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Preliminary Investigation of Undergraduate Students' Zone of Proximal Development (ZPD) in Writing Lab Reports in Entry-level Engineering Laboratory Courses at Three Universities

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PRELIMINARY INVESTIGATION OF UNDERGRADUATE STUDENTS' ZONE OF PROXIMAL DEVELOPMENT (ZPD) IN WRITING LAB REPORTS IN ENTRY-LEVEL ENGINEERING LABORATORY COURSES AT THREE UNIVERSITIES

Abstract

Engineering undergraduates should be able to communicate the results of scientific inquiry via lab reports (ABET Outcome 6) in a manner that the audience comprehends and from which the audience can draw useful conclusions (ABET Outcome 3). Lab reports are often the first engineering literacies that undergraduates are assigned. Before entering their first engineering laboratory courses, they are exposed to various general education writing curricula such as first-year composition and/or technical writing, or a writing-across-the-curriculum approach. However, engineering educators often do not have enough knowledge about students' prior writing knowledge and how they can connect students' learning from early writing courses to their writing in their engineering lab courses. Writing transfer theories offer a potential solution but require a clear understanding of the zone of proximal development (ZPD). According to the lens of Vygotsky's theory of scaffolding, how can the ZPD in lab report writing be defined in the context of entry-level undergraduate engineering courses?

In this study, lab report samples from three entry-level engineering courses at three different universities were collected as a preliminary investigation. The participating lab courses include a sophomore-level Materials Lab course at a private liberal-arts university, a sophomore-level Civil Engineering Materials course at a public polytechnic university, and a junior-level Introduction of Engineering Materials course at a public research university. Although the educational environments such as general education writing curricula, engineering curricula, and class size are varied among three institutions, they all include material testing labs such as tensile tests and hardness tests in the lab topics. We collected and analyzed undergraduates' lab report samples (n = 18) of the first lab and the last lab in order to identify the ZPD of lab report writing in the context of three entry-level engineering lab courses. We developed and used an inclusive assessment rubric originated from the 2014 Writing Program Administrators Outcomes Statement for First-Year Composition (WPA 3.0 outcomes) to analyze recurrent patterns of students' writing 1) in disciplinary meaning-making (i.e. organizational structures, reasoning, use of sources, etc.) and 2) technical communication (i.e. writing conventions, use of multi-modal design and/or quality of graphs/tables, etc.). This preliminary research uses Vygotsky's ZPD to identify the area of writing knowledge that undergraduates can acquire during one term of entry-level materials testing lab courses from three schools.

1. Introduction

Lab reports are the most common genre assigned in engineering courses. They are considered effective pedagogical tools to prepare students to write successfully as engineers because they require students to exhibit, in their writing, basic professional forms, characteristics, and conventions associated with engineering literacy [1-3]. Through the lab reports, engineering undergraduates need to communicate the results of scientific inquiry (related to ABET Outcome 6) in a manner that the technical audience comprehends, and from which the technical audience can draw useful conclusions (related to ABET Outcomes 3 and 6). Before entering their first engineering laboratory courses, most engineering undergraduates learn how to write extensively through general education writing courses such as first-year composition and/or technical writing. According to 'transfer of learning' theories, students build on what they already know and have come to understand through formal and informal past experiences [4]. Therefore, their past writing experiences (the transfer source: general education writing courses in the study) can affect learning and performance in a new situation (the transfer target: engineering lab courses in the study). It is not well known how students' prior writing knowledge is related to their writing in engineering lab courses. In order to clarify how engineering students' writing knowledge from the general education writing courses is connected to their lab report writing in the majors, we use the theoretical lens of Vygotsky's sociocultural theory of human learning [5,6]. Vygostky introduced the concept of the zone of proximal development (ZPD), an area of learning that is successful when students are cognitively prepared and assisted by instructors or highly-skilled peers. Figure 1 illustrates three areas in learning. The smallest area is the prior knowledge, what students can do unaided. The second circle, representing the ZPD, is the learning area where students cannot complete tasks unaided, but can complete them with appropriate guidance. The area beyond the ZPD is what students cannot do without significant guidance or without becoming discouraged.

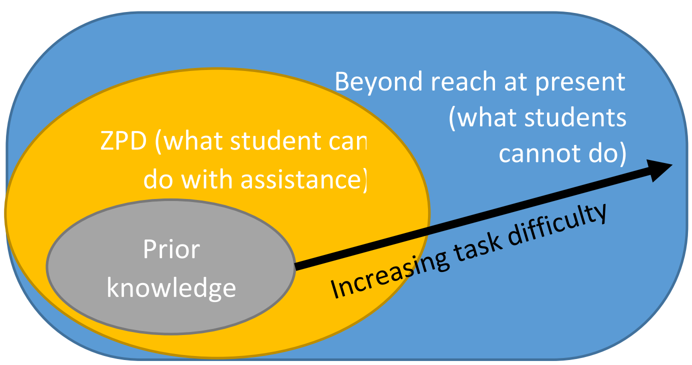

Figure 1. Illustration of ZPD

Engineering educators have studied engineering undergraduates' lab report writing with most study results predominately focused on best practices for supporting lab report instruction in classroom settings [7-14]. The best practices include tutoring support and automated feedback, peer evaluations, self-evaluations, and assessment standards, and a web-based writing support system. Having said that, studies on the areas of learning in lab report writing are limited. In this study, we identify the zone of proximal development (ZPD) in lab report writing in the context of entry-level undergraduate engineering materials laboratory courses of three engineering schools, which have distinct general education writing curricula.

2. About the case

The participating lab courses include a sophomore-level Materials Lab course of a private comprehensive university, a sophomore-level Civil Engineering Materials course of a public polytechnic university, and a junior-level Introduction to Engineering Materials course of a public research university. This section describes the pedagogical context of these three lab courses.

2.1 Institutions

Oregon Institute of Technology (OIT) is the only public polytechnic institution in the Pacific Northwest. The College of Engineering, Technology, and Management has four ABET accredited engineering programs: civil, electrical, mechanical, and renewable energy. In total, these programs have approximately 650 students, 13 graduate students (Masters only), and 30 full-time faculty members. The university is known for its hands-on curriculum with most engineering courses having a laboratory component that is taught by faculty. Washington State University Vancouver (WSU-V) is one institution of the multi-campus system of WSU, the state's land-grant university. More than half of WSU-V undergraduate students meet Pell eligibility requirements, which indicate low household incomes and are correlated with first-generation college students. WSU-V offers two ABET accredited engineering programs: electrical and mechanical. Together these programs have approximately 350 undergraduate students, 40 graduate students (Masters only), and 15 full-time faculty members. The University of Portland (UP) is an independently governed Catholic institution with a commitment to liberal arts as the foundation of learning. UP's School of Engineering has three ABET accredited engineering programs: civil, electrical, and mechanical. These engineering programs have approximately 550 undergraduate students and 20 full-time faculty members.

2.2 General education writing courses prior to the engineering lab courses

Engineering students at two of the participating schools (OIT and WSU-V) are required to complete FYC courses. These FYC courses are rhetorically-focused and specifically designed to continue supporting the development of students' composing processes, which is represented in the WPA 3.0 outcomes [15]. OIT offers a required technical writing course (taught by Communication faculty) each quarter of the sophomore year; therefore, most OIT students take an introductory technical writing course focusing on technical report genres before or while taking early engineering lab courses. Unlike the other two institutions, UP does not offer an FYC course or a technical writing course in their curriculum. UP's general education, writing-embedded course (ENG 112: Thinking Through Literature) is literature-focused and designed to introduce literary genres and criticism through writing about literature.

2.3 The participating engineering lab courses

The course descriptions of three engineering lab courses for the study are the following:

OIT's ENGR213: Engineering Mechanics – Strength of Materials is preceded by statics and supports courses in structural analysis and machine design for civil and mechanical engineering majors. There are nine labs covering general experimentation and report writing, tensile testing, connections, torsion, bending stresses and deflections, stress transformation, and column buckling. Students use a universal testing machine and various other bench-scale test frames. Students confirm theoretical relationships and design relevant components with a lab report memorandum required for seven of the nine laboratories.

Table 1. Summary of the pedagogical context of the courses.

		UP	WSU-V	OIT
Institutional context	Institution classification	private; semester; comprehensive university	public; semester; a branch campus of a Research 1 university.	public; quarter; a 4-year polytechnic institution
	Writing courses taken by students prior to the engineering lab course	Literature-focused first-year composition	Rhetorically-focused first-year composition	Rhetorically-focused first-year composition and introductory technical writing
Lab course context	Engineering lab course	EGR270 Materials Laboratory	Mech 309: Introduction of Engineering Materials	ENGR213: Engineering Mechanics – Strength of Materials
	Course credits	1 lab credit (3 lab hours/week)	2 lecture credits, 1 lab credits (3 lab hours/week)	3 lecture credits, 1 lab credit (3 lab hours/week)
	Instructional structure	Labs by instructor, grading by undergraduate assistants	Lectures by instructor; Labs by graduate TAs	Lectures and labs by instructor; supported by laboratory TA
	Typical students and their majors	Sophomores in mechanical engineering	Juniors in mechanical engineering	Sophomores in civil and mechanical engineering
	Number of lab reports assigned in the course	5	6	7
	% of lab report scores in total grade	40%	33%	50%
	Time between lab report assignment and lab due	1 week	2 weeks	1 week

WSU-V's Mech 309 Introduction of Engineering Materials: This course is an introductory materials science course covering structure of materials, phase equilibrium, phase transformations, mechanical failure, and mechanical properties. There are six labs and their topics include material identification, elastic deformation, tensile testing, material properties, metal strengthening, and heat treatment. Students develop and conduct materials testing with use of XRD diffractometer, strain gages, data acquisition system, universal tensile tester, hardness testers, optical microscope, etc. Lab reports are required for each lab.

UP's EGR270 Materials Laboratory: This course is an introductory mechanical engineering materials laboratory course covering measurement and calibration, mechanical property testing, microscopy, and heat treating. There is a semester-long project where small teams design and conduct an experiment to answer an engineering design question.

Table 1 summarizes the pedagogical context of three materials courses in this study.

3.2 Research Instrument

Writing lab reports is metacognitive. Like many disciplinary writing tasks, the writing process is a way of knowing and doing in the disciplines—not just delivery of disciplinary information [17]. Therefore, the act of lab report writing is a meaning-making task and it requires students to engage in critical thinking practices including analysis, synthesis, and evaluation of their lab data/products. Additionally, lab reports are an important communication tool for students' addressing a technical audience, an audience expecting engineering language, styles, and conventions commonly agreed upon in the culture of writing in engineering (the engineering discourse community). We developed and used an inclusive assessment rubric (Table A in Appendix) in two categories: 1) disciplinary meaning-making (i.e. organizational structures, reasoning, use of sources, etc.) and 2) technical communication (i.e. writing conventions, use of multi-modal design and/or quality of graphs/tables, etc.). The writing knowledge identified in the rubric is originated from the ABET Outcomes [18], 2014 Writing Program Administrators Outcomes Statement for First-Year Composition (WPA 3.0 outcomes) [15], and our past research results [19-21].

4. Results and Discussion

4.1 Analysis results of the first lab reports

Table 2 presents the background information including lab topic, genre assigned, audience specified (explicitly or implicitly), percent of the report scores in total course grade of the first labs and the last labs. The first lab topics of two courses are tensile testing, while one school has x-ray diffraction lab. The first lab reports' genres are technical letter, email, and memorandum. The commonality of these three genres is the message to the specific audience, i.e. the instructor in this case. The percent of report in total course grade ranges from 5% to 6.25%. The last lab topics are impact testing, metal strengthening, and beam deflection. Two courses assign memorandum as the genre of the report, while one course assign a research-paper style lab report. The audience of the reports are specified as instructor, hypothetical engineers, and/or hypothetical client. The percent of the last report in total course grade ranges from 5.5% to 15%.

Table 2. Background information of the first labs and the last labs.

(a) First labs

	Year/Term	Lab topic	Genre of lab report	Audience	% of report in total course grade
UP	Sophomore/Spring 2018	Tensile testing	Technical letter	Instructor	5%
WSU	Junior/Fall 2018	X-ray diffraction	Email	Instructor	5.5%
OIT	Sophomore/Spring 2018	Tensile testing	Memorandum	Instructor/Hypothetical Client	6.25%

(b) Last labs

	Year/Term	Lab topic	Genre of lab report	Audience	% of report in total course grade
UP	Sophomore/Spring 2018	Impact testing	Memorandum	Instructor	15%
WSU	Junior/Fall 2018	Metal strengthening	Lab report (research paper)	Instructor/Hypothetical Engineers	5.5%
OIT	Sophomore/Spring 2018	Beam deflection	Memorandum	Instructor/Hypothetical Client	6.25%

Table 3 can summarize the qualities and content of undergraduate laboratory writing of the first 1ab. Data collected via the samples from the first lab show the nature of undergraduate engineering lab writing or what undergraduates can write before extensive engineering writing interventions by engineering instructors are given. As shown in Table 3, undergraduates' prior writing knowledge commonly found in all three courses can be summarized as 1) a progression of lab contents using an introduction, body, and conclusion; 2) presentation of the lab data using graphs and/or tables; and 3) error-free prose.

Table 3. Writing knowledge lists from the lab report samples in the first lab

	Writing as disciplinary meaning-making	Writing as technical communication
UP	• Some letters have a logical progression of ideas using intro, body, conclusion sections. • Some letters do not have conclusion. • Well-described lab activities. • Limited or no discussions about the data. • Limited interpretations of the data. • All letters present the data without explaining them in the body.	• Well formatted letters. • Some letters have lack of formality (active voice and casual language). • Graphical presentation (line graph, bar graph) of the data • Table presentation of the data • Photos of the lab results • Well-labeled and titled figures/tables • All letters used one style of reference formatting.
WSU	• Logical progression with intro, body, and conclusion sections. • Multiple emotional appeals in some reports. • Lab data analysis process in some reports. • Analysis results of lab data. • Lack of lab data interpretation using secondary sources. • All reports have conclusions.	• Limited or no descriptions about experimentation processes • Consistent errors on the figures/tables in some reports. • Little to no consistent and appropriate referencing formats.
OIT	• Clear intro, body, and conclusion. The body has sections of procedures, Tables and figures, discussion, etc. • Lack of meaningful conclusion • Compile the data in a table format to make a comparative analysis. • Limited or no discussions about the data with supporting secondary sources (outside references).	• High level of formality (passive voice and neutral stands) • Graphical presentation (line graph) of the data. • Table presentation of the data • Well-labeled and titled figures/tables • Typo errors

As shown in Table 3, there is a variation in the students' writing knowledge among courses. This may be due to 1) each school's unique general writing course structure, 2) the variation of instructor's expectations, and/or 3) the students' perspectives and effort on lab report writing. In specific, some samples from UP and WSU contain a lack of understanding of audience awareness. For example, all UP student samples of the first labs include well-described lab activities and one example is shown in the following example:

"The method of testing was determined by the ASTM Stadard[1]. The testing was done using a SATEC machine that was within the ASTM standard [Fig1]. To test each of the specimens they were loaded into the SATEC machine by screwing each side of the specimen into the ends of the machine [Fig2]. Then the SATEC machine applied an ever increasing force, slowly pulling the material apart until they reached failure. The slow application of force allowed for the applied force, time, to be recorded. After the material reached failure the change in length and diameter were recorded, and stress strain diagrams were produced from the data [Graphs 1-5]."

As illustrated above, the audience can visualize how the student did during the lab. This student demonstrates descriptive writing about an event. Descriptive writing within the scope of UP's ENG 112: Thinking Through Literature might affect UP engineering students' writing knowledge on lab activity description. Although the student describes overall lab activities, some information in the report are not clear. For example, the student used "the ASTM standard" or "slowly pulling" instead of "the ASTM standard E8" or "pulling by the strain rate of 0.1 in/min". This may show a lack of engineering audience awareness when writing lab report. It is certain that this lab report represents the student's first report written to the engineering audience.

Another example from WSU shows multiple emotional appeals in the report:

"XRD analysis is used on polymers only occasionally, mostly just to find out the degree of crystallinity in polymers (from http://www.intertek.com/polymers/x-ray-diffraction-composites/ and http://www.polymertechnology.it/bacheca/NanocompositeForm/page5/files/rx_2.pdf) – which makes sense, as they do not have the same sorts of structures as metals, being in strings rather than cubic units. Since there is no other polymer to compare this with, and we have not gone over crystallinity in my university classes yet, I fear I am unqualified to determine the type or crystallinity of this polymer, and this task would be better suited to someone more qualified."

Emotional appeals are well received in some genres like essays; however, engineers mostly rely on logical or ethical appeals in the technical report genres. The student tries to convey his arguments emotionally, so the report has "makes sense" and "I fear". In addition, this example proves a lack of conventional knowledge in technical writing on referencing. The webpage links are attached in the parenthesis on the report.

All OIT student samples show knowledge of conventions mostly accepted in engineering literacies in their first lab reports. The following sample demonstrates an OIT student's understanding of technical convention.

"The following plots in Figures 2-7 and corresponding calculations were produced by the United Testing Machine computer. For sake of clarity and due to the conditions of the data, the yield strength, ultimate strength, and point of fracture are not labeled in plot. Elongation at failure was calculated by dividing the position of failure estimated from the position vs load plot by 3, then converting that into a percent. These elongation percentages are recorded in Table 1 in addition to tensile yield strength, ultimate strength, and elastic modulus for each sample. Table 2 displays data fielded from *Mechanics of Materials, 9th Edition* (Hibbeler, 2014) to be used as the control."

Most OIT sophomores take an introductory technical writing course, which focuses on technical conventions. Therefore, OIT students already know how to construct and present the lab data in the figure and table formats in the first lab reports. Although this sample shows appropriate use of technical convention, there is limited or no discussion about the lab data with supporting secondary sources. Analysis and interpretation of lab data can be the learning area where students could not gain from the technical writing course.

4.2 Analysis results of the last lab report samples.

Table 4 lists the qualities and content of undergraduate laboratory writing of the last 1ab. When compared with the results from the first lab reports (Table 3), there is less variation found among the courses. This means that all students learned engineering audience's expectations in the context of lab report writing through the courses. A sample from UP demonstrates improved lab report writing both in disciplinary meaning-making and technical communication.

"The ASTM A36 Steel, 1045CR Steel, and 1045 HR Steel have shown serious change in toughness with different change of temperatures. This is especially seen in ASTM A36 steel. As can be seen in Figure 1, the toughness in ASTM A36 steel is increasing with the increase of temperature. According to this data, if the test were to repeated at higher temperatures, the toughness of ASTM A36 steel will increase. At low temperatures steel is more brittle has a low impact toughness. At high temperatures steel is more ductile and has a high impact toughness. So for steel, toughness is greatly affect by temperature[1]."

As show in the sample, the technical convention such as the referencing style, level of formality, etc. is improved from the first lab sample. A sample from WSU also shows the similar trend.

"Through annealing, the brass increased its ductility. As shown on Table 2, the HRB of the brass decreased almost to its initial value from 65.5 HRB after strain hardening to 27.5 HRB post annealing. During this process, [2] the metallurgical changes occurred returning the metal to its pre-cold-worked state. The brass' dislocations decreased making it less brittle as its yield strength decreased, and thus proving the sample became less hard/tough after it was treated into an oven at 482 °C for 30 minutes. Although, the flattened brass' height and diameter after trial 3 of Table 1 did not change much after annealing."

This student specifies the lab data to support the claim made in the beginning of the paragraph. Then, an outside reference is quoted to support the claim repeatedly. The knowledge of technical convention in this sample is improved from the first lab report sample.

Table 4. Writing knowledge lists from the lab report samples in the last lab

	Writing as disciplinary meaning-making	Writing as technical communication
UP	• Clearly written the purpose of the report, but conclusions were not clearly written. • Some memos have a logical progression of ideas using intro, body, conclusion sections. • All memos have discussions about the test results. • Some students made claims with supporting evidence from the secondary sources (outside references) without using the primary sources or the data in the figures or tables in the report. • All memos have one or multiple interpretations for each data set. • Use of engineering terms accurately (ASTM vs ASTM-A36)	• All memos have passive voice and neutral stands, but some memos have casual language. • Well formatted. • Graphical presentation (line graph, bar graph) of the data • Table presentation of the data • Multiple styles of reference formatting.
WSU	• Clearly sectioned report: intro, body, and conclusion. The body section has procedure, data, and analysis/discussion. • All reports have the objective of lab reports in the introduction, but some of them are not well-written (unclear or not-well connected to the lab report). • All students made claims with supporting evidence from both the primary sources (lab data) and/or the secondary sources (outside references). • All students used secondary sources. Some of them are inappropriate (lack of credibility). • Conclusions in all reports have key findings; however, not all conclusions have the lab objective or summary of lab procedure.	• High level of formality (passive voice and neutral stands) • Brief descriptions of lab procedures. • Graphical presentation (line graph) in some reports. • Well-labeled and titled figures/tables. • Appropriate and consistent style of referencing.
OIT	• All reports have intro, body, and conclusion. The body has sections of assumptions, procedures, Tables and figures, Material values, etc. • Some memos have claims with supporting evidence from the primary sources (lab data), not from the secondary sources (outside references). • All memos have design problem sections and some memos have extensive discussions on the designs and computations for each design case.	• High level of formality (passive voice and neutral stands) • Graphical presentation (line graph) of the data. • Table presentation of the data • Well-labeled and titled figures/tables

4.3 The ZPD of writing knowledge in three materials lab courses

A comparative analysis of the reports between the first and last labs provide the undergraduate students' ZPD of engineering lab report writing or the writing skills too difficult to master on their own, but that can be achieved through interventions in the contexts of three entry-level lab courses. Table 5 summarizes ZPD of lab report writing knowledge of three courses. Like prior knowledge, the ZPD also heavily depends on the course; however, we could identify the ZPD of lab report writing knowledge regardless of courses. The common ZPD can be identified as 1) focus on lab data computation and analysis and 2) logical appeals based on the lab data. Analysis of the last lab reports can provide the area that undergraduates could not do in their lab report writing although the interventions were provided for one term. The writing knowledge beyond reach at present in the context of three courses includes 1) statistical data analysis; 2) multiple interpretations of the lab data using multiple secondary sources (outside references); 3) presentation of statistical analysis and/or error analysis in the graphs/tables.

Table 5. Prior knowledge, ZPD, and beyond reach at present of writing knowledge in the context of three engineering materials lab courses.

	Prior knowledge contributing to lab report writing (what students already know)	ZPD in lab report writing (what students can learn when interventions are given)	Beyond reach at present
UP's EGR270 Materials Laboratory	• Consideration of audience expectations based on its purpose; • Description of lab activities; • Graphical presentations of the numerical lab data; and • Error-free prose.	• Lab data computation and analysis; • Use of additional technical information for lab data interpretation; and • Conventions mostly accepted in engineering literacies (i.e. presenting lab data in well-constructed figures and tables).	• Logical appeals based on factual and/or quantitative evidences; and • Clear lab report objective and its connection to meaningful conclusion. • Statistical analysis of the lab data.
WSU-V's Mech 309 Intro to Engineering Materials	• Consideration of audience expectations based on its purpose and context; • Analysis of lab data to make claims; and • Error-free prose.	• Logical appeals based on factual and/or quantitative evidences (lab data); • Reading additional technical information for lab data interpretation; and • Conventions mostly accepted in engineering literacies (i.e. presenting lab data in well-constructed figures and tables).	• Use of credible sources. • Meaning conclusion with the lab purpose, summary of lab procedure, and key findings. • Statistical analysis of the lab data.
OIT's ENGR213: Engineering Mechanics –	• Consideration of audience expectations based on its purpose and context; • Conventions mostly accepted in engineering literacies (i.e. presenting lab data in well-constructed figures and tables); • Error-free prose.	• Lab data computation and analysis; • Logical appeals based on factual and/or quantitative evidences (lab data); and • Error analysis using statistics.	• Reading additional technical information for lab data interpretation; and • Clear lab report objective and its connection to meaningful conclusion.

5. Conclusion

This preliminary research uses Vygotsky's ZPD to identify the area of writing knowledge that undergraduates can acquire during one term of entry-level materials testing lab courses from three schools. ZPD is defined as the learning zone between what students can do by themselves and what cannot be achieved without the explicit support of an instructor—the engineering lab report instructors in this case. We list students' writing knowledge in disciplinary meaning-making (generation of disciplinary information with considering the technical audience) and 2) technical communication (delivery of disciplinary information to the technical audience). Students' prior writing knowledge, ZPD, and the learning area beyond reach at present are related to their writing experiences in the lower-division general education writing courses as well as the lab course context. A writing-across-the-curriculum approach appears to produce more descriptive writers who will necessarily require more practice in engineering writing conventions. A technical writing prerequisite course appears to produce students better versed in engineering conventions and making logical appeals based on data but less inclined to refer to outside resources.

Although students of three courses have common prior writing knowledge such as awareness of purpose in the lab report genre and graphical presentation of lab data, students' prior writing knowledge appears to be highly dependent on students' prior writing preparation. Students in a school requires an introductory technical writing in the lower division have knowledge of conventions mostly accepted in technical reports even in the first lab. On the other hand, students in two schools not offering lower division technical writing do not possess strong knowledge of conventions in their first labs.

Unlike the prior knowledge, the ZPD of three courses are similar. Across three courses, students show their knowledge on lab data computation and analysis, lab data interpretation with use of secondary sources, and technical genre conventions such as graphs, tables, and referencing. However, the ZPD and the learning area beyond reach at present depend on the course.

Limitations of this study include the small sample size of lab reports and the number of participating classes. Future work by the authors will focus on expanding the sample size and lab courses to generalize our findings. Given a clear understanding of the ZPD in a variety of contexts, broadly applicable learning tools can be developed for adoption as needed in a variety of instructional scenarios.

6. Acknowledgement

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8. Appendix

Table A. Lab report assessment instrument: Rubric

Student outcomes		Highly achieved knowledge	Moderately achieved knowledge	Lack of knowledge
Lab report as disciplinary meaning-making	Consideration of audience expectations based on its purpose and context.* †	The outcomes can be observed in all student lab report samples.	The outcomes can be observed occasionally among student lab report samples.	The outcomes can be observed rarely among student lab report samples.
	Purposeful shift of ideas with well-designed structure. †			
	Logical appeals based on the analysis of lab data as factual and quantitative evidences.* †			
	Interpretation of lab data with using secondary sources.* ※			
	Meaningful conclusion containing a summary of the lab objective, process, and key findings.*			
Lab report as technical communication	Clear communication of appropriate experimentation development process.*			
	Presentation of lab data in the appropriate graphical/table forms. †			
	Integration of the statistical analysis to lab data presentation. ※			
	Use of appropriate referencing style. ※			
	Error-free prose. †			

* outcomes are based on the ABET outcomes [18].

† outcomes are based on the WPA 3.0 outcomes [15].

※ outcomes are based on our past research [19-21]