Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #45583

Analysis of a Scientific Paper to Scaffold Lab Report Writing Skills

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Abstract

Instruction on data presentation and report writing is difficult to incorporate into undergraduate laboratory courses in which the instructional focus is experimentation and analysis rather than technical writing. In the first lab session of the semester students typically do not have sufficient content knowledge to perform an experiment. In many courses, therefore, the start of labs is delayed to the second week of the term or later. If utilized, the first lab session is often dedicated to a review of safety rules and/or a lecture presentation on lab expectations which may include details of report writing and formatting. These activities do not engage students or excite them about the course. Here, an introductory activity is described for a mechanical behavior of materials laboratory course that requires minimal instructor preparation and no student prior knowledge. The activity is a collaborative analysis of a scientific paper that challenges students to think about report formatting and data presentation while getting to know their peers. The task can be easily adapted to fit the instructional goals of the educator and be made appropriate for any discipline. The activity serves to foster relationships between students and teaching assistants, introduce the online platform used for assignment submission in the course, and model scientific writing and report formatting standards in an engaging way.

Introduction

MASC 310L: Materials Behavior and Processing is an introductory materials science course at the University of Southern California. The course is required for mechanical engineers and taken as an elective by students in other engineering disciplines. While the course is aimed at junior level students it is taken by an even mix of sophomores, juniors, and seniors. With necessary cancellations for university holidays there are 11 weeks of possible lab sessions in the 15-week semester, and 10 experiments in the curriculum. With a holiday occurring the second week of the semester (Labor Day in the fall and Martin Luther King Jr. Day in the spring) not utilizing the first week of the lab sessions would result in labs not starting until week 3 of the semester. This would necessitate a full experiment taking place the first time students enter the lab and meet their lab mates and teaching assistants (TAs). To make sure students locate the lab and get into the habit of attending their scheduled lab session, an introductory activity was developed for the first week of the course in which students work in groups to analyze a scientific paper. The goals of the activity are threefold: (1) give students an opportunity to meet each other and the lab TAs in a low-stakes setting, (2) familiarize students with the online system they will use throughout the semester for assignment submissions, and (3) model the format and expectations for the lab reports they will prepare in the course.

Studies have shown that working engineers typically devote 20-40% of their workday to communication (a percentage that increases with career advancement) but less than 5% of engineering education is devoted to communication skills [1]. Engineering students are exposed to technical writing at various points during their academic careers. Because students in MASC 310L are from a range of disciplines and at a range of class standings, their prior instruction on writing is highly diverse. While improving writing skills is not a learning objective for the course, the more opportunities students get to receive feedback on their writing and practice technical writing skills, the more prepared they are to enter the engineering workforce. Prof.

Amber Genau has reported on an activity utilized in her undergraduate materials lab courses in which students do a close read of an instructor selected scientific journal article and answer a series of questions [2]. Ramirez-Echeverry et al. similarly describe a series of steps used to enhance technical writing skills which includes reading and summarizing instructor selected scientific papers [3]. The activity described here is an extension of these approaches, in which a published paper is used to model formatting and technical writing standards, particularly for data presentation in figures and tables, captioning, and referencing. The activity was designed to supplement instructor provided lab report guidelines and rubrics with an active learning exercise to enhance student's self-efficacy around report writing and foster self-regulated learning.

Self-regulated learning, or the ability a student has to control their own learning environment, is influenced by cognition, metacognition, and motivation [4]. While it takes decades to develop the skills of self-regulated learning, instructors can provide students with the tools needed to progress from fully dependent to more autonomous learners. A critical component of the motivational side of learning is self-efficacy. Schraw et al. propose that vicarious learning and modeling are two variables with a significant influence on student self-efficacy [4]. When students are asked to observe the work of others, rather than perform a task themselves, mental load and anxiety are reduced. Vicarious learning can be implemented for technical writing instruction by providing students with examples of published works that showcase the established reporting standards in the field. Students enter undergraduate laboratory courses as novices, not only from the context of course content, experimentation, and analysis, but also technical communication skills. It is also important to acknowledge that expertise does not equate solely to content knowledge. Experts are not only knowledgeable, but their knowledge is better organized, they have better strategies for accessing that knowledge, and they are highly self-regulated [5]. Modelling expert thinking and exposing students to the writing of those more senior in the field can be an effective strategy for scaffolding technical report writing and helping students move along the continuum from novice to expert.

Preparation

Prior to the start of the semester a scientific paper was selected by the instructor [6]. The paper was chosen based on both format and content. Several experiments in the MASC 310L lab utilize Vickers hardness testing, in which students compare the sizes of indent impressions to observe property differences between metals (i.e. copper and aluminum) and between the same metal in different conditions (i.e. brass after cold working and annealing and steel after various heat treatments). Prior to the course students have little to no exposure to hardness testing, so a paper was selected that showcases images of Vickers indents. The chosen paper also follows a format consistent with the formatting expectations for the lab reports students write throughout the semester. These formatting requirements include an abstract, introduction, experimental methods, results and discussion, and conclusions sections as well as numerical citations that appear in square brackets in the text with a numbered reference list at the end of the paper.

To prepare for the activity several copies of the paper were printed. Lab sections in the course have 12 students and lab experiments and reports are completed in groups of 2-4 depending on the week. This activity was designed to be done collaboratively in similarly sized groups. 6 full copies of the paper, printed single sided, were cut apart and each table and figure as well as all captions were separated. To enable to activity to be done across multiple lab sections and repeated for several semesters the individual figures, tables, and captions were laminated (this step is optional). The figures, tables, and captions from each copy of the paper were shuffled and inserted into large envelopes. 12 copies (enough for one per student, to be reused in each lab section) were printed of only the abstract, introduction, and experimental methods sections of the paper, which fit on one double sided page. Finally, 12 copies of the full paper were printed double sided. The same paper has been used for 6 semesters in MASC 310L, though a different paper could easily be selected to update the activity or modify it for a different course.

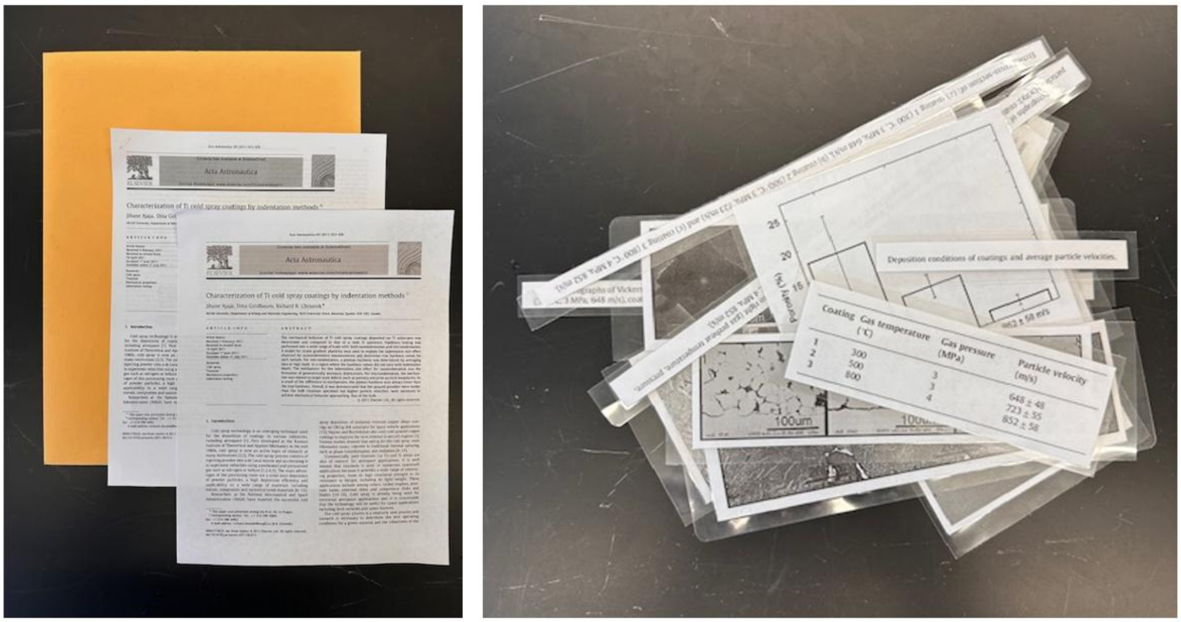

Figure 1. Prepared materials for analysis of a scientific paper activity (left). The envelope contains laminated figures, tables, and captions from the paper, all individually cut out and shuffled in random order (right). Printouts include both the full paper and a truncated single page version.

Facilitation

When students arrive to lab the first week of classes the TAs introduce themselves, briefly go over safety polices, and have students sign a safety agreement. Students are then asked to introduce themselves and organize into groups of 2-4 (groups of 3 are ideal and encouraged by the TAs). Once groups are established the TAs provide each group with an envelope containing the figures and tables from the chosen paper, as well as all captions. With no additional background or outside information student groups are tasked with matching each caption to the appropriate table/figure. The purpose of this task is to draw attention to the level of detail that should be included in a caption and the care with which figures and tables are formatted to clearly convey information. Even with no knowledge of the test methods or subject matter students can use context clues to successfully match each caption to the proper visual. Once the matching is complete the students alert the TAs who provide them with the abstract, introduction, and experimental methods sections of the paper.

With the additional information provided in the abstract, introduction, and experimental methods, groups are asked to arrange the figures and tables into the order in which they would expect them to appear in the body of the paper. The goal of this task is to have students perform a close read of the abstract and introduction of a scientific paper and observe how researchers use these elements of the paper to lay out the motivation for the study, the key results, and the important takeaways. Proper presentation of an experimental methods section is also modeled, which provides more insight into the data presented in the figures and tables the students have examined in the matching portion of the activity. Once the ordering step is complete the TAs provide each group with the full text of the paper. Students are not required to read the full paper (though it is posted to the course learning management system for later review) but are able to use the full text to check their matching and ordering. Finally, students answer a series of discussion questions. The activity typically takes between 1-1.5 hrs of the allotted 2 hr lab section. The general timing and flow of the activity is presented in Figure 2.

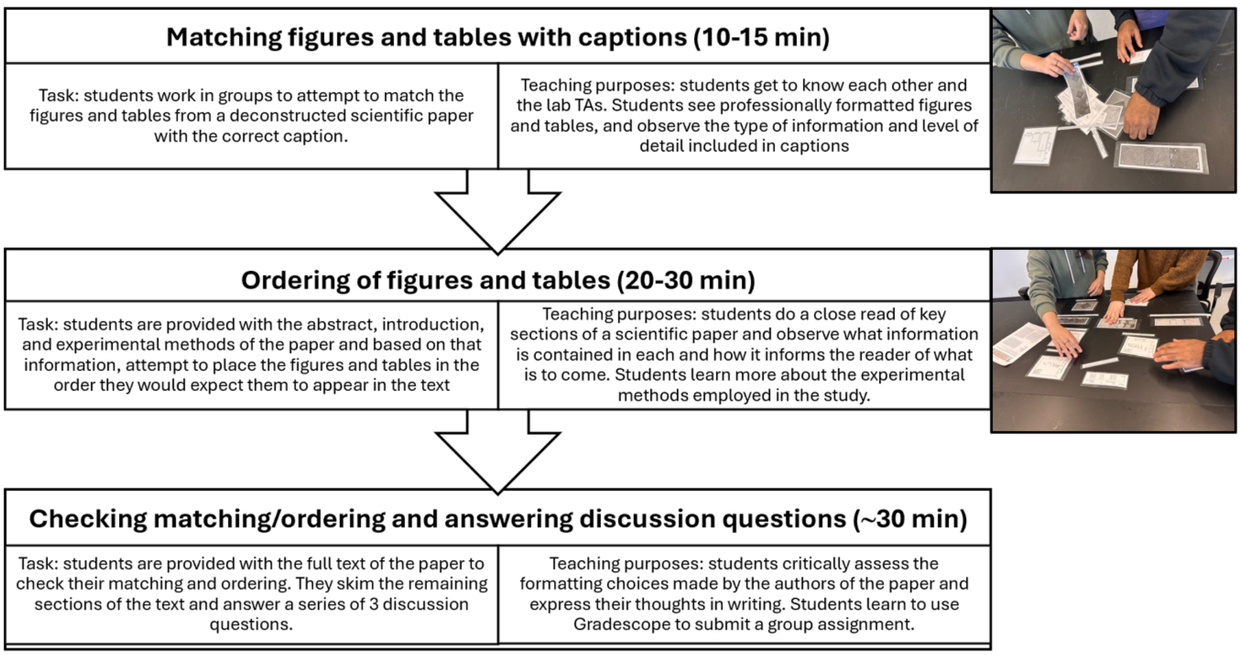

Figure 2. Outline of activity with pictures of a student group matching captions (top) and ordering figures and tables

The discussions questions students respond to are listed below:

1. What do you notice about the scale bars in figures with microscope images (micrographs)? Consider, in particular, figures with multiple images. Why do you think the authors made the choices they did when creating these figures?
2. Did the authors include every micrograph they took for this study and all experimental data in the paper? If not, is the data included sufficient to tell the story?
3. The paper you were given is well constructed and has been through peer review, but it was not selected for this exercise because it is "perfect." What would you change to improve the data presentation in the paper? Don't worry about technical content, focus on visual aspects and general communication of information. If any of your matching or ordering was "incorrect", do you attribute it to an error on your part or the part of the authors?

These questions were generated to meet specific instructional aims and can be adapted to the needs of a particular course. Discussion questions require students to express their thoughts both verbally (to peers) as they formulate a response and in writing (to the instructor) in their final submissions. This reflection and articulation of ideas helps to reinforce the learning objectives of the activity. Having students submit answers to discussion questions serves the secondary but important purpose of introducing students to the online platform (Gradescope) used for all assignment submissions in the course. The activity is not graded (though it could be at the instructor's discretion), but including a Gradescope submission requires students to access the platform via the course learning management system, gain familiarity with its navigation, and learn how to create a group submission and add group members to the submission. This is accomplished while in the lab under the supervision of TAs who are available to assist with any issues, thereby reducing technical difficulties in the submission of subsequent assignments.

Outcomes

Although detailed lab report guidelines and a lab report grading rubric are provided to students each semester, prior to the introduction of this activity there were a few common issues that would arise in student submissions. The most common was inefficient and novice presentation of data. Vickers hardness number, for example, is calculated based on the indentation load and the projected area of the resulting indent impression. When indents are performed at a consistent load, therefore, the size of the resulting indents can be used as a visual indication of relative properties. While it may seem obvious to someone familiar with Vickers hardness testing to present indents at the same scale and in a multipart figure for ease of comparison, nearly all student groups historically presented each indent image individually, often cropped (resulting in different scaling between images), and across multiple pages. While this technically satisfies the requirement of presenting indent data, it shows a lack of understanding of what information is gleaned from microscope images of Vickers indent impressions and how that information is best conveyed. The paper chosen for the introductory lab activity models a more expert approach to formatting and allows students to see the utility of intelligent data presentation for themselves. Answers to the first discussion question over the past several semesters have included things like the following (all spelling and formatting is the student's own).

Question 1: What do you notice about the scale bars in figures with microscope images (micrographs)? Consider, in particular, figures with multiple images. Why do you think the authors made the choices they did when creating these figures?

Example student responses:

- *The authors chose to keep the scale the same across all three images. This is most likely due to its ease of visual comparison from image to image. In some image sets, they chose 100 µm, while others the authors chose 20 µm. Both of these are generally common, being in base 10. Therefore, it is more commonly used than an arbitrary choice (i.e. 37 um).*
- *The scale bars are all kept the same size in the microscope images. The authors held the scale constant between images so that you could see the variation in the coating. Within figures the scale is the same, but between figures it is different. It would only be necessary to keep the scale consistent from image to image if comparison between figures is made.*

- *In the figures with multiple images, the scale bar is always the same length and corresponds to the same measurement. The authors probably made this choice to keep everything consistent and intuitive for better comparison.*
- *The scale bars in figures with microscope images are large enough size in comparison with the image itself for easy measurement and interpretation. With multiple images, the scales remained the same for easy comparison.*
- *They chose the color of the scale bars deliberately so that they are more visible. The size of the scale bars are consistent. The scale bars are on the corner so that readers can see the image.*

These responses show that students are highly capable and can recognize the decision making behind expert formatting choices despite the fact that in the absence of provided examples or explicit instructor directives they will not independently make those choices.

Another common issue with student lab reports, historically, was a lack of understanding of what information to include. Students would commonly provide unnecessary information in their submissions including images of every indent performed in a sample (a minimum of 4 indents is taken on each metal in each condition to arrive at a representative average hardness number) and copying the full table of all indent diagonal measurements from the data sheet they fill out during the experiment into their report. The second question in the analysis activity prompts students to recognize that key results can be conveyed in a more concise manner and a "more is more" approach will not yield the best result (or in the case of lab reports, the highest grade). Again, example responses are provided below.

Question 2: Did the authors include every micrograph they took for this study and all experimental data in the paper? If not, is the data included sufficient to tell the story?

Example student responses:

- *The authors most likely did not include every micrograph and experimental data they took for this study. Likely, the authors chose the obtained images and data that best illustrate their findings without repetition or further confusion.*
- *The authors mentioned taking five indentations per sample, but only depicted one per sample. This is sufficient to tell the story provided they are not omitting outliers and presenting misleading data.*
- *The author did not include every micrograph and only included the data necessary for the analysis and conclusions found. Inclusion of every micrograph would've been busy and unnecessary. Not all raw data is put into the tables, but are included in the graphs themselves, which is sufficient.*
- *The data they included seems sufficient to tell the story without being repetitive. If they took additional micrographs, they did not include them all, probably for efficiency and clarity.*

The final common mistake observed in student lab reports has been formatting and content errors, particularly in the results section. It was not uncommon in the past for students to submit a report in which the results section was simply a series of figures and tables with little to no descriptive text and minimal detail in captions. The final discussion question posed in the activity often solicits responses related to this type of issue.

Question 3: The paper you were given is well constructed and has been through peer review, but it was not selected for this exercise because it is "perfect." What would you change to improve the data presentation in the paper? Don't worry about technical content, focus on visual aspects and general communication of information. If any of your matching or ordering was "incorrect", do you attribute it to an error on your part or the part of the authors?

Example student responses:

- *The figures are clumped together, without immediate introduction to them individually. The introduction of the figures is listed in a singular paragraph with all relevant figures following rather than each figure having its own introduction. This makes it difficult for readers to understand which figure is correlated to the analysis presented. The changes we would make would be restructuring the figures so that they flow where they are immediately mentioned. This way, the presentation of the data becomes clearer based on the findings of the results.*
- *The authors should have introduced each figure and table in the text before displaying them to ensure clarity and concision.*
- *To improve the data presentation in the paper, we would not clump up all the graphs and tables together. Instead, we would show each table and figure based on where their data is presented in the report.*
- *It would have been helpful for the images and data to be in a sequential order. Having a paragraph describing an image, showing the image, and then explaining the data collected and the analysis of that data below would be helpful.*

While students are excellent at critiquing the work of others, they do not always look upon their own work with as discerning an eye. For this reason, student responses from the introductory activity are incorporated into a presentation given by the TAs prior to submission of the first lab report of the semester. Quotes pulled from student responses, such as those presented above, are mapped to components of the lab report guidelines, and used to highlight key aspects of report preparation by reminding students of their own suggestions for effective presentation. This is accomplished in a 15-20 minute presentation by the TAs at the start of the lab session preceding the first report submission. With minimal class time and instructor involvement, and using content generated largely by the students themselves, students take a step forward on the path from novice to expert. Example student reports from before and after the introduction of the paper analysis activity are presented in Figure 3 on the following page.

While the activity described here was introduced to improve lab report writing, secondary benefits include setting a precedent that all lab meetings for the course will be utilized rather than waiting to start labs in the third week of the term, making sure students locate the lab so they arrive on time to subsequent sessions in which experiments will be performed, providing the TAs a chance to remind students of appropriate laboratory attire and safety rules, and introducing students to the assignment submission platform for the course including the group submission functionality. The active group task fosters relationships between students in each lab section as well as between students and TAs, and lays the groundwork for the collaborative nature of the lab sections throughout the course. These aspects together facilitate a smooth start to the semester. The activity also creates a buffer for students who add the course late, such that they do not miss an experiment in the first week and can be quickly brought up to speed. This activity combined with a detailed set of lab report guidelines and a report template have led to higher quality reports being submitted and reduced the grading burden on the instructor with minimal effort and class time required.

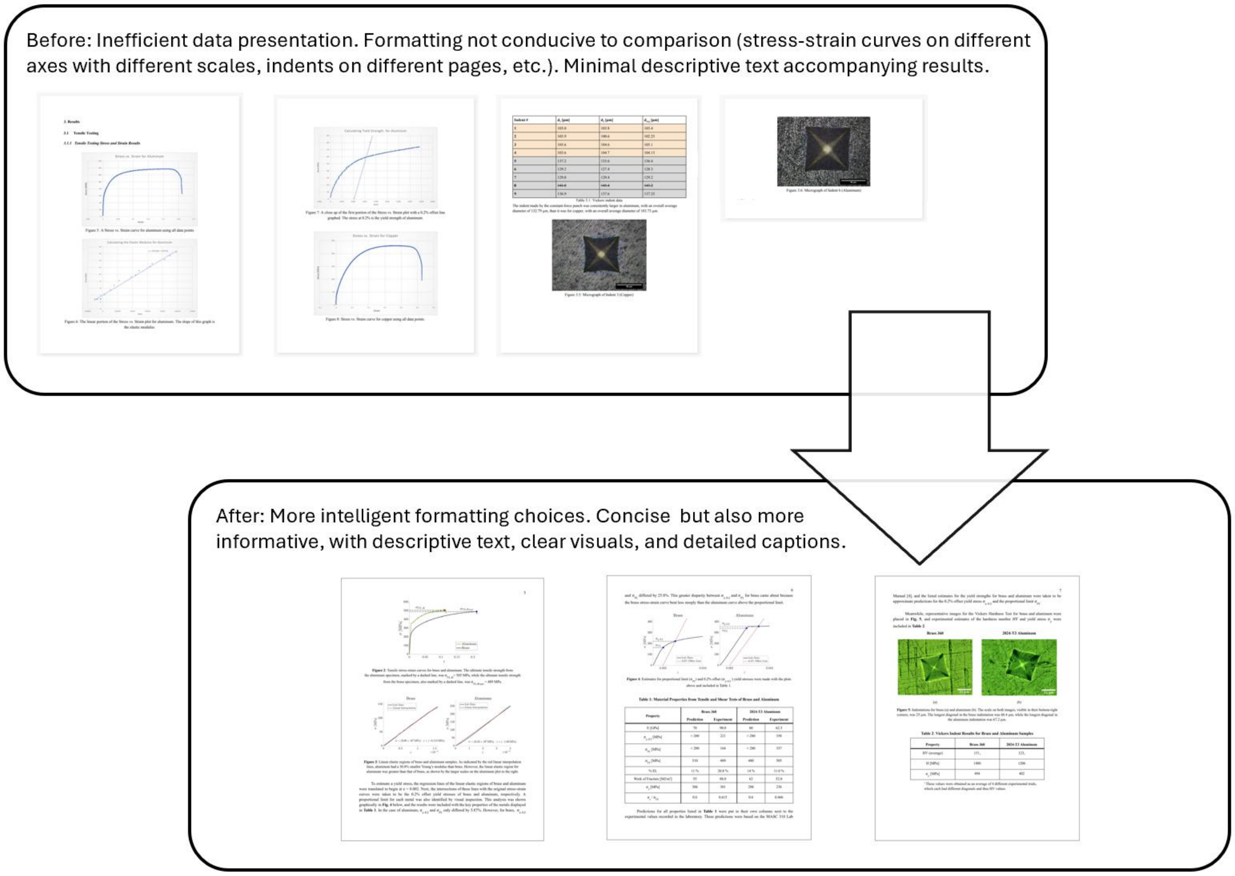

Figure 3. Examples of student lab reports submitted prior to the introduction of this activity (top) and after (bottom). In general, data formatting and report writing has been positively impacted.

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