for two different production cycles.

Figures can consist of graphs and charts, but also diagrams and photos. Graphs should always follow proper formatting practices and include axis labels with units, titles, and legends where appropriate.

**Appendix Content**

The appendix can hold data tables that are too large to effectively present within a document. These can be referenced just as any table would, noting the location in the appendix and page number.

If a lab provided you with more than one or two graphs that provide the same information, you can put extras in the appendix. Remember that figures and tables in the appendix still require labels and references.
Oral Communication

Presentations

The oral presentation is an opportunity for each student team to practice communicating their ideas concisely and in a way that is captivating to the audience.

Content

The oral presentation should contain the following:

- Cover slide
- Overview slide (i.e. structure and flow of the presentation)
- Major content areas
- Visual aids (e.g. tables, figures, images, etc.)
- Summary slide (i.e. summary of important ideas or a conclusion of students’ learning experience)
- References

Format

The oral presentation should be organized into main points, flow well from topic to topic, include an appropriate amount of text/information per slide, contain suitable colors/contrast and last approximately 5-6 minutes.

Suggestions & Recommendations

- Be your natural, professional self
- Do not discuss the project specifications (if they are the same for each group).

When preparing for your presentation:

- Know who your audience will be
- Remember your objective
- Anticipate potential questions
- Practice, practice, practice
- Take care of yourself (sleep, eat, relax, etc.)

When communicating verbally:

- Speak at an appropriate volume (loud enough for everyone to hear you)
- Pace yourself when presenting
- Use pauses to help with flow and clarity
- Use voice inflections
- Convey an appropriate tone (usually relaxed, but serious)
- Avoid using filler words such as “uhh,” “like,” “so,” “well,” “y’know,” etc.

When communicating nonverbally:

- Stand in a location where you and your presentation material can be seen
- Stand with a confident, relaxed posture
• Move around some and be animated
• Use natural gestures
• Use positive and genuine facial expressions
• Make eye contact with the audience

A Sample PowerPoint Presentation can be found in Appendix B.
Multimedia (Posters, Slides, Videos)

Summary of Quality Design Features

• Presentation space is visually appealing including use of figures/images and minimizing text
• Images used are high-resolution
• Segments, slides or Prezi spaces are numbered
• Color scheme shows high contrast between background color and text color
• Format is consistent across entire presentation
• Graphics and figures effectively convey data and support a main point clearly
• Font is consistent (color, style, capitalization, size)
• Text font is large enough to be read easily in the back of the presentation space (test in advance)
• Links to any external media are tested in advance
• Audio is tested in advance to verify volume

Summary of Quality Content Features

• Content is focused on the message and supports it
• Elements of information or persuasion are obvious (depending upon purpose of presentation)
• Titles indicate the organization of your messages
• Titles/text use a consistent capitalization scheme
• Research and other resources are cited in the appropriate format and as directed by your instructor
• Content is free of errors (spelling, typos, grammar)

Organization for a Poster

Each section of a poster is typically labeled with a keyword that indicates the function of information within it such as Introduction, Design Phases, Designs, Strengths of Final Design, and Conclusions in the case of a Design Project poster.

When creating an electronic or physical poster
Use the upper left quadrant for the “Introduction” section. Place the purpose, statement of problem, or design question here. Usually, the title of the poster appears across the top with the team members’ names listed below it or in the footer at the bottom of the poster.

On an electronic or physical poster
The section in the lower left corner may list the design stages, main points, or project segments to be discussed. Often a bulleted list is used.

An electronic or physical poster
The “Discussion” should be in the middle column of the poster and may include graphics of the initial and final design. These graphics can include call-outs or bulleted lists of the strengths and/or weaknesses of the designs. Since space on posters is limited, unless the improved design was radically different from the initial design, it is unlikely that there would be space on the poster to illustrate that intermediate step.
**Design Process**
The design process may be illustrated in the upper right corner of the poster since the process is often important to the discoveries made by the team.

**Conclusions & Recommendations**
On electronic or physical posters, the conclusions and/or recommendations typically appear in the lower right quadrant of the poster.

For additional guidelines and examples of academic posters see [http://www.ncsu.edu/project/posters/](http://www.ncsu.edu/project/posters/).

**Conclusions & Recommendations**

**Success Factors for High Quality Delivery**
The best delivery skills have the following factors in common:

- Poise is the ability to appear calm and confident and to maintain a professional demeanor (even when unexpected event occur during a presentation, such as when a link does not open, a slide will not transition to the next, or the projector does not operate as expected).
- A clearly audible voice and consistent eye contact with the audience
- Voice modulation including energy and enthusiasm and avoiding monotone
- Consistent, medium vocal pace with pauses to add emphasis when key facts are presented. If your audience includes internationals, slow the pace and increase the number and length of pauses.
- A presentation that is extemporaneous rather than read from cards or a script and NEVER read from the screen.
- Use of hand gestures or use of a pointer for emphasis and to point out key facets of a graphic on the screen.
- Use of body language such as facing the audience, moving in a relaxed manner in front of the audience or even among the audience while speaking, smiling through most of the presentation, when accepting questions, nodding to signify understanding.
- During question/answer, thank the audience member for their question, answer it and ask, “What other questions do you have?” to the entire audience. Give the audience at least a 5 second pause to think and react before you end your presentation.
A note about team presentations
As speakers change during a team presentation, a transition
must be announced to the audience. The best transitions are
offered by speakers who indicate that their segment is
complete and name the next speaker and the content of their
segment. For example a speaker might say,

“With this graphic, I close my part of the presentation.
Now, Laura will describe how wind turbines can be
strategically located geographically to generate the most
power.”

Conclusions and Questions
When your presentation is complete, it is typical to ask for
questions. Rather than asking, “Are there any questions?” the
better phrase is, “What questions do you have?”

Assume there will be questions. It is best to consider the
questions that might be raised in advance of the presentation
and decide how to respond to them.
Appendix A: Effective Communication Strategies

Integrating Purpose and Organization

As you practice writing in different document types, it will be very helpful if you can understand the connection between a given format and its purpose. Rather than just “filling in the blanks,” for each format, try to see the bigger picture.

PURPOSE

- An Executive Summary is a condensed “thumbnail” of a lab that contains the purpose, a summary of the results, and a conclusion.
- A Lab Memo has much in common with a standard (relatively brief) business memo; it’s more detailed than an Executive Summary, but less detailed than a Lab Report.
- A Lab Report has a format similar to that of a business report; it is longer, more detailed, and more formally organized than a Lab Memo.
- A Project Notebook contains a variety of document types (including summaries, memos, and reports) and is intended to be a record of a longer-term project; in this case, you’ll be asked to keep a hardcopy of your records in a binder.

ORGANIZATION

No matter its size or scope, a lab document should contain the following elements:

Introduction/Purpose

Explains the premise of a lab (what is the purpose of the experiment? what hypothesis is being tested? what variables will be controlled/tested? etc.) It is a good idea to start with a broad overview before moving on to more specific details (someone not familiar with a given lab should be able to understand its purpose by reading your documents).

Outline/Parallel Structure

Whether you’re writing a summary or a report, it’s always helpful to start with a rough draft organizing your ideas, document sections, data, and tables/figures.

Topic sentences / Paragraphs / Transitions

Near the beginning of every paragraph should be a topic sentence that explains its main idea (just as an essay should have a clear thesis, a paragraph should have a topic sentence). It is also important to provide transitions between paragraphs and different sections of the document.

Conclusion

In addition to including the data you gathered, the conclusion interprets and analyzes the data, explaining its meaning in real-world terms.
Additional Tools

Table of Contents Tool
Often a table of contents is required in a technical document, providing the reader with an outline of what is contained in the document. The Table of Contents Tool in MS Word is helpful for this purpose.

Steps for creating a Table of Contents:
1. On the home tab, use the Heading Styles for various headings, labels, etc.
2. Select the Table of Contents under the Table of Contents group of the References tab and select a table format.

Refer to the sample report or this document for an example on the Table of Contents.

Plot / Figure Editing Tools
Snipping Tool
The Snipping Tool can be used capture a screen shot, or snip, of any object on the screen, and then annotate, save, or share the image. The Snipping Tool is particularly useful for images that need to be inserted as figures or plots.

Steps for using Snipping Tool:
1. Open Snipping Tool located in All Programs under Start.
2. Drag the Snipping Tool cursor to select the area that needs to be snipped.
3. Save the image. This image can be inserted in the desired location.

Keyboard Shortcuts
There are a few keyboard shortcuts that may be used for figure/plot editing. These are as follows,

- PRINT SCRNR – This will capture a screen shot (copy) of the whole screen. This may be pasted in the desired location by CNTRL+V.
- ALT + PRINT SCRNR – This will capture a screen shot of only a particular window or box. This may be pasted in the desired location by CNTRL +V. Before using the ALT + PRINT SCRNR command, the particular window or box must be selected using the mouse cursor.
Writing Strong Sentences

Common Structural Errors

Run-On Sentences
Run-on sentences occur when two or more main clauses are attached together without the correct punctuation.

1. “Magic Johnson was one of the greatest basketball players of all time, his passing ability and court vision were second to none.”

These sentences can be corrected in one of two ways:

1. Separate the clauses into two separate sentences:
   a. “Magic Johnson was one of the greatest basketball players of all time. His passing ability and court vision were second to none.”

2. If the ideas in the two clauses are closely linked, they can be joined with a semicolon:
   a. “Magic Johnson was one of the greatest basketball players of all time; his passing ability and court vision were second to none.”

Comma Splices
Similar to run-on sentences, comma splices occur when two independent clauses are joined by a comma. If the clause before the comma and the clause after the comma form a complete sentence, you have written a comma splice.

- “My new television is great, it’s got a 60-inch screen and awesome clarity.”

Comma splices are also fixed in a similar fashion to run-ons. You should choose which one sounds the best for each sentence.

1. Replace the comma with a semicolon:
   a. “My new television is great; it’s got a 60-inch screen and awesome clarity.”

2. Write the sentence as two sentences. This should only be one if both clauses are long or one is long and the other is of normal length.
   a. Incorrect: “Amanda’s newest invention earned her a load of money, it also got her noticed by a number of large, important design firms who wanted to hire her immediately.”
   b. Correct: “Amanda’s newest invention earned her a load of money. It also got her noticed by a number of large, important design firms who wanted to hire her immediately.”

3. A coordinating conjunction (and, but, so, or, nor, for, yet) can be added after the comma.
   a. Incorrect: “The test results proved inconclusive, no link between the test groups could be found.”
b. **Correct:** “The test results proved inconclusive, for no link between the test groups could be found.”

4. Use a semicolon and a conjunctive adverb (however, moreover, consequently, nevertheless, therefore, for instance), followed by a comma, to separate the clauses.
   a. **Incorrect:** Ex. “No link between the test groups could be found, the test results proved inconclusive.”
   b. **Correct:** “No link between the test groups could be found; therefore, the test results proved inconclusive.”

**Sentence Fragments**

A sentence fragment is a group of words that is punctuated like a complete sentence but isn’t one. The second “sentence” in the following example is a fragment.

- “After observing the results, we noticed two things. The low temperatures and the high pressures.”

When looking for fragments, use these three tests:

1. Does the sentence contain a subject? If no, the sentence is a fragment.
2. Does the sentence contain a verb? If no, the sentence is a fragment.
3. If the subject and verb start with a subordinating word (because, since, etc.) and lack an independent clause to complete the thought, then the sentence is a fragment.

For example, the phrase “Since you’ve been gone.” is not a sentence, but the phrase “Since you’ve been gone, I can breathe for the first time.” is a sentence.
Using Parallel Structure
What is parallel structure? Write sentences such that words, phrases, or clauses are placed into the same grammatical and logical form.

Simple sentence example
Duties in the second month of your internship include resolving customers’ concerns, supervising desk staff, and planning store displays.

Parallel structure in paragraphs Original Text
Within this memo is an overview of the lengths of pipes by themselves and with their fittings, a sketch of the finished roller coaster that met all lab requirements, an analysis over how well built the roller coaster was, also an analysis of the starting and ending heights of the roller coaster, and an explanation of the challenges that were experienced while executing this lab.

Improved with parallel structure
This memo provides: an overview of the pipe lengths alone and with their fittings; a sketch of the finished roller coaster that met all lab requirements; an analysis of the quality of the roller coaster’s construction; a description of the starting and ending heights of the roller coaster; and an explanation of the challenges experienced while executing this lab.
Using Transitions

To show additional or continuation of the same idea
- Also
- First, second, third
- In addition
- Similarly

To introduce another important idea
- Furthermore
- Moreover

To introduce an example
- For example
- For instance
- Indeed
- To illustrate
- Namely
- Specifically

To contrast ideas
- In contrast
- On the other hand
- Or

To show that the contrast is more important than the previous idea
- But
- However
- Nevertheless
- On the contrary

To show cause and effect
- As a result
- Because
- Consequently
- For this reason
- Therefore
Punctuation

Apostrophes

Apostrophes (‘) are used in three ways:

1. To show singular and plural possession.

   John’s Nintendo system used to belong to the Hudsons’ youngest child, Billy.

   • Possessives primarily show ownership, such as in the phrases “the doll’s head” or “Chelsea’s stereo.” They can also take the place of a prepositional phrase that starts with “of.” For example, the phrase “the door of the refrigerator” can be changed to “the refrigerator’s door.”

   • Apostrophes are always followed by an “s” when showing possession, unless the word is a plural noun ending in “s” (Ex. the Hudsons’ youngest child).

2. To pluralize a letter, number, symbol, or word used as a term.

   The document did not contain nearly as many D’s, 3’s, or *’s as it used to.

3. To show contractions.

   Since Sarah couldn’t complete the project on time, it’s likely she will fail the class.

   • Apostrophes replace the missing letters in contractions. These missing letters are not pronounced when the word is spoken aloud, so “could not” becomes “couldn’t” and “it is” becomes “it’s.”

   Note: In technical communications, contractions are typically avoided.
Commas
Commas (,) are primarily used to indicate a pause in the sentence when it is spoken aloud. Commas are used in many different situations, including:

1. With words and phrases that come before the main subject and verb:

   *In the Spanish lecture, Michael’s cell phone started to ring loudly.*

2. To join two sentences along with a conjunction:

   *She attended every class on time, and she got A’s in all of them.*

3. To separate three or more items in a series:

   *The three items necessary to take the exam are a pencil, a calculator, and your BuckID.*

4. To separate an embedded clause from the rest of a sentence:

   *Lenny, Luke’s roommate throughout college, was shocked to hear that the concert had been canceled.*

5. To separate dates and addresses:

   *We moved into our new house at 100 High Street, Columbus, Ohio on February 16th, 2012.*

6. To make a sentence more clear:

   *As he ran over, his wife let out an exasperated sigh.*

   **Note:** Without the comma, the sentence would have been confusing. Commas should go wherever there is a natural pause in the spoken sentence.

7. In dialogue with speech tags:

   *“Have a cookie, they’re delicious,” said Peter.*

   **Note:** When using quotation marks, place all punctuation inside the quotes.
Semicolons

Semicolons are among the most misunderstood pieces of punctuation. The biggest pitfall for many writers is to want to use them in place of commas.

This usage is correct only in very specific contexts. Semicolons have a specific use in the world of writing. Below you can find the acceptable uses of semicolons.

1. Semicolons are used to connect two independent clauses (phrases that are capable of standing alone) that are related to each other.

   The sentence pair “I saw the cat run away. It ran under the bridge.” could be connected with a semicolon since they are directly related. “I saw the cat run away; it ran under the bridge.” Now consider the following sentence pair. “I saw the cat run away. The dog barked loudly.” It would not make sense to use a semicolon to connect these clauses, as they have nothing to do with each other.

2. Using semicolons is also a good way to correct comma splices without losing the meaning of the sentence.

   “After the party, my friends and I went home to play some Mario Kart; we all love that game.” Using a comma here would have resulted in a comma splice, but using a period after “Mario Kart” causes the sentence to lose some meaning; not to mention it sounds awkward.

   **Note:** Never use a semicolon with a conjunction (and, nor, for, but, yet, or, so). You should only use commas with conjunctions.
Appendix B: Sample Documentation

Executive Summary – Bridge Breaking Sample

Write an Executive Summary
For details on content and formatting, see the Technical Communications Guide on Executive Summary specifications.

Lab Specific Directions

- In addition to requirements listed in the Technical Communications Guide, be sure to briefly address the following questions. Answer within your summary, not with numbers or bullets.
  - Discuss the effectiveness and use of your team meetings
  - Briefly compare your final design to real-world bridges
  - Discuss the scenario in the introduction: Using only balsa wood and Elmer’s Glue, can a significant structure be created to hold over 40 pounds?
Executive Summary

The Bridge Building Lab consisted of designing and constructing a wood bridge that would have the greatest strength-to-weight ratio (grams-pounds). Other goals of the lab were to participate in a team activity, focusing on time and stress management, planning, and practical application of a physical invention. During lab, the strength-to-weight ratio was found by placing a load carefully on the bridge deck until complete structural failure. The project had a few constraints, such as length and width requirements, as well as limited materials and testing opportunities. The balsa wood bridge was designed to fit a gap of 10 inches in length and 3 inches in width. First, each team member drafted their own design and the group compared pros and cons of each design. One design was too difficult to build, requiring very precise cuts and fasteners, which was avoided due to limited materials. The group decided another design would not work due to the fragility of the wood. Of the remaining designs, the reverse Pratt truss was chosen based on ease of construction and success in real-world applications. The final design can be found in Figure 1 in the appendix.

After completing construction, the final bridge weight was 22.0 grams. It held approximately 25.9 kilograms until it collapsed, meaning it had a strength-to-weight ratio of about 1,180. The bridge failed in the center where the load was placed. The bottom beam on the right was the first to break and caused the rest of the bridge to buckle. This was contrary to the anticipated fail point near the angled support trusses close to the ends of the bridge, however extra glue may have helped prevent failure at these locations. In order to improve the performance of the bridge, the remaining balsa wood should have been used to reinforce the bottom. This would have helped the tension-compression action caused by the force acting upon the bridge. Less glue could have been used in certain areas without compromising the structural integrity, which would have resulted in a higher mass-to-load ratio.

The team was proactive in meeting for the bridge building lab, meeting five times to discuss various aspects of the bridge design. The first several meetings were to discuss the design of the bridge in order to create the most efficient design. In order to design the balsa wood bridge, the team researched existing designs which were capable of being reproduced using balsa wood. In the latter team meetings, sketches were made of the bridge design and then the bridge was built. The team was effective at using time wisely by completing the bridge in a timely manner. We worked quickly and efficiently. The team’s only problem was finding a place to start when designing the bridge; once a design was chosen, there were no problems. The team brainstormed aloud in order to decide what design to use.

There is a reason the “classical” bridge design is the conventional bridge design. The simplicity of the design was instrumental in the success of the bridge. The reverse Pratt design played to the strengths of the balsa wood, as it capitalized on the strengths in compression of the balsa wood. In the construction phase, the initial hardship was in binding the members together with Elmer’s glue. After a process was developed, the rest of the bridge design went a lot better. This lab was very effective in accomplishing its educational goals, which were: effective team building, time management, stress management, planning, and practical application of engineering on paper to an actual physical invention. Based on the results in this experiment, structures can be created out of only balsa wood and Elmer’s glue to hold significant weight.
Sample Data

<table>
<thead>
<tr>
<th>Weight (Grams, g)</th>
<th>Maximum Load (Kilograms, kg)</th>
<th>Strength-to-Weight Ratio (Dimensionless)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.0</td>
<td>25.9</td>
<td>1,177.27</td>
</tr>
</tbody>
</table>

Sample Calculations

The following equation shows how the strength-to-weight value in Table 1 was found. Sample calculations can be found in equation A1.

\[
Strength\ -\ to\ -\ Weight\ Ratio = \frac{\text{Maximum Load}}{\text{Weight}} \quad \text{(A1)}
\]

\[
Strength\ -\ to\ -\ Weight\ Ratio = \frac{25.9\ kg}{22.0\ g}
\]

\[
Strength\ -\ to\ -\ Weight\ Ratio = 1,177.27
\]
Lab Memo – Fuel Cell Sample

Write a Lab Memo
For details on content and formatting, see the Technical Communications Guide on Lab Memo specifications.

Lab Specific Directions

Results & Discussion
• What is the value of the decomposition voltage of water? Describe how it was determined and whether or not it matches your results from lab.
• Determine the efficiency of the electrolyzer, including calculations.
• What is the maximum power for the given fuel cell? What might this number be important?
• Determine the efficiency of the fuel cell, including calculations.
• Assume the energy efficiency of the fuel cells produced by your company is the same as those calculated by you in lab. Estimate the rate of volume of hydrogen needed (in m³/hr) to meet the individual load. Assume that the entire load is operated by fuel cells. Include calculations.
• Calculate what volume of hydrogen would be needed for a typical family of four for one day. What are the storage implications for a day’s worth of hydrogen? Include calculations.

Conclusion & Recommendations (Individual)
• Each individual engineer is requested to provide their perspective in this area.
• Now that you have gained some familiarity with fuel cells as one type of alternative energy device, what is your impression about the need for such devices? What do you think are some challenges (engineering and otherwise) involved? How are these challenges being addressed?
Memo
Date: October 16, 2014
To: Inst. Annie Abell & GTA Russ Stech
From: Group D - Cody Allison, Eric Marko, Danielle Meyer, Monica Okon
Subject: Fuel Cell Lab

Introduction
The set of experiments done in the Fuel Cell Lab enabled characterization of the given fuel cell through investigative experiments. The goals of the lab described the fuel cell’s impedance, hydrogen production rate, maximum power output, and hydrogen consumption. The experiments involved an electrolyzer, which created hydrogen, and the fuel cell, which converted the hydrogen into electricity. This memo contains the results that provide justification for the conclusion on those characteristics previously mentioned as well as a qualitative and quantitative discussion of the use of fuel cells.

Results & Discussion
Data from the lab was recorded and is presented below. Table 1 below shows the electrolyzer’s measured voltages in relationship to a certain resistance from Task 1. During this experiment, the total voltage $V_T$ and decomposition voltage $V_D$ were 1.84 volts and it was found that the board and lead resistance, $R_B$, was 0.2 Ohms.

<table>
<thead>
<tr>
<th>Resistor Board Switch setting</th>
<th>Resistance Value R (Ohms)</th>
<th>Total Resistance $R_T = R + R_B$ (Ohms)</th>
<th>Voltage across electrolyzer ($V_E$)</th>
<th>Voltage across resistance $V_R = V_T - V_E$</th>
<th>Current $I = V_R / R_T$ (Amps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW#1</td>
<td>0</td>
<td>0.2</td>
<td>1.82</td>
<td>0.02</td>
<td>0.10</td>
</tr>
<tr>
<td>SW#2</td>
<td>0.5</td>
<td>0.7</td>
<td>1.72</td>
<td>0.12</td>
<td>0.17</td>
</tr>
<tr>
<td>SW#3</td>
<td>1</td>
<td>1.2</td>
<td>1.67</td>
<td>0.17</td>
<td>0.14</td>
</tr>
<tr>
<td>SW#4</td>
<td>2</td>
<td>2.2</td>
<td>1.62</td>
<td>0.23</td>
<td>0.100</td>
</tr>
<tr>
<td>SW#5</td>
<td>3</td>
<td>3.2</td>
<td>1.59</td>
<td>0.26</td>
<td>0.081</td>
</tr>
<tr>
<td>SW#6</td>
<td>5</td>
<td>5.2</td>
<td>1.56</td>
<td>0.29</td>
<td>0.056</td>
</tr>
<tr>
<td>SW#7</td>
<td>10</td>
<td>10.2</td>
<td>1.53</td>
<td>0.32</td>
<td>0.031</td>
</tr>
<tr>
<td>SW#8</td>
<td>15</td>
<td>15.2</td>
<td>1.51</td>
<td>0.33</td>
<td>0.022</td>
</tr>
<tr>
<td>SW#9</td>
<td>20</td>
<td>20.2</td>
<td>1.50</td>
<td>0.34</td>
<td>0.017</td>
</tr>
<tr>
<td>SW#10</td>
<td>30</td>
<td>30.2</td>
<td>1.49</td>
<td>0.35</td>
<td>0.012</td>
</tr>
<tr>
<td>SW#11</td>
<td>50</td>
<td>50.2</td>
<td>1.48</td>
<td>0.36</td>
<td>0.0072</td>
</tr>
<tr>
<td>SW#12</td>
<td>100</td>
<td>100.2</td>
<td>1.46</td>
<td>0.38</td>
<td>0.0038</td>
</tr>
</tbody>
</table>
The following equations were used to calculate the values in Table 1. The sample calculations can be found in the appendix in equations A1 to A3.

**Total Resistance**

\[ R_T = R + R_B \]

*Total Resistance (Ohms, Ω) = Resistance Value from the Resistor Board (Ω) + Resistance across board and leads (Ω)* (1)

**Voltage across resistor**

\[ V_R = V_T - V_E \]

*Voltage across resistor (Voltage, V) = Total voltage (V) - Voltage across electrolyzer (V)* (2)

**Current across resistor**

\[ I = \frac{V_R}{R_T} \]

*Current across resistor (Amps, A) = Voltage across resistance (V) × Total resistance (Ω)* (3)

As shown in Figure 1 below, the graph appeared to have a steep increase until reaching its maximum around 1.75 volts at 0.17 Amps. Figure 1 explained that the impedance of the electrolyzer was matched to the power supply. The voltage for the decomposition of water is slightly less than 1.5 volts. For this reason, the graph matched what was observed in lab because the current is zero at values below this threshold.

![Figure 1: Electrolyzer Circuit Information](image)
Table 2 showed the amount of hydrogen produced from Task 2. The water level, $V_{\text{initial}}$, indicated there was 3 cubic centimeters of water at the start of the experiment.

<table>
<thead>
<tr>
<th>Observed Water level mark (cm$^3$)</th>
<th>Volume of Hydrogen produced (cm$^3$)</th>
<th>Time, t (s)</th>
<th>Voltage across electrolyzer ($V_E$)</th>
<th>Voltage across resistance $V_R=V_T-V_E$</th>
<th>Current $I=V_R/R_T$ (Amps)</th>
<th>Power, $P=V_IE$ (Watts)</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{\text{initial}}+2$</td>
<td>2</td>
<td>75.5</td>
<td>1.68</td>
<td>0.16</td>
<td>0.13</td>
<td>0.22</td>
<td>1.5</td>
</tr>
<tr>
<td>$V_{\text{initial}}+4$</td>
<td>4</td>
<td>138.3</td>
<td>1.68</td>
<td>0.16</td>
<td>0.13</td>
<td>0.22</td>
<td>1.7</td>
</tr>
<tr>
<td>$V_{\text{initial}}+6$</td>
<td>6</td>
<td>242.3</td>
<td>1.68</td>
<td>0.16</td>
<td>0.13</td>
<td>0.22</td>
<td>1.4</td>
</tr>
</tbody>
</table>

The following equations showed how some of the values in Table 2 were found. Sample calculations can be found in equations A4 and A5.

$$\eta_{\text{electrolyser}} = \frac{V_{HH}}{V_H} \quad \eta_{\text{electrolyser}} = \frac{E_{\text{hydrogen}(m^3)}}{E_{\text{electric}(m^3)}} \quad (4)$$

$H_H$ = calorific value of hydrogen (energy content) = $12.745 \times 10^6$ J/m$^3$

$V_{HH}$ = volume of hydrogen produced, m$^3$

Power across electrolyser $P = V_E \times I$

Power across electrolyser (Watts, W) = Voltage across electrolyser (V) $\times$ Current (A) \quad (5)

Figure 2 on the next page showed the amount of hydrogen produced over time.
From Figure 2, the electrolyzer produced hydrogen linearly. Table 3 showed a summary of the fuel cell characteristics. The total voltage during this experiment was found to be 0.97 volts. The maximum power was found to be 0.078 Watts at switch number 4, with resistance of 2.2 Ohms.

### Table 3: Fuel Cell Voltage Characteristics

<table>
<thead>
<tr>
<th>Resistor Board Switch Setting</th>
<th>Resistance Value R (Ohms)</th>
<th>Total Resistance RT = R + RB (Ohms)</th>
<th>Voltage across fuel cell (VF)</th>
<th>Current I = VF/RT (Amps)</th>
<th>Power P = VfI (Watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW#1</td>
<td>0</td>
<td>0.2</td>
<td>0.03</td>
<td>0.15</td>
<td>0.0045</td>
</tr>
<tr>
<td>SW#2</td>
<td>0.5</td>
<td>0.7</td>
<td>0.17</td>
<td>0.24</td>
<td>0.041</td>
</tr>
<tr>
<td>SW#3</td>
<td>1</td>
<td>1.2</td>
<td>0.27</td>
<td>0.23</td>
<td>0.062</td>
</tr>
<tr>
<td>SW#4</td>
<td>2</td>
<td>2.2</td>
<td>0.41</td>
<td>0.19</td>
<td>0.078</td>
</tr>
<tr>
<td>SW#5</td>
<td>3</td>
<td>3.2</td>
<td>0.49</td>
<td>0.15</td>
<td>0.074</td>
</tr>
<tr>
<td>SW#6</td>
<td>5</td>
<td>5.2</td>
<td>0.59</td>
<td>0.11</td>
<td>0.065</td>
</tr>
<tr>
<td>SW#7</td>
<td>10</td>
<td>10.2</td>
<td>0.68</td>
<td>0.067</td>
<td>0.046</td>
</tr>
<tr>
<td>SW#8</td>
<td>15</td>
<td>15.2</td>
<td>0.73</td>
<td>0.048</td>
<td>0.035</td>
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<tr>
<td>SW#9</td>
<td>20</td>
<td>20.2</td>
<td>0.75</td>
<td>0.037</td>
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<tr>
<td>SW#10</td>
<td>30</td>
<td>30.2</td>
<td>0.79</td>
<td>0.026</td>
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<tr>
<td>SW#11</td>
<td>50</td>
<td>50.2</td>
<td>0.83</td>
<td>0.17</td>
<td>0.014</td>
</tr>
<tr>
<td>SW#12</td>
<td>100</td>
<td>100.2</td>
<td>0.87</td>
<td>0.0087</td>
<td>0.0076</td>
</tr>
</tbody>
</table>
Figure 3 showed which resistance was best to use to maximize power. The power reached maximum of 0.078 Watts at 0.7 Ohms. Knowing the optimum resistance level is important because the fuel cell’s power was maximized.

![Fuel Cell Power vs Resistance](image)

*Figure 3: Fuel Cell Power Compared to Resistance*

Table 4 showed the amount of hydrogen consumed and the efficiency based on power production. Figure 4 on the next page shows the data in chart form from Table 4. Figure 4 indicates that the fuel cell consumed hydrogen at a constant rate.

*Table 4: H₂ Consumption Data*

<table>
<thead>
<tr>
<th>Volume of Hydrogen consumed by fuel cell (cm³)</th>
<th>Time, t (s)</th>
<th>Voltage (V)</th>
<th>Current I = V/R (Ohms) (Amps)</th>
<th>Power P = VI (watts)</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>71.9</td>
<td>0.364</td>
<td>0.17</td>
<td>0.060</td>
<td>1.999*10⁻⁴</td>
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<tr>
<td>4</td>
<td>150.7</td>
<td>0.32</td>
<td>0.15</td>
<td>0.048</td>
<td>1.661*10⁻⁴</td>
</tr>
<tr>
<td>6</td>
<td>240.5</td>
<td>0.287</td>
<td>0.13</td>
<td>0.037</td>
<td>1.385*10⁻⁴</td>
</tr>
</tbody>
</table>
In order to meet the individual load using fuel cells of similar efficiency, the rate of volume of hydrogen needed would be $2.76 \times 10^{-3}$ m$^3$/hr. Sample calculations for this can be found in the appendix equation set A6. For a typical family of four, about 0.265 m$^3$/day of hydrogen would be needed. The sample calculation can be found in equation A7.
Conclusion & Recommendation – Cody Allison

This experiment enabled the group to understand how fuel cells can work to create electricity from the hydrogen produced by an electrolyzer. Finding low pollution renewable sources of energy is important. Hydrogen fuel cells can reach up to 70% efficiency much better than the 30% efficiency of the combustion engine. Fuel Cells produce little or no harmful emissions depending on whether or not they use pure hydrogen. However, there are many challenges that must be overcome before fuel cell technology can become practical. Currently, the cost of fuel cells is too high to be affordable to the general public. Also, the durability and reliability of fuel cells is too low to be made widely available.

Another problem is the storage of hydrogen. In cars, the storage technology must improve in order to reduce the size of the storage tank but still be able to hold enough hydrogen for long trips. However, the biggest problem facing fuel cells is the lack of fueling stations. An entire system of hydrogen distribution facilities would have to be constructed. Consequently, many auto makers and governmental agencies, such as NASA, are researching fuel cells to solve some of these challenges.

A normal fuel cell was characterized. The amount of hydrogen produced and consumed were found as well as the impedance of the system. There was no evidence to show that fuel cells cannot work as a potential fuel source in the future or should not be used more than any other alternative energy sources. While the results found in this memo were reasonable, there were still problems, such as the use of multiple data sets to confirm the values found. Using multiple techniques should be able to confirm results. However, the system was too sensitive to environmental conditions and so this confirmation step was difficult and time consuming. The set of experiments and the discussion showed that more work will needed to make fuel cells practical.
Conclusion & Recommendation – Eric Marko


Conclusion & Recommendation – Danielle Meyer


Conclusion & Recommendation – Monica Okon


References

### Appendix

#### Sample Calculations

**Total Resistance**

\[
R_T = R + R_B \quad \text{Total Resistance (Ohms, Ω) = Resistance Value from the Resistor Board (Ω) + Resistance across board and leads (Ω)}
\]

\[
R_T = 0.2 \ Ω
\]

**Voltage across resistor**

\[
V_R = V_T - V_E \quad \text{Voltage across resistor (Voltage, V) = Total voltage (V) - Voltage across electrolyzer (V)}
\]

\[
V_R = 1.84 \ V - 1.82 \ V = 0.02 \ V
\]

\[
I = \frac{V_R}{R_T} \quad \text{Current across resistor (Amps, A) = Voltage across resistance (V) × Total resistance (Ω)}
\]

\[
I = \frac{0.02 \ V}{0.2 \ Ω} = 0.10 \ A
\]

**Efficiency of the Electrolyser**

\[
\eta_{\text{electrolyser}} = \frac{V_{H_2} \times H_i}{V_t} \quad \eta_{\text{electrolyser}} = \frac{E_{\text{hydrogen}(m^3)}}{E_{\text{electric (m^3)}}}
\]

\[
H_i = \text{calorific value of hydrogen (energy content) = 12.745 × 10^6 J/m}^3
\]

\[
V_{H_2} = \text{volume of hydrogen produced, m}^3
\]

**Power across electrolyser**

\[
P = V_E \times I \quad \text{Power across electrolyser (Watts,W) = Voltage across electrolyser (V) × Current (A)}
\]

\[
0.1682 = \frac{44 \ MJ \ yr}{V_{H_2} \times 10.8 \times 10^6 \ J/m^3} \quad \text{Power across electrolyser (Watts,W) = Voltage across electrolyser (V) × Current (A)}
\]

\[
5.9453 = \frac{V_{H_2} \times 10.8 \times 10^6 \ J/m^3}{5.02 \times 10^3 \ J/hr}
\]

\[
V_{H_2} = \frac{2.76 \times 10^{-3} \ J/hr}{1 \ m^3} \quad \text{Power across electrolyser (Watts,W) = Voltage across electrolyser (V) × Current (A)}
\]

\[
0.1682 = \frac{44 \ MJ \ yr}{V_{H_2} \times 10.8 \times 10^6 \ J/m^3} \quad \text{Power across electrolyser (Watts,W) = Voltage across electrolyser (V) × Current (A)}
\]

\[
5.9453 = \frac{V_{H_2} \times 10.8 \times 10^6 \ J/m^3}{5.02 \times 10^3 \ J/hr}
\]

\[
V_{H_2} = \frac{2.76 \times 10^{-3} \ J/hr}{1 \ m^3} \quad \text{Power across electrolyser (Watts,W) = Voltage across electrolyser (V) × Current (A)}
\]

\[
2.76 \times 10^{-3} \ m^3/hr \times 24 \ hr/day \times 4 \ people = 0.265 \ m^3/day
\]
Wind Turbine Lab Report

Submitted to:
Inst. Annie Abell
GTA Russ Stech

Created by:
Team D
Cody Allison
Eric Marko
Danielle Meyer
Monica Okon

Engineering 1181
The Ohio State University
Columbus, OH
31 October 2014
Executive Summary


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Introduction


Experimental Methodology


Results


![Chart Title](chart.png)

Efficiency of the Electrolyser

\[ \eta_{\text{electrolyser}} = \frac{V_{H_2}}{V_t} \]

\[ \eta_{\text{electrolyser}} = \frac{E_{\text{hydrogen}}(m^3)}{E_{\text{electric}}(m^3)} \]  

\[ H_H = \text{calorific value of hydrogen (energy content)} = 12.745 \times 10^6 \text{ J/m}^3 \]

\[ V_{H_2} = \text{volume of hydrogen produced, m}^3 \]

\[ P = V_E \times I \]

Power across electrolyser (Watts, W) = Voltage across electrolyser (V) × Current (A)


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<thead>
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<th>Table 1: Title</th>
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<tbody>
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<td>Column 1</td>
<td>Column 2</td>
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<tr>
<td>Item 2</td>
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<tr>
<td>Item 3</td>
<td></td>
</tr>
</tbody>
</table>


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quis consequat mauris nunc non mauris. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae;

Table 2: Title

<table>
<thead>
<tr>
<th>Column 1</th>
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<tr>
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</tr>
<tr>
<td>Item 3</td>
<td></td>
</tr>
<tr>
<td>Item 4</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2: Title


\[ R_T = R + R_B \]

\[ Total \ Resistance \ (Ohms, \ \Omega) = Resistance \]

\[ Value \ from \ the \ Resistor \ Board \ (\Omega) + \]

\[ Resistance \ across \ board \ and \ leads \ (\Omega) \]


Discussion


malesuada fames ac turpis egestas. Nunc accumsan eleifend sapien, sed ornare est porttitor in. Nam non lobortis nisi, sed sagittis felis. Quisque nec volutpat velit.


Conclusion & Recommendations – Cody


Conclusion & Recommendations – Eric


Conclusion & Recommendations – Danielle


Conclusion & Recommendations – Monica


References


Appendix

Table A1: Title

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<tr>
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<td></td>
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</tr>
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</table>

Table A2: Title

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Figure A1: Title

Table A3: Title

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<tr>
<td>Item 5</td>
<td></td>
</tr>
<tr>
<td>Item 6</td>
<td></td>
</tr>
<tr>
<td>Item 7</td>
<td></td>
</tr>
</tbody>
</table>
See sample calculations from Lab Memo Example!
PowerPoint Example

The following example is related to a hypothetical presentation about fuel cells.
Fuel Cells

GROUP Z
BRUTUS BUCKEYE, GREGORY HOUSE, TONY STARK, BRUCE WAYNE
Overview

- What is a Fuel Cell?
  - Real world examples
- Types of Fuel Cells
- PEM Fuel Cells and Electrolyzers
- Present Limitations
- References
- Question and Answer
What is a Fuel Cell?

- Devices that produce electricity through electrochemical conversion
- Generate electrical power efficiently, without pollution
- Its byproducts are heat and water
- No moving parts, making them reliable products
Commercial Applications of Fuel Cells

Airbus debuted the first commercial aircraft powered by fuel cells in 2008.

Honda started production of its FCX Clarity fuel cell car in the summer of 2008.
Types of Fuel Cells

- Direct Methanol Fuel Cell
- Alkaline Fuel Cell
- Molten Carbonate Fuel Cell
- Solid Oxide Fuel Cell (SOFC)
- Polymer Electrolyte Membrane (PEM)
Polymer Electrolyte Membrane (PEM)

- $\text{H}_2$ gas is supplied to anode
- $\text{O}_2$ gas is supplied to cathode
- Reactions at each end convert gases into ions
- Electrons move through the circuit, produce electricity
- Ions come together, produce water
Electrolyzer

- Uses electrical energy to convert water into hydrogen and oxygen gases
- A technique commonly used to create fuel required for PEM fuel cells
Fuel Cell Stacks

Several fuel cells need to be combined into a single unit to achieve appreciable output voltage.
Present Limitations

- Initial cost is very high
  - Honda leases FCX model at $600/month
- Difficult to safely store hydrogen gas
- Fuel cell membranes degrade over time
  - Replacement can lead to long-term expenses
References

1) http://americanhistory.si.edu/fuelcells/basics.htm
2) http://gigaom2.files.wordpress.com/2011/10/fuelcellenergy.jpg
5) http://www.h-tec.com/uploads/pics/PEM_Brennstoffzelle_06.JPG
6) http://images.machinedesign.com/images/archive/heading0400jpg_00000036466.jpg
Questions?
Appendix C: Project Sample Documentation

Arduino Code Example

Each line of code must be commented and describe what the line of code does. Follow the examples shown below for formatting your Arduino code in the appendix of the lab documents.

Example 1:

```c
celerate(1,0,10,3); // Accelerate motor 1, from 0% to 10% power, over 3 sec
goFor(1.0); // Run last command (motor 1 at 10% power) for 1 sec
celerate(1,0,15,2); // Accelerate motor 1, from 0% to 15% power, over 2 sec
motorSpeed(2,21); // Set motor 2 speed to 21%
goFor(2.0); // Run last two commands for 2 sec (motor 2 at 21% power and
//motor 1 at 15% power)
motorSpeed(4,10); // Set all motors to 10%
goToAbsolutePosition(200); // Runs the last command until AEV travels 200 total wheel counts.
celerate(4,10,0,5); // Decelerate all motors, 10% to 0%, over 5 sec
brake(4); // Brake all motors
```

Example 2:

```c
// Accelerate motor 1, 0% to 10% power, over 3 sec
celerate(1,0,10,3);

// Run last command (motor 1 at 10% power) for 1 sec
goFor(1.0);

// Accelerate motor 1, from 0% to 15% power, over 2 sec
celerate(1,0,15,2);

// Set motor 2 speed to 21%
motorSpeed(2,21);

// Run last two commands for 2 sec (motor 2 at 21% power and
//motor 1 at 15% power)
goFor(2.0);

// Set all motors to 10%
motorSpeed(4,10);

// Runs the last command until AEV travels 200 total wheel counts.
goToAbsolutePosition(200);

// Decelerate all motors, 10% to 0% power, over 5 sec
celerate(4,10,0,5);

// Brake all motors
brake(4);
```
Sample Schedule

A schedule is to help the team stay on task, plan the appropriate time for tasks, and help the instructor see what the team has completed or needs to complete. The two primary methods for displaying the schedule are a task list and a Gannt chart (there are examples of both below).

The schedule should include the task that needs to be completed, start and finish dates, when the task is due, the teammates working on the task, and its percent completed at the end of due date. Note, not all percent completion may be 100 percent. The team may have been unable to complete some tasks and will carry them forward. Occasionally, tasks will take longer than expected (see red below). Each task will be described in the body of the report or memo.

Example 1:

<table>
<thead>
<tr>
<th>No.</th>
<th>Task</th>
<th>Start</th>
<th>Finish</th>
<th>Due Date</th>
<th>Est Time</th>
<th>Team Member 1</th>
<th>Team Member 2</th>
<th>Team Member 3</th>
<th>Team Member 4</th>
<th>% Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wind Tunnel</td>
<td>8-Jun</td>
<td>8-Jun</td>
<td>12-Jun</td>
<td>4.0 h</td>
<td>1.0 h</td>
<td>1.0 h</td>
<td>1.0 h</td>
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<td>2</td>
<td>AEV 1 Construction</td>
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<td>1.0 h</td>
<td>0.75 h</td>
<td>0.75 h</td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>AEV 1 Testing</td>
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<td>12-Jun</td>
<td>12-Jun</td>
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<td>0.5 h</td>
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<td>4</td>
<td>AEV 2 Construction</td>
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<td>12-Jun</td>
<td>12-Jun</td>
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<td>3.0 h</td>
<td>1.0 h</td>
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<td>7</td>
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<td>1.0 h</td>
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Example 2:

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</tbody>
</table>
Team Meeting Notes

The team meeting notes should be informative of what the team discussed and what needs to be completed. Typical team meeting notes include the following:

- Header (date, time, method, members present)
- Objective of Meeting (1 or 2 sentences)
- Tasks completed from previous week or last meeting
  - Bullets with task
  - Assigned person to each task
  - Short summary of status
- Tasks to be completed for the upcoming week
  - Bullets with task
  - Assigned person to each task
- Timeline/Gantt Chart with major milestones
- Decisions made by group (were they a consensus or did the project manager decide?)
- Reflection on previous assignment
  - Were there any roadblocks or bottlenecks
  - Were any deadlines missed
  - Was any work sub-standard
  - Were there differing expectations
  - Any conflicts or misunderstandings
  - How can things be improved for the next time
Example 1:

**Date**: 03 – Nov – 2015  
**Time**: 10:13 pm (Face-to-Face)  
**Members Present**: Jacob Allenstein, Nicholas Ohanian, & Dustin West  
**Topics Discussed**: Lab 1 Post-Lab

---

**Objective**:  
Today’s main focus was on meeting as a team to discuss how to construct the Executive Summary for Lab 1 and talk about designs and start the AEV u.osu.edu website

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**To do/Action Items**:  
- U.OSU.EDU – (JA, DW)  
- Executive Summary (JA, NO, DW)

---

**Decisions**:  
- The group decided to go with Design 2

---

**Reflections**:  
- We did not have enough time to proofread the report properly.  
- Next time we need to make sure the data is processed quicker so everybody can complete their part of the lab report quicker.

Example 2:

**Date**: 10 – Nov – 2015  
**Time**: 12:07 pm (google chat)  
**Members Present**: Jacob Allenstein and Nicholas Ohanian

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**Objective**:  
Today’s main focus was on creating webpages for Lab 3 and Lab 4 and going to the hobby store to look over parts. The team also brainstormed ideas of what to 3D print and would be beneficial to the AEV design.

---

**Topics Discussed**: Updating Labs 3 and 4

---

**To do/Action Items**:  
- Continue making of the website (Jacob A)  
- Talk to Professor and discuss layout of the project portfolio (Jacob A)  
- Talk to the GTA on the limitations on 3D printing (Nicholas O)

---

**Decisions**:  
- The group decided to 3D print a new base to keep the motors from being obstructed.

---

**Reflections**:  
- Jacob felt he spent more time working than anybody in the group because of the time demand of formatting the online portfolio  
- The online portfolio is a task we will consider splitting up amongst two people in the future.
AEV SolidWorks Model

Throughout the AEV project it will be required to provide a SolidWorks model of the AEV design for reports. The model must have the 3 primary orthographic views with the overall basic dimensions (overall length, height, width and the propeller diameter). Along with the overall dimensions the weight estimated cost and bill of materials should be provided. The estimated cost can be approximated by using the AEV checklist (extra copy of the AEV checklist is provided in the Lab Manual).

![Sample AEV Dimensioned]
**Figure 6: Sample AEV with Bill of Materials (BOM)**

<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>PART NUMBER</th>
<th>QTY.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Large Rectangle</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Right Trapezoid</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>90-deg bracket</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>45-deg bracket</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Motor Mount Clip</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>AEV Motor</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Support Arm 2 ABS</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Wheel</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>Prop 1</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td>Battery Pack Clamp Plate Narrow</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>Battery</td>
<td>2</td>
</tr>
<tr>
<td>17</td>
<td>Battery Spacer</td>
<td>3</td>
</tr>
<tr>
<td>19</td>
<td>Rotation Sensor Board</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>Medium Screws 1</td>
<td>12</td>
</tr>
<tr>
<td>21</td>
<td>Medium Screws 2</td>
<td>6</td>
</tr>
<tr>
<td>22</td>
<td>Nuts</td>
<td>20</td>
</tr>
<tr>
<td>23</td>
<td>Medium Screws 3</td>
<td>5</td>
</tr>
<tr>
<td>24</td>
<td>Small Screws</td>
<td>2</td>
</tr>
<tr>
<td>25</td>
<td>Small Nuts</td>
<td>2</td>
</tr>
<tr>
<td>26</td>
<td>Long Screws</td>
<td>2</td>
</tr>
</tbody>
</table>
### Table 2: Bill of Materials with costs

<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>PART IDENTIFICATION</th>
<th>QUANTITY</th>
<th>COST</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Large Rectangle</td>
<td>1</td>
<td>$ 2.00</td>
<td>$ 2.00</td>
</tr>
<tr>
<td>2</td>
<td>Right Trapezoid</td>
<td>2</td>
<td>$ 1.00</td>
<td>$ 2.00</td>
</tr>
<tr>
<td>3</td>
<td>90-deg bracket</td>
<td>3</td>
<td>$ 0.84</td>
<td>$ 2.52</td>
</tr>
<tr>
<td>4</td>
<td>45-deg bracket</td>
<td>4</td>
<td>$ 0.84</td>
<td>$ 3.36</td>
</tr>
<tr>
<td>5</td>
<td>Motor Mount Clip</td>
<td>2</td>
<td>$ 0.59</td>
<td>$ 1.18</td>
</tr>
<tr>
<td>6</td>
<td>AEV Motor</td>
<td>2</td>
<td>$ 9.99</td>
<td>$ 19.98</td>
</tr>
<tr>
<td>7</td>
<td>Support Arm 2 ABS</td>
<td>1</td>
<td>$ 3.00</td>
<td>$ 3.00</td>
</tr>
<tr>
<td>9</td>
<td>Wheel</td>
<td>2</td>
<td>$ 7.50</td>
<td>$ 15.00</td>
</tr>
<tr>
<td>13</td>
<td>Prop (EP-2510)</td>
<td>2</td>
<td>$ 0.45</td>
<td>$ 0.90</td>
</tr>
<tr>
<td>14</td>
<td>Battery Pack Clamp</td>
<td>1</td>
<td>$ 1.00</td>
<td>$ 1.00</td>
</tr>
<tr>
<td>20</td>
<td>Rotation Sensor Board with wire</td>
<td>1</td>
<td>$ 4.00</td>
<td>$ 4.00</td>
</tr>
<tr>
<td>Various</td>
<td>Bulk nuts and screws</td>
<td>1</td>
<td>$ 2.88</td>
<td>$ 2.88</td>
</tr>
<tr>
<td>28</td>
<td>Arduino</td>
<td>1</td>
<td>$ 100.00</td>
<td>$ 100.00</td>
</tr>
</tbody>
</table>

It can be noted that the various nuts and screws can be lumped into one cost. This includes all the bolts, nuts and the spacers used for the battery. If there were parts made ask the instructor the cost to make the part or provide a copy of the receipt of a purchased part.