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# Work in Progress: Supporting Engineering Laboratory Report Writing with Modules Targeted for Instructors

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# Work in Progress: Supporting Engineering Laboratory Report Writing with Modules Targeted for Instructors


## Abstract

Laboratory reports are a genre of writing that students are exposed to early in their engineering curriculum. Varied student writing preparation ensures that students need differentiated support in laboratory writing to achieve learning outcomes. Supported by the National Science Foundation Improving Undergraduate STEM Education initiative, researchers at three institutions have developed a series of scaffolded laboratory writing modules related to different components of a laboratory report. The module contents were informed by prior research into student performance in laboratory report writing in multiple engineering disciplines and with varied writing preparation. The modules provide definitions and guidance for novice report writers and instructor support for developing assignments and rubrics for laboratory reports. The scaffolded modules treat elements of a laboratory report at fundamental, intermediate, and advanced levels. Fundamental modules include audience expectations, lab report organization and conventions, simple statistics, and data presentation in tables and graphs. Intermediate modules address primary and secondary sources of data, trendlines, summary and conclusion writing, and referencing secondary sources. Advanced modules address logical appeals and encourage student writers to consider error analysis and error propagation. This paper describes the structure and content of the modules as well as the process used to develop them. Initial assessments by instructors as module users are presented. Other publicly available writing-support resources are catalogued to demonstrate the novelty and value of the lab report writing modules.


## Introduction

Writing, particularly in engineering laboratory settings, prepares students for technical writing activities in engineering practice. Early laboratory courses are often the first place engineering students encounter writing about technical subjects to a technical audience. Lab reports allow students to document methods of experimentation and data analysis techniques, as well as interpret results in basic professional forms and conventions and offer conclusions that are meaningful for both a technical audience and as a demonstration of their own learning [1-3].

The instructional modules presented in this paper build on research involving writing transfer concepts that address the transfer source (prior writing experience) and the transfer target (writing in a new situation, in this case an engineering laboratory). In this situation, the transfer can be considered “far transfer” because the writing skills in English and engineering disciplines contain few similar general features [4-5]. Effective transfer requires the use of shared language and effective review of prior knowledge to form a basis for the instruction of new material [6-9].

Many laboratory report writing instructional tools exist at websites created by others. The Purdue Online Writing Lab (OWL) has a robust library of writing guidance in a variety of fields and genres [10]. It provides guidance for tutors supporting early lab report writers and students interested in report format and contents. It also includes videos offering guidance in the technical report genre. The Civil Engineering Writing Project provides materials developed by a team led by Susan Conrad [11]. It offers excellent technical writing guidance with language units, grammar and mechanics lessons, and examples of specific genres like memoranda, cover letters, site reports and proposals. The language instruction is very specific, including word choice, sentence structure, and active/passive voice, but the project does not specifically address the laboratory report genre. On the other hand, a website available from Monash University offers guidance on the structure of a laboratory report as well as specific guidance on writing in the various sections of the report [12]. The site also provides self-paced exercises and quizzing to allow a student to check their knowledge as they work through the material. Michael Alley at Penn State has developed a website at craftofsciencewriting.com that offers text and video explanations, report templates, and sample lab reports [13].

The modules described in this paper differ from the existing materials available because they target students as they transition from courses taught by written communication experts (e.g. English literature, composition, rhetoric, and technical writing instructors) to those taught by engineering experts focused on introducing them to engineering experimentation in technical fields of study. Early laboratory courses are often crowded with technical content, but they also often rely on laboratory reports or technical memos as ways for students to demonstrate their understanding. Evidence-based instructional tools at this level are critical for improving the writing skills of engineering students early in their curriculum and beyond. The remainder of this paper will describe module development process and the first iteration of modules that have grown out of this writing transfer-focused work.

**Module Development**

Most engineering laboratory reports follow the IMRDC format: introduction, methods, results, discussion, conclusion [14,15]. The authors have previously published a learning outcomes rubric based on APA writing outcomes [16] and ABET EAC outcomes [17] that ties outcomes to the relevant sections of a typical engineering laboratory report (Table 1) [citation to be included in final draft]. The authors developed modules targeting laboratory instructors to support each of these outcomes with a scaffolded approach, based on research into student writing preparation [18] and student performance on early and later lab reports in an early laboratory class in a variety of programs and curricula [19].

Table 1. Lab report writing outcomes rubric (I = introduction; M = methods; R = results; D = discussion; C = conclusion).

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

The laboratory report writing modules presented here were developed by the authors through a collaborative process. The authors have expertise in mechanical, civil, and electrical engineering and each has at least 15 years of experience teaching laboratory courses. Twelve modules were produced plus three sections in the preface. Each module developer prepared three modules that were then reviewed by a different developer with a goal of improving the content. The reviewer provided their feedback in the module documents and the pairs met to discuss. Learning objectives and informational content were reviewed for relevance and clarity, examples and resources were reviewed, and connections to other modules were considered. In some cases, additional resources, like spreadsheet examples or graded work, were suggested and developed because of these meetings. The result is a series of interconnected modules each with a similar structure:

- Learning objectives
- Definitions
- Why should students care?
- How to…
- Example(s)
- Common mistakes by students
- Tools: templates, presentations, spreadsheets, and other resources

Based on the report writing outcomes and investigations of student report writing performance at the three participating institutions [19-21], the authors prepared scaffolded learning modules organized around (1) fundamental concepts needed to submit a successful first report, (2) intermediate concepts intended to support more rigorous consideration of data sources, methods of analysis, and conclusions, and (3) advanced concepts in error and logical appeals. A preface was developed to orient users and support instructors with guidance around assessment design and the use of effective rubrics. The organization and titles of the modules are provided here:

- Preface
  - Introduction to Modules for Engineering Lab Instructors
  - Assignment Design
  - Assignment Rubric Design
- Fundamental
  - F1 - Audiences of Engineering Lab Reports
  - F2 - Lab Report Organization
  - F3 - Lab Report Conventions
  - F4 - Data Analysis 1: Simple Statistics
  - F5 - Data Presentation
- Intermediate
  - I1 - Lab Data as a Primary Source
  - I2 - Summary/Conclusion Writing
  - I3 - Data Analysis 2: Trendlines
  - I4 - Referencing
- Advanced
  - A1 - Logical Appeals (Claim-Evidence-Warrant)
  - A2 - Data Analysis 3: Error
  - A3 - Data Analysis 4: Propagation of Error

The modules are meant to be very concise, simple, and easy-to-use aids for helping engineering students improve their engineering laboratory report writing skills, specifically preparing and presenting the results of engineering experiments. The collection of modules was designed and structured with scaffolding in mind. Early concepts in writing lab reports are covered in the fundamental section for students new to lab report writing. More experienced students might skip these sections and be directed to topics in the intermediate or advanced sections. Module content could be used for just-in-time instruction when student questions or early performance indicates the need, or a module could be incorporated as a whole lesson with progressive instruction in lab report conduct and writing that could occur over the course of an academic term. The modules are independent, not sequential, so an instructor may use fundamental modules in one topic, and advanced modules in other topics. The modules are arranged according to writing outcomes and relevant sections of a report in Table 2.

Table 2. Relationship of writing outcomes, lab report section, and module.

| **Writers in early engineering lab courses are able to** | **Mostly related to** | **Related Modules** |
|---|---|---|
| 1) Address technical audience expectations by providing the purpose, context, and background information, incorporating secondary sources as appropriate. | Introduction | F1 – Audiences of Engineering Lab Reports |
| 2) Present experimentation processes accurately and concisely. | Methods | F2 – Lab Report Organization |
| 3) Illustrate lab data using the appropriate graphic/table forms. | Results | F5 – Data Presentation |
| 4) Analyze lab data using appropriate methods (statistical, comparative, uncertainty, etc.). | Results/ Discussion | F4 – Data Analysis 1: Simple Statistics<br>I1 – Lab Data as a Primary Source<br>I3 – Data Analysis 2: Trendlines<br>A2 – Data Analysis 3: Error<br>A3 – Data Analysis 4: Propagation of Error |
| 5) Interpret lab data using factual and quantitative evidence (primary and/or secondary sources). | Results/ Discussion | I1 – Lab Data as a Primary Source<br>A1 – Logical Appeals<br>A2 – Data Analysis 3: Error<br>A3 – Data Analysis 4: Propagation of Error |
| 6) Provide an effective conclusion that summarizes the laboratory's purpose, process, and key findings, and makes appropriate recommendations | Conclusion | F1 – Audiences of Engineering Lab Reports<br>I2 – Summary/Conclusion Writing |
| 7) Develop ideas using effective reasoning and productive patterns of organization (cause-effect, compare-contrast, etc.). | IMRDC | F4 – Data Analysis 1: Simple Statistics<br>I1 – Lab Data as a Primary Source |
| 8) Demonstrate appropriate genre conventions, including organizational structure and format (i.e., introduction, body, conclusion, appendix, etc.). | IMRDC | F1 – Audiences of Engineering Lab Reports<br>F2 – Lab Report Organization |
| 9) Establish solid and consistent control of conventions for a technical audience (grammar, tone, mechanics, citation style, etc.). | IMRDC | F3 – Lab Report Conventions<br>I4 - Referencing |

The scaffolded nature of the modules should become apparent after reviewing Table 2. For example, the fundamental modules provide students with an ability to report and present data in a whole lab report with relatively little guidance on interpretation and drawing conclusions. The intermediate and advanced modules develop these skills once students have mastered the report conventions and format; then, they can engage the technical aspects of the laboratory work, thinking deeply about their results and other guidance in relevant literature, drawing reasonable conclusions, and referencing sources accurately.

The draft modules were compiled as pdfs by the developers and translated to a web page for hosting by a student worker. The developers visited the pages to ensure the contents were translated accurately and that links were functional. The modules can be accessed by visiting https://labs.wsu.edu/engineering-lab-report-writing/ and using the password *lab*. The password will be removed when the module test is completed in 2023. Module contents are currently available as both webpage and downloadable pdfs, but other formats are still under consideration.

**Module Learning Objectives and Structure**

A list of the modules with their learning objectives and an example of the structure (Figure 1) are provided here to give the reader a sense of the goals of the modules as well as the ways they are connected to prior writing. The reader should note the many references to genre expectations and conventions intended to bridge the gap between prior writing outside of engineering contexts and writing in the engineering disciplines.

- Preface
    1. Introduce the structure and contents of the modules to engineering lab instructors.
    2. Introduce assignment design processes.
    3. Introduce assignment rubric design processes.
- Fundamental Modules

  *F1 - Audiences of Engineering Lab Reports*
    - Identify the audience of an engineering lab report.
    - Describe the typical audience expectations from engineering lab reports.
    - Describe the genre expectations (audience, writer, purpose) of typical engineering lab reports.

  *F2 - Lab Report Organization*
    - Bridge from the typical freshman composition course essay's organization (Introduction, Body, and Conclusion) to the engineering lab report's typical organization: Introduction-Method-Results-Discussion-Conclusion (IMRDC).

  *F3 - Lab Report Conventions*
    - Describe and apply the conventions of the lab report genre.

  *F4 - Data Analysis 1: Simple Statistics*
    - Describe data analysis processes.
    - Explain what is meant by data variability and what causes it.
    - Explain the role of statistics in analyzing data.
    - Determine basic statistical parameters of engineering data (sample mean and sample standard deviation).

  *F5 - Data Presentation*
    - Explain why tables, graphs, and photographs are essential for laboratory reports.
    - Identify three common methods of presenting data and how they are best applied.

    - Identify features that allow tables, graphs and photographs be effective communication tools.
    - Use Excel to make simple graphs and tables.
    - Explain how to learn more about presenting data.
- Intermediate Modules

  *I1 - Lab Data as a Primary Source*
    - Focus on lab data as a primary source for analysis and interpretation.
    - Use technical information from outside references as a secondary source to support lab data analysis and interpretation.

  *I2 - Summary/Conclusion Writing*
    - Identify technical audience expectations for engineering lab report conclusions.
    - Describe what makes a conclusion meaningful, especially to a technical audience.
    - Relate the idea of audience expectations to prior writing instruction.
    - Write meaningful conclusions for an engineering lab report.
    - Summarize the important contents of the laboratory report clearly, succinctly, and with sufficient specificity.
    - Support conclusions with the evidence presented earlier in the lab report.

  *I3 - Data Analysis 2: Trendlines*
    - Define and explain trendlines (aka curve fitting, least squares fit, lines of best fit, and regression).
    - Identify a plausible trend by observation of plotted bivariate data.
    - Define the coefficient of determination and use it to quantify the correlation of data assuming a particular trend.

  *I4 - Referencing*
    - Evaluate the credibility of references (secondary sources) to use them properly in the lab report.
    - Identify typical citation and referencing styles in engineering literature.
    - Describe why the preferred citation/referencing styles (or conventions) in engineering are different from other disciplines, such as humanities and social sciences.
- Advanced Modules

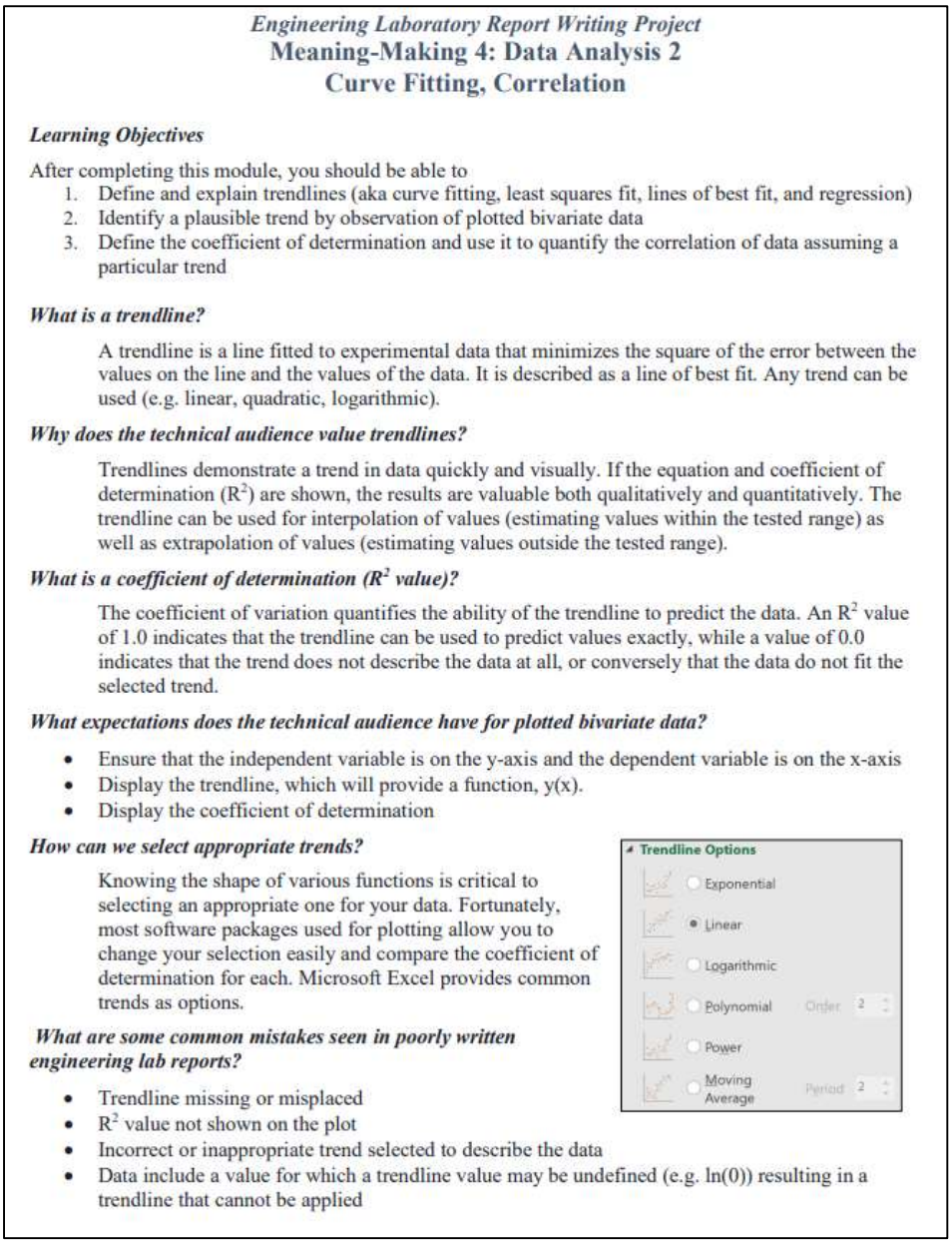
  *A1 - Logical Appeals (Claim-Evidence-Warrant)*
    - Describe why engineers' appeals should be logical (logos) and ethical (ethos).
    - Define the three parts of a logical appeal: claim, evidence, and warrant (reasoning).
    - Use the logical appeal when analyzing and interpreting lab data.

  *A2 - Data Analysis 3: Error*
    - Define systematic and random error.
    - Calculate the systematic error (aka bias) in a sample and explain its source.

- Calculate the random error (aka uncertainty) in a sample and recommend ways to reduce it.
- Differentiate systematic and random error.
- Present error in both absolute (as a quantity) and relative (as a percentage) terms.

*A3 - Data Analysis 4: Propagation of Error*

- Explain how error propagates or compounds in computations involving random variables.
- Use a rule of thumb to estimate the error in computed results.
- Calculate the error in a result computed using products or quotients.



*Engineering Laboratory Report Writing Project*

**Meaning-Making 4: Data Analysis 2**

**Curve Fitting, Correlation**

***Learning Objectives***

After completing this module, you should be able to

1. Define and explain trendlines (aka curve fitting, least squares fit, lines of best fit, and regression)
2. Identify a plausible trend by observation of plotted bivariate data
3. Define the coefficient of determination and use it to quantify the correlation of data assuming a particular trend

***What is a trendline?***

A trendline is a line fitted to experimental data that minimizes the square of the error between the values on the line and the values of the data. It is described as a line of best fit. Any trend can be used (e.g. linear, quadratic, logarithmic).

***Why does the technical audience value trendlines?***

Trendlines demonstrate a trend in data quickly and visually. If the equation and coefficient of determination ($R^2$) are shown, the results are valuable both qualitatively and quantitatively. The trendline can be used for interpolation of values (estimating values within the tested range) as well as extrapolation of values (estimating values outside the tested range).

***What is a coefficient of determination ($R^2$ value)?***

The coefficient of variation quantifies the ability of the trendline to predict the data. An $R^2$ value of 1.0 indicates that the trendline can be used to predict values exactly, while a value of 0.0 indicates that the trend does not describe the data at all, or conversely that the data do not fit the selected trend.

***What expectations does the technical audience have for plotted bivariate data?***

- Ensure that the independent variable is on the y-axis and the dependent variable is on the x-axis
- Display the trendline, which will provide a function, y(x).
- Display the coefficient of determination

***How can we select appropriate trends?***

Knowing the shape of various functions is critical to selecting an appropriate one for your data. Fortunately, most software packages used for plotting allow you to change your selection easily and compare the coefficient of determination for each. Microsoft Excel provides common trends as options.



***What are some common mistakes seen in poorly written engineering lab reports?***

- Trendline missing or misplaced
- $R^2$ value not shown on the plot
- Incorrect or inappropriate trend selected to describe the data
- Data include a value for which a trendline value may be undefined (e.g. ln(0)) resulting in a trendline that cannot be applied

Figure 1. Example module structure and content.

**Early Instructor Feedback**

The module webpage has been distributed to instructors who have agreed to participate in the research project associated with this work. Instructors were not asked to do anything other than consider the use of the modules in their lab course. The degree to which they have adopted module contents and their feedback is an area of interest for the module developers. The results of three interviews are provided here.

Interview of WSU scholarly assistant professor on January 18, 2022
Q1. Did you use the modules? If yes, when, and how often? If not, why?
A. Yes, early in the semester to update my lab handouts. See below.

Q2. Which module topic/content(s) helped you the most?
A. Module F2: Lab Report Organization. Some of the other modules, e.g., Data Analysis, did not seem relevant to the ECE 214 lab topics. There is too much information in the modules to apply in ECE 214. Students will not read anything more than one or two pages.

Q3. How did you use the module content(s)? For example, did you update your lab handouts, lab instruction, lab report assessment, or anything else?
A. Yes, I copied and pasted text from Module F2: Lab Report Organization to create a one-page lab report template for all the labs in ECE 214. The default template served for most labs, but I added some lab-specific reminders to a few of the templates. For example, remind students to include a specific table in the results section. Students could download the templates in DOCX format from Canvas. I also put a link to https://labs.wsu.edu/engineering-lab-report-writing/sample-page/preface/ on Canvas, but I don't know if any of the students used it.

Q4. What content(s) do you need in addition to the existing ones?
A. Perhaps sample grading rubrics.

Q5. Any room for improvement on the web page to improve the user interface?
A. The organization of the landing page is not clear. I didn't understand what I was looking at. Some of the terms are not defined. What is a module? What is a scaffold? What is the meaning of the scaffold levels fundamental/intermediate/advanced? Some modules, such as Data Analysis seem more relevant to mechanical/civil engineering than to EE. Reusing the same module name with a number suffix is confusing, e.g., Data Analysis 1/2/3/4.

Interview of WSU assistant professor on August 18, 2021
Q1. Did you use the modules? If yes, when, and how often? If not, why?
A. Yes, I visited the web when updating my lab syllabus.

Q2. Which module topic/content(s) helped you the most?
A. Module Preface: Assignment design and assignment rubric.

Q3. How did you use the module content(s)? For example, did you update your lab handouts, lab instruction, lab report assessment, or anything else?
A. I could update my lab report assessment rubrics.

Q4. What content(s) do you need in addition to the existing ones?
A. I do not have much time to review the entire modules.

Q5. Any room for improvement on the web page to improve the user interface?
A. The module web looks great, and it may contain excellent materials for lab writing education. As a tenure track assistant professor, my time to develop or update lab course materials is extremely limited. It will be good if the module materials are concise and to the point (easy to copy and paste).

Interview of OIT assistant professor on February 15, 2022

Q1. Did you use the modules? If yes, when, and how often? If not, why?
A. Yes! I used the modules a lot when developing the lab report template. I also used the modules when grading the lab reports.

Q2. Which module topic/content(s) helped you the most?
A. Since I used the modules for a sophomore level course, I mostly used the Fundamental Levels (F1-F5). I found Intermediate Levels helpful for the class as well.

Q3. How did you use the module content(s)? For example, did you update your lab handouts, lab instruction, lab report assessment, or anything else?
A.

1. I updated the lab report template using the structures and some language from F2, I2 and I4.
2. I introduced the module website to the students during class and included the website in the lab report template.
3. I used the modules when grading the lab report.

Q4. What content(s) do you need in addition to the existing ones?
A. I think the existing contents are well prepared and organized. If I must add something, that would be sample lab reports and templates.

Q5. Any room for improvement on the web page to improve the user interface?
A. Not much. The web page is easy to navigate and user-friendly for mobile devices.

## Discussion

The goal of this work-in-progress paper is to document and present the work completed thus far as instructional modules are developed to support instructors teaching early engineering laboratory courses. Based on initial feedback from instructors who have used the modules, there are strengths and areas for improvement.

Strengths of the modules according to this feedback include the support for instructors to develop effective assignments and grading rubrics; this is content provided in the preface and most specifically geared toward instructors. Instructors also appreciate the ability to copy and paste content into their own assignment documents and learning management systems. So far, only the report organization module has been used for student instruction.

Areas for improvement include module organization and naming, adoptability and ease of use for time-limited faculty, brevity of module contents (or perceived brevity), additional sample grading rubrics, tailoring of contents for specific disciplines. Canvas Commons, KEEN Cards, or other repositories of easily adopted instructional materials could be valuable places to include this content to improve adoptability.

## Conclusion

This paper presents the development, contents, and early instructor assessment of instructional modules intended for instructors of early engineering laboratory classes with a lab report writing component. The module development process was based on prior research of student report writing performance using a report writing outcomes rubric developed by the authors. The modules are scaffolded to support instruction of students at all levels of lab report genre awareness; they can be used to support students' early lab report writing as well as for improvement in more advanced data analysis and interpretation. While early feedback indicates there are opportunities to improve the modules, they serve as a valuable contribution to laboratory report writing instruction.

## Future Work

These materials are in the process of beta testing by a select group of faculty. Assessment of both the adoption by engineering lab instructors and the performance of students are being studied. The modules will be refined and made publicly available once they have been fully vetted and tested.

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