Advancing Engineering Students’ Technical Writing Skills by Implementing Team-Based Learning Instructional Modules in an Existing Laboratory Curriculum

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Abstract: Technical writing is a crucial skill for engineering students’ effective written communication, which shapes and affects their professional careers. This study designs team-based learning (TBL) instructional modules that are integrated into an existing engineering laboratory curriculum and evaluates their feasibility and effectiveness in improving engineering students’ technical writing skills. The data were collected from structured survey questions distributed to student participants and from the instructor’s independent evaluation of students’ lab reports. The effect of assigning a team leader on students’ writing performances was also evaluated. Our results indicated that students who have received TBL modules perceive a greater improvement in their technical writing skills than those who did not. A strong correlation was found between students’ perception and the instructor’s evaluation of the students’ technical writing skills. Assigning a team leader in TBL instructional modules has not played a significant role in improving engineering students’ technical writing skills. The same happens with gender. Overall, utilization of TBL instructional modules can advance engineering students’ technical writing skills.

Keywords: technical writing; team-based learning; team leader role; engineering education

1. Introduction

The importance of technical writing in engineering practice has been widely recognized by engineering faculty, the professional community, and industry [1]. Effective technical writing skills enable students to communicate with a wide range of audiences in a professional manner, which is explicitly specified in the student outcomes in the Accreditation Board for Engineering and Technology (ABET) evaluation [2]. The development of technical writing skills is also related to enhancing students’ critical thinking and active learning and addresses the needs of students with different learning styles, as well as serving as a powerful tool to evaluate students’ understanding of technical knowledge [1,3–5]. A variety of approaches such as the incorporation of writing into the existing engineering curriculum, collaboration with writing centers, and application of evidence-based pedagogy have been proposed and developed by higher education instructors to improve engineering students’ technical writing skills [6–10]. With the increasing complexity of engineering knowledge, the utilization of a modular approach that shifts traditional methods of instruction to an outcome-based learning paradigm is gaining popularity in higher education institutions [9]. Rather than providing a traditional top-down lecture on how to write a lab report, we designed team-based learning (TBL) modules that
were integrated into the existing laboratory curriculum, which was aimed at improving students’ learning experience and outcomes on technical writing skills. We also evaluated the effect of assigning team leaders and of gender on the effectiveness of TBL.

The research objectives of this study are: (1) to evaluate the effectiveness of TBL in improving engineering students’ technical writing skills by conducting a comparison between the lab sessions applied with TBL and those without; (2) to evaluate the effectiveness of assigning team leaders in TBL activities by conducting a comparison between the TBL applied lab sessions with assigned a team leader and those without. The outcomes of this study would shed light on how to improve STEM students’ technical writing skills and learning experience using designed TBL instructional modules.

2. Literature Review

Several issues in engineering students’ technical writing have been recognized by instructors. A study performed by Conrad [10] compared the writing of practitioners and students in civil engineering and recognized that student writings had more complicated sentence structures, more errors in grammar and punctuation, less accurate word choice, and less linear organization. Although engineering students have taken English composition courses in their freshmen levels, there is a lack of explicit consensus across the college about what we want our engineering students to learn about writing [11].

Due to the fact that technical writing is highly related to the technical contents in each engineering discipline, Walker [12] proposed a writing center model at the department level that integrates writing instruction into engineering courses, without sacrificing the focus on technical subject matter. Yalvac et al. [13] proposed a how people learn (HPL) pedagogical approach to the writing interventions, such as modifying the technical writing challenge to help students imagine themselves in a professional role and using a more student-centered event to teach technical writing, which suggested that an HPL approach in a writing across the curriculum (WAC) context is helpful for promoting learning in writing. Weiss and Scarola [14] engaged an English writing tutor in an engineering class, and the tutor critiqued students’ grammar in laboratory reports. Calvo and Ellis [15] used Glosser, an automated feedback system, which provides feedback on students’ four aspects of writing: structure, coherence, topics, and keywords. This study suggested that students would benefit from more explanations about the purpose of feedback, and also suggested that engineering faculty who wish to use Glosser need to work carefully to frame and value the tolls in ways that support deeper learning.

Joint teaching of lab courses and technical writing can provide a better way that ties technical contents to technical writing, as the joint structure serves to educate students in a variety of aspects of professional practice including solving open-ended problems, system-level integration of disciplinary coursework, project development, and planning, oral and written communication, peer review, and teamwork [16–19].

Boyd and Hassett [20] developed a system that consists of two components and works backward, starting with teaching students the assessment strategy (rubric) to be used in the evaluation of their work. The first system component or rubric becomes a guide to teach students how to connect their ideas (sentence subjects) in sequence without ambiguity or implied connectivity. The second component of the system consists of written assignments initiated with “work orders” that state specifically what is expected of the student in each paragraph and includes formatting instructions.

Maharaj and Banta [21] used the writing to learn (WTL) technique, assigned and completed in the engineer’s log, using sample log entries to illustrate students’ use and to suggest that expressive writing, or writing for the self, continues to prove itself a successful technique for learning. Taken together, the WTL activities—summaries, analogies, word problems, and explanations/explorations—were combined to promote students’ understanding and learning of course content, and the act of writing about content helped students to undertake a major leap from passive learning (common in the traditional lec-
ture problem-solving approach to studying engineering) to a more active form of learning. Students were therefore given more active responsibility for their learning.

Hanson and Williams [22] explored the use of writing as a tool for metacognition in a Statics engineering class. The objectives associated with the “explain-a-problem” assignments were grouped under student self-assessment, student communication, and administration. Performance on each of the four grading criteria for each assignment was tracked throughout the terms. The data indicated that explain-a-problem assignments help students achieve the self-assessment and communication objectives, although the impact on overall course performance was not as significant as hoped. The assignment evolved to the point that the administrative objectives were also met.

Project-based learning has been found to enhance students’ writing ability [23], forcing them to think reflectively and leading them to engage with society. Gao developed a project-based instruction (PBI) for teaching technical writing in a graduate engineering course, and he emphasized the importance of including administrators in higher education and industry representatives to collaborate on improving the curriculum design and course delivery [24]. Tatzl et al. proposed a model for project-based collaborative technical writing instruction, specially developed for workload-intensive education settings [25]. They found that both language and content matter. Such a project-based approach encourages collaboration, which appears to be successful to enhance undergraduate and graduate students’ and native and non-native students’ technical writing skills [23–26].

Team-based learning is a unique way to foster small group learning in class, providing students with a sense of belonging and enhancing their conceptual understanding and problem-solving skills in a coherent framework. A typical TBL cycle has several phases, which are forming small groups, readiness assurance process, appeal, application exercise, and peer evaluation [27]. TBL has proved to be an effective supplement to improving academic performance and students’ attitudes toward teamwork in medical education when TBL and non-TBL in two universities are compared [28]. TBL had positive effects on engagements and accountability when compared TBL with lecture engagement [29]. There are many applications of TBL in STEM education, but it is rarely used as a modular approach to improve engineering students’ technical writing skills [24,27–29]. This study addresses such a gap and provides a better understanding of the utilization of TBL modules in an existing engineering lab curriculum that has technical writing components.

3. Design and Implementation of TBL Instructional Modules

3.1. Design of TBL Instructional Modules

Four TBL instructional modules were designed and introduced into an existing civil engineering lab curriculum. Each instructional module covered one particular technical writing topic, including introduction and technical language (Module I); table, figures, and equations (Module II); references and citation (Module III); literature review and others (Module IV). The TBL instructional module had six stages in a cycle: mini-lecture, individual readiness assurance test (iRAT), peer evaluation, and peer evaluation, which are introduced as follows, respectively.

- **Mini-lecture**: A traditional TBL class that requested students to complete the reading assignment prior to the class. However, most students failed to do so and therefore were not able to prepare themselves well. A mini-lecture was delivered by the instructor to cover the technical writing topic in a concise manner, which focused on the conceptual knowledge and common practices relevant to the topic. The mini-lecture typically took 15 min.

- **Individual readiness assurance test (iRAT)**: Five multiple-choice questions were designed in iRAT, which was to evaluate students’ conceptual knowledge of a technical writing topic. Students were asked to complete the iRAT in five minutes, and fill out the answer table by placing points on each equation. An example of iRAT questions is provided in Appendix A, focusing on “Module I: Introduction and Technical Language”. An example of an iRAT answer sheet is provided in Appendix B.
• Team readiness assurance test (tRAT): After iRAT, students in the same team discussed the questions using the immediate feedback assessment technique (IFAT®) in which the correct answers were hidden in the covering for each question. Students were asked to discuss and work together to scratch off the coverings to find the correct answer. The correct answer was denoted as a star under the covering. If a team scratched off covering for one time to expose the correct answer, this team earned 5 points. Otherwise, the more scratching, the fewer points they earned. Most students actively engaged in seeking answers, discussing with teammates, and finalizing their choices. In the end, the instructor collected all teams’ final scores, wrote them on the whiteboard for the class, and announced the winners. All teams were able to see other teams’ scores. This fostered competition among teams, and students enjoyed the competition.

• Appeal: If a team was not satisfied with the earned points, they received a chance to appeal on one question for which they lost the most points. The appeal was held and judged by the instructor like a courtroom, and each team took turns to appeal by stating their reasons. If their appeal failed, they would lose all points of the question they appealed to; if succeeded, they would recover the lost points for that question. The instructor has found that the appeal session greatly inspired students to participate and engage in reasoning and arguing, and teaming up allowed them to work out the problem quickly.

• Application: A small application activity was undertaken after the appeal activity. Each student was asked to practice a 5 min application exercise. Such writing exercises were in versatile forms, such as describing a laboratory experiment procedure, providing an in-text citation and a reference, plotting a chart and inserting it into text with the appropriate title, inserting a table in the text, and describing a sentence with the appropriate embedded equation. The instructor walked around the class and checked students’ writing and provided immediate feedback. Finally, the instructor wrapped up the application exercise and highlighted the critical issues.

• Peer evaluation: Peer evaluation was undertaken to collect each student’s experience in the TBL application and also provided peer pressure on the team. Each student evaluated other teammates’ performance and contributions. An example of a peer evaluation sheet is exhibited in Appendix C. In addition, two questions were included: “What is the single most valuable contribution this person makes to your team?” and “What is the single most important way this person could alter their behavior to more effectively help your team?”

3.2. Design and Implementation of Study

Figure 1A,B presents the flow chart for the study that is integrated with TBL in-class activities, and without TBL activities, respectively. The course included a series of labs and field activities with respect to the technical contents of civil engineering materials such as aggregate, concrete, and asphalt, which were scheduled from the 1st week to the 15th week. As seen in Figure 1A, four TBL technical writing modules were integrated into the course schedule in weeks 2, 5, 10, and 14, respectively. TBL modules were applied to both two lab sessions, and the only difference between the two lab sessions was that in Session 1 there was no assigned team leader, while in Session 2 there was. Students were asked to write lab memos after each lab activity within a week. Two types of memos were introduced: group memos and individual memos, which accounted for 70% of the final grade. At the end of the semester, students were asked to submit a formal individual report which accounted for 20% of their final grade. Students were also asked to present a topic they selected, which accounted for 10% of their final grade in week 15.
The conventional lab sessions without TBL modules, as shown in Figure 1B, are similar to the lab sessions with TBL modules with respect to lab activities and lab report assignments, as well as an overall schedule, except that the instructor delivered a conventional lecture on those technical writing presentations in weeks 2, 5, 10, and 14 without any TBL in-class activities executed.

4. Methods
4.1. Student Participants

This study was conducted with students who are majoring in civil engineering and was approved by the university’s institutional review board (IRB). Participants were junior-level students who enrolled in civil engineering materials lab courses in the fall of 2019 and 2020. There were a total of four lab sessions for students who participated in this study: two lab sessions of students were conducted by introducing TBL, and the other two lab sessions of students were conducted without TBL. Table 1 presents the distribution of students with respect to native speakers and gender. In each lab session, students were
split into three-person teams. Technical writing TBL instructional modules were applied to Sessions 1 and 2. Only in lab Session 2 were the teams assigned a team leader.

### Table 1. Distribution of participants.

| TBL       | Lab Session       | Students Number | Number of Teams | Non-Native Speaker (%) vs. Native Speaker (%) | Female (%) vs. Male (%) |
|-----------|-------------------|-----------------|-----------------|-----------------------------------------------|-------------------------|
| Without TBL | 3 (without team leader) | 14              | 4               | 0 (0%): 14 (100%)                             | 4 (29%): 10 (71%)       |
|           | 4 (without team leader) | 22              | 6               | 1 (5%): 21 (95%)                              | 5 (23%): 17 (77%)       |
|           | Total              | 36              | 10              | 1 (3%): 35 (97%)                              | 9 (25%): 27 (75%)       |
| With TBL  | 1 (without team leader) | 21              | 7               | 1 (5%): 20 (95%)                              | 6 (29%): 15 (71%)       |
|           | 2 (with team leader) | 27              | 9               | 6 (22%): 21 (78%)                             | 4 (15%): 23 (85%)       |
|           | Total              | 48              | 16              | 7 (15%): 41 (85%)                             | 10 (21%): 38 (79%)      |
| Overall   |                    | 84              | 26              | 8 (10%): 76 (90%)                             | 19 (23%): 65 (77%)      |

#### 4.2. Data Collection Procedures

##### 4.2.1. Perception Survey

The perception survey was designed to capture students’ personal feelings about their overall and specific technical writing skills. The survey questions were adopted from Nardo and Hufana [30] and Isnin’s [31] studies to assess students’ self-efficacy in their technical writing skills. The same survey questions were distributed to each student at the beginning of the semester as well as at the end of the semester. The question was “what is your current level of proficiency in putting together a technical report?” in a 29-dimension evaluation (Appendix D), with five Likert scales: strongly agree, agree, neither agree nor disagree, disagree, and strongly disagree.

##### 4.2.2. Technical Writing Evaluation by Instructor

Besides students’ perception surveys, the collected technical writing assignments were graded consistently by the instructor using the same grading rubric (Appendix E). Technical writing assignments were in the forms of a two-page individual memo, group memo, and final individual formal report. There were a total of nine assignments distributed throughout the semester. Students received specific comments on the assignment from the instructor and graded scores. Instructors’ independent evaluation results were used for further analysis.

#### 4.3. Data Analysis Procedures

For each surveyed question (a Likert item), students’ responses include strongly agree, agree, neither agree nor disagree, disagree, and strongly disagree, which were converted into quantitative numbers from 5 to 1, where 5 indicated “strongly agree” and 1 indicated “strongly disagree”. The average score and standard deviation of students’ perception in terms of numeric value were calculated using Microsoft Excel software. The improvement ratio was calculated by how much the average score increased from pre-survey result to the post-survey result.

For the instructor’s evaluation of students’ technical reports, the average score and standard deviation were calculated using Microsoft Excel software. The Mann–Whitney U test was used to compare whether there was a difference in the report evaluation for two independent groups, namely, TBL vs. non-TBL, and assigned team leaders vs. no assigned team leaders.

To further analyze students’ report scores, a paired t-test was conducted to test whether there was a significant difference between the average score of Report No. 1 and that of Report No. 9 using Microsoft Excel software.

Furthermore, the linear correlation between instructors’ evaluation of students’ technical writing reports and students’ own perception of their technical writing skills was
plotted by a trend line. The coefficient of determination ($R^2$) was calculated by Microsoft Excel software. The higher the positive $R^2$, the better correlation between the two variables.

5. Results
5.1. Comparison between Non-TBL and TBL

To answer the research question of whether the integration of TBL modules can enhance engineering students’ technical writing skills or not, the comparison between non-TBL classes and TBL classes was conducted in terms of students’ perceptions by collected survey results and instructors’ perceptions by lab report evaluation results.

5.1.1. Students’ Perception of Technical Writing Skills

The students’ perception survey results on their technical writing skills for non-TBL and TBL modules are shown in Table 2, namely the average score, standard deviation, and improvement ratio, which is between pre-survey and post-survey for each technical writing skill dimension. It is evident that regardless of non-TBL and TBL modules, all students perceived their technical writing skills to have improved. Such an improvement could be attributed to the extensive training in technical knowledge, technical writing instruction, and intensive nine writing assignments.

Table 2. Pre-class and post-class survey results on students’ perceptions.

| No. | Technical Writing Skill Dimension                                                                 | Non-TBL | TBL     |
|-----|-------------------------------------------------------------------------------------------------|---------|---------|
|     |                                                                                                 | Pre-Survey | Post-Survey | Ratio | Pre-Survey | Post-Survey | Ratio |
| 1   | I am able to write a project report using the correct format.                                    | 4.1 ± 0.9 | 4.4 ± 0.6 | 8%    | 3.8 ± 0.7 | 4.5 ± 0.5 | 17%   |
| 2   | I am able to write technical documents with correct grammar.                                     | 4.4 ± 0.7 | 4.5 ± 0.5 | 3%    | 4.1 ± 0.7 | 4.5 ± 0.6 | 10%   |
| 3   | I am able to write technical documents with correct spelling.                                    | 4.6 ± 0.5 | 4.7 ± 0.5 | 2%    | 4.3 ± 0.8 | 4.6 ± 0.6 | 9%    |
| 4   | I am able to write technical documents with correct capitalization (capital and small letters)  | 4.7 ± 0.5 | 4.8 ± 0.4 | 3%    | 4.5 ± 0.6 | 4.7 ± 0.5 | 4%    |
| 5   | I am able to write technical documents with correct punctuation.                                 | 4.4 ± 0.7 | 4.6 ± 0.5 | 6%    | 4.1 ± 0.8 | 4.6 ± 0.5 | 13%   |
| 6   | I am able to construct concise objectives for a project.                                          | 4.1 ± 0.6 | 4.5 ± 0.6 | 11%   | 4.1 ± 0.6 | 4.5 ± 0.5 | 12%   |
| 7   | I am able to conceptualize a problem.                                                             | 4.2 ± 0.6 | 4.4 ± 0.5 | 7%    | 4.0 ± 0.6 | 4.5 ± 0.5 | 11%   |
| 8   | I am able to compose an abstract in a report.                                                     | 3.7 ± 0.7 | 4.2 ± 0.6 | 13%   | 3.4 ± 0.8 | 4.3 ± 0.7 | 27%   |
| 9   | I am able to illustrate a process.                                                                | 4.3 ± 0.7 | 4.5 ± 0.6 | 5%    | 4.0 ± 0.5 | 4.6 ± 0.5 | 16%   |
| 10  | I am able to construct figures that present data clearly and precisely.                           | 4.1 ± 0.5 | 4.4 ± 0.6 | 7%    | 3.9 ± 0.7 | 4.5 ± 0.6 | 14%   |
| 11  | I am able to construct tables that present data clearly and precisely.                            | 4.1 ± 0.6 | 4.4 ± 0.6 | 8%    | 4.0 ± 0.7 | 4.6 ± 0.5 | 13%   |
| 12  | I am able to interpret graphic presentations such as figures and tables.                          | 4.3 ± 0.5 | 4.6 ± 0.5 | 6%    | 4.1 ± 0.6 | 4.5 ± 0.5 | 9%    |
| 13  | I am able to analyze data of a research project accurately.                                      | 4.1 ± 0.6 | 4.4 ± 0.6 | 6%    | 3.8 ± 0.7 | 4.5 ± 0.5 | 18%   |
Table 2. Cont.

| No. | Technical Writing Skill Dimension | Non-TBL | TBL | Ratio | Non-TBL | TBL | Ratio |
|-----|----------------------------------|---------|-----|-------|---------|-----|-------|
|     | Pre-Survey | Post-Survey | | Pre-Survey | Post-Survey | | |
| 14  | I am able to collate research data. | 3.8 ± 0.8 | 4.3 ± 0.8 | 11% | 3.8 ± 0.8 | 4.5 ± 0.5 | 17% |
| 15  | I am able to qualify claims based on gathered data. | 4.0 ± 0.5 | 4.4 ± 0.6 | 8% | 3.9 ± 0.6 | 4.5 ± 0.5 | 17% |
| 16  | I am able to transpose verbal data to non-verbal materials and vice versa. | 3.7 ± 0.8 | 4.2 ± 0.7 | 14% | 3.7 ± 0.7 | 4.3 ± 0.6 | 18% |
| 17  | I am able to define technical terms in my own words. | 4.1 ± 0.6 | 4.6 ± 0.6 | 12% | 3.8 ± 1.0 | 4.4 ± 0.5 | 17% |
| 18  | I am able to construct conclusion from research findings in a project report. | 4.2 ± 0.5 | 4.4 ± 0.7 | 5% | 4.0 ± 0.7 | 4.5 ± 0.5 | 13% |
| 19  | I am able to propose recommendations from research findings. | 4.1 ± 0.6 | 4.2 ± 0.7 | 4% | 3.8 ± 0.8 | 4.4 ± 0.5 | 18% |
| 20  | I am able to write references for a project report using a correct way. | 3.8 ± 0.7 | 4.3 ± 0.7 | 11% | 3.6 ± 0.8 | 4.3 ± 0.7 | 21% |
| 21  | I am able to differentiate the features of technical reports. | 3.8 ± 0.7 | 4.4 ± 0.6 | 16% | 3.2 ± 0.8 | 4.4 ± 0.5 | 37% |
| 22  | I am able to distinguish an opinion from a fact. | 4.4 ± 0.5 | 4.8 ± 0.4 | 8% | 4.4 ± 0.6 | 4.6 ± 0.5 | 3% |
| 23  | I am able to spot errors in a technical report. | 3.8 ± 0.7 | 4.3 ± 0.6 | 15% | 3.3 ± 0.9 | 4.3 ± 0.7 | 29% |
| 24  | I am able to analyze content of technical reports. | 3.9 ± 0.7 | 4.5 ± 0.5 | 14% | 3.7 ± 0.8 | 4.5 ± 0.6 | 22% |
| 25  | I am able to recognize classification of terms according to methods and functions. | 3.8 ± 0.7 | 4.2 ± 0.7 | 12% | 3.5 ± 0.9 | 4.5 ± 0.6 | 27% |
| 26  | I am able to distinguish the differences between technical writing and other forms of writing. | 3.9 ± 0.8 | 4.5 ± 0.6 | 15% | 3.6 ± 0.9 | 4.5 ± 0.7 | 23% |
| 27  | I am able to write using various technical writing styles. | 3.5 ± 1.0 | 4.2 ± 0.8 | 19% | 3.0 ± 0.9 | 4.3 ± 0.7 | 42% |
| 28  | I am able to distinguish between formal and informal English in technical writing. | 4.2 ± 0.6 | 4.6 ± 0.7 | 9% | 4.0 ± 0.9 | 4.6 ± 0.5 | 15% |
| 29  | I am able to show that proper ethics are followed in my report. | 4.4 ± 0.6 | 4.6 ± 0.5 | 4% | 4.0 ± 0.9 | 4.5 ± 0.6 | 13% |
|     | Average | 4.1 ± 0.6 | 4.4 ± 0.6 | 9% | 3.8 ± 0.8 | 4.5 ± 0.6 | 17% |

Figure 2 further plots the average score for each survey question to illustrate the comparison. It is clear that regardless of TBL modules, students perceived that their technical writing skills had been improved. The extent of the improvement is more evident for students who received TBL modules, as illustrated by the higher percent increase in score highlighted in the blue column in Figure 2. In other words, integration of TBL modules in the lab lecture can help students perceive their writing skills in a more positive manner to some extent, leading to them being more confident in technical writing.
5.1.2. Instructors’ Perception of Students’ Technical Writing Skills

Next, the instructor’s perception of students’ technical writing skills is evaluated by lab report scores. Table 3 presents the average scores and standard deviation of students’ graded lab reports, as well as the Mann–Whitney statistical analysis results with a significance level of 0.05. Figure 3 further plots the score trend from the first report to the final report. For both TBL and non-TBL, the instructor perceived that students did not perform very well in the first lab report writing. There appears to be a consistent pattern that from Report No. 1 to No. 3, students’ lab report score increases, which is most likely due to students’ increased familiarity with the lab report writing and training on technical writing; however, the score is not linearly increased with the sequence of reports, with exhibited ups and downs in the curves shown. Two peak scores are Report No. 3 and No. 7 which vis-à-vis the lab reports summarizing the field visit to a concrete plant and an asphalt plant, respectively. It appears that lab activities beyond the classroom environment can inspire students’ greatest interests and engage them [32], which reflects in their better technical writing score that integrates their field observations in the lab report vividly. The second-lowest score is exhibited in Report No. 5 which requires students to use statistical analysis using collected data, which needs further addressing in the data processing.

Table 3. Students’ report mean score and standard deviation: non-TBL vs. TBL.

| Report No. | Lab Report Content               | Non-TBL   | TBL      | Mann–Whitney p-Value | Significant Difference? |
|-----------|----------------------------------|-----------|----------|----------------------|-------------------------|
| 1         | Aggregate property               | 86 ± 6    | 83 ± 9   | 1.99                 | YES                     |
| 2         | Aggregate gradation              | 90 ± 3    | 84 ± 11  | 4.69                 | YES                     |
| 3         | Concrete plant                   | 97 ± 3    | 95 ± 4   | 1.94                 | NO                      |
| 4         | Concrete mix design and batch    | 95 ± 3    | 88 ± 7   | 5.10                 | YES                     |
| 5         | Concrete 7-day test              | 87 ± 11   | 86 ± 7   | 1.19                 | NO                      |
| 6         | Concrete 28-day test             | 93 ± 5    | 91 ± 6   | 1.00                 | NO                      |
| 7         | Asphalt plant visit              | 96 ± 3    | 97 ± 4   | 0.52                 | NO                      |
| 8         | Asphalt test                     | 88 ± 4    | 93 ± 6   | 5.26                 | YES                     |
| 9         | Final formal report              | 88 ± 4    | 93 ± 4   | 4.52                 | YES                     |

Figure 2. Results of students’ perception of their technical writing skills with and without TBL modules.
Figure 3. Lab report score trend.

From Report No. 1 to No. 3, students who did not receive TBL modules show higher lab report scores than students who did, denoting that the conventional technical writing setting (non-TBL) can help students quickly adapt themselves to the writing assignment; however, starting from Report No. 5, students who received TBL modules caught up and exhibited significantly better performance in Lab Reports 8 and 9. Different from a two-page memo, Report No. 9 is a final formal report that comprehensively includes a cover page, table of contents, abstract, literature review, methodology, results and discussions, conclusions, references, and appendix. Based on instructors’ evaluation of students’ technical writing assignments using consistent grading rubrics, the integration of TBL modules in a lab curriculum can help students develop more robust and comprehensive technical writing skills in the long run, while conventional technical writing instructional modules (non-TBL) can help students quickly meet instructors’ expectation but the improvement is not lasting as the TBL modules. In other words, the TBL modules can better engage students and develop their writing skills in a more far-reaching manner.

It is also noted that the average lab score increased from 83 to 93 for students who received TBL modules while the average lab score increased from 86 to 88 for those who did not. A paired t-test was further conducted to compare the average score of Report No. 1 with that of Report No. 9 for non-TBL and TBL lab sessions, with the results showing: $p$-value of non-TBL = 0.06, and $p$-value of TBL = $3.14 \times 10^{-9}$, indicating that students who received TBL modules had a significant improvement in technical writing based on instructors’ objective evaluation of their lab writing assignments.

5.1.3. Correlation between Instructors’ Evaluation and Students’ Perception

There is a strong correlation between instructors’ evaluation of students’ technical writing assignments and students’ own perception of their technical writing skills, as depicted in Figure 4.

5.2. Effect of Team Leader in TBL

5.2.1. Students’ Perception of Technical Writing Skills

Table 4 shows the average score, standard deviation, and improvement ratio that is between pre-survey and post-survey for each specific technical writing skill dimension for TBL with an assigned team leader and TBL without an assigned team leader.
### Table 4. Pre-class and post-class survey results on students’ perception of their technical writing skills for TBL modules: assigned vs. no assigned team leader.

| No. | Technical Writing Skill Dimension                                                                 | No Assigned Team Leader | Assigned Team Leader |
|-----|---------------------------------------------------------------------------------------------------|-------------------------|----------------------|
| 1   | I am able to write a project report using the correct format.                                      | 4.1 ± 0.7               | 3.7 ± 0.8            |
|     |                                                                                                  | 4.5 ± 0.5               | 4.5 ± 0.5            |
|     |                                                                                                  | 11%                     | 22%                  |
| 2   | I am able to write technical documents with correct grammar.                                      | 4.4 ± 0.7               | 4.4 ± 0.7            |
|     |                                                                                                  | 4.5 ± 0.5               | 4.7 ± 0.5            |
|     |                                                                                                  | 3%                      | 10%                  |
| 3   | I am able to write technical documents with correct spelling.                                     | 4.3 ± 0.8               | 4.3 ± 0.8            |
|     |                                                                                                  | 4.6 ± 0.5               | 4.7 ± 0.6            |
|     |                                                                                                  | 7%                      | 10%                  |
| 4   | I am able to write technical documents with correct capitalization (capital and small letters).   | 4.6 ± 0.5               | 4.4 ± 0.7            |
|     |                                                                                                  | 4.6 ± 0.5               | 4.7 ± 0.4            |
|     |                                                                                                  | 0%                      | 7%                   |
| 5   | I am able to write technical documents with correct punctuation.                                  | 4.3 ± 0.7               | 4.0 ± 0.9            |
|     |                                                                                                  | 4.6 ± 0.5               | 4.6 ± 0.6            |
|     |                                                                                                  | 8%                      | 17%                  |
| 6   | I am able to construct concise objectives for a project.                                          | 4.4 ± 0.6               | 3.8 ± 0.6            |
|     |                                                                                                  | 4.5 ± 0.6               | 4.6 ± 0.5            |
|     |                                                                                                  | 3%                      | 20%                  |
| 7   | I am able to conceptualize a problem.                                                              | 4.3 ± 0.5               | 3.8 ± 0.6            |
|     |                                                                                                  | 4.6 ± 0.5               | 4.4 ± 0.6            |
|     |                                                                                                  | 6%                      | 16%                  |
| 8   | I am able to compose an abstract in a report.                                                     | 3.7 ± 0.8               | 3.2 ± 0.8            |
|     |                                                                                                  | 4.5 ± 0.6               | 4.2 ± 0.8            |
|     |                                                                                                  | 23%                     | 30%                  |
| 9   | I am able to illustrate a process.                                                                | 4.2 ± 0.4               | 3.8 ± 0.5            |
|     |                                                                                                  | 4.6 ± 0.5               | 4.6 ± 0.5            |
|     |                                                                                                  | 10%                     | 22%                  |
| 10  | I am able to construct figures that present data clearly and precisely.                           | 4.1 ± 0.8               | 3.8 ± 0.7            |
|     |                                                                                                  | 4.4 ± 0.6               | 4.6 ± 0.6            |
|     |                                                                                                  | 8%                      | 20%                  |
| 11  | I am able to construct tables that present data clearly and precisely.                            | 4.2 ± 0.8               | 3.9 ± 0.7            |
|     |                                                                                                  | 4.6 ± 0.5               | 4.6 ± 0.6            |
|     |                                                                                                  | 10%                     | 16%                  |
| 12  | I am able to interpret graphic presentations such as figures and tables.                          | 4.4 ± 0.6               | 4.0 ± 0.6            |
|     |                                                                                                  | 4.5 ± 0.6               | 4.5 ± 0.5            |
|     |                                                                                                  | 4%                      | 14%                  |

**Figure 4.** Correlation of instructors’ perception and students’ perceptions of technical writing skills.

The equation for the line of best fit is:

\[ y = 12.651x + 34.125 \]

with a coefficient of determination of:

\[ R^2 = 0.8119 \]
Table 4. Cont.

| No. | Technical Writing Skill Dimension | No Assigned Team Leader | Assigned Team Leader |
|-----|----------------------------------|-------------------------|----------------------|
|     |                                  | Pre-Survey | Post-Survey | Ratio | Pre-Survey | Post-Survey | Ratio |
| 13  | I am able to analyze data of a research project accurately. | 4.2 ± 0.6 | 4.5 ± 0.5 | 8% | 3.6 ± 0.7 | 4.6 ± 0.5 | 28% |
| 14  | I am able to collate research data. | 4.1 ± 0.8 | 4.5 ± 0.5 | 11% | 3.6 ± 0.8 | 4.5 ± 0.5 | 24% |
| 15  | I am able to qualify claims based on gathered data. | 4.1 ± 0.6 | 4.6 ± 0.5 | 13% | 3.7 ± 0.5 | 4.5 ± 0.6 | 21% |
| 16  | I am able to transpose verbal data to non-verbal materials and vice versa. | 4.0 ± 0.7 | 4.3 ± 0.7 | 10% | 3.5 ± 0.7 | 4.3 ± 0.6 | 25% |
| 17  | I am able to define technical terms in my own words. | 4.0 ± 0.9 | 4.4 ± 0.5 | 10% | 3.6 ± 1.0 | 4.5 ± 0.6 | 24% |
| 18  | I am able to construct conclusion from research findings in a project report. | 4.1 ± 0.7 | 4.4 ± 0.5 | 7% | 4.0 ± 0.6 | 4.7 ± 0.5 | 18% |
| 19  | I am able to propose recommendations from research findings. | 4.1 ± 0.8 | 4.5 ± 0.5 | 11% | 3.5 ± 0.7 | 4.4 ± 0.5 | 26% |
| 20  | I am able to write references for a project report using a correct way. | 3.9 ± 0.7 | 4.3 ± 0.6 | 13% | 3.4 ± 0.8 | 4.3 ± 0.8 | 28% |
| 21  | I am able to differentiate the features of technical reports. | 3.4 ± 0.8 | 4.4 ± 0.5 | 29% | 3.1 ± 0.8 | 4.4 ± 0.6 | 44% |
| 22  | I am able to distinguish an opinion from a fact. | 4.6 ± 0.6 | 4.5 ± 0.6 | −1% | 4.3 ± 0.6 | 4.6 ± 0.5 | 6% |
| 23  | I am able to spot errors in a technical report. | 3.5 ± 1.0 | 4.3 ± 0.6 | 22% | 3.2 ± 0.8 | 4.3 ± 0.8 | 36% |
| 24  | I am able to analyze content of technical reports. | 4.0 ± 0.8 | 4.5 ± 0.6 | 15% | 3.5 ± 0.7 | 4.4 ± 0.6 | 29% |
| 25  | I am able to recognize classification of terms according to methods and functions. | 3.7 ± 1.0 | 4.5 ± 0.6 | 24% | 3.4 ± 0.7 | 4.4 ± 0.6 | 29% |
| 26  | I am able to distinguish the differences between technical writing and other forms of writing. | 3.8 ± 1.0 | 4.4 ± 0.7 | 17% | 3.5 ± 0.8 | 4.5 ± 0.6 | 28% |
| 27  | I am able to write using various technical writing styles. | 3.0 ± 1.1 | 4.3 ± 0.7 | 43% | 3.0 ± 0.7 | 4.3 ± 0.7 | 41% |
| 28  | I am able to distinguish between formal and informal English in technical writing. | 4.4 ± 0.7 | 4.6 ± 0.5 | 5% | 3.7 ± 1.0 | 4.6 ± 0.6 | 24% |
| 29  | I am able to show that proper ethics are followed in my report. | 4.2 ± 1.0 | 4.5 ± 0.6 | 7% | 3.8 ± 0.9 | 4.5 ± 0.6 | 18% |
|     | Average | 4.0 ± 0.7 | 4.5 ± 0.6 | 12% | 3.7 ± 0.7 | 4.5 ± 0.6 | 23% |

Figure 5 presents the average score of students' perception of their technical writing skills: without assigning team leaders and with assigning team leaders. The percent increase is the average score between before and after the semester, and it is seen that student teams who were assigned team leaders perceived their technical writing skill improvement as being at a faster rate than those who were not assigned team leaders.
5.2.2. Instructors’ Evaluation of Reports: TBL with Team Leader vs. TBL without Team Leader

Table 5 presents the students’ report mean score and standard deviation, as well as Mann–Whitney statistical results for comparing TBL with a team leader and without a team leader. It is found that there was no statistically significant difference in the lab report score between students without a team leader and with a team leader for most reports, except for Report No. 8. It appears that assigning a team leader may not necessarily advance students’ technical writing skill to a greater extent, because the team leader was only present during TBL class activities, and not throughout all the writing assignment. It is also interesting to note that, for Lab Report 8, students without assigned team leaders performed even better than students with assigned team leaders.

Table 5. Students’ report mean score and standard deviation: no team leader vs. team leader.

| Report No. | Lab Report Content                  | Without Team Leader | With Team Leader | Mann–Whitney p-value | Significant Difference? |
|------------|-------------------------------------|---------------------|-----------------|-----------------------|-------------------------|
| 1          | Aggregate property                  | 81 ± 10             | 83 ± 8          | 0.4354                | NO                      |
| 2          | Aggregate gradation                 | 89 ± 5              | 84 ± 11         | 0.34722               | NO                      |
| 3          | Concrete plant                      | 97 ± 4              | 94 ± 5          | 0.08364               | NO                      |
| 4          | Concrete mix design and batch       | 92 ± 5              | 87 ± 7          | 0.05486               | NO                      |
| 5          | Concrete 7-day test                 | 85 ± 7              | 87 ± 7          | 0.38978               | NO                      |
| 6          | Concrete 28-day test                | 91 ± 7              | 90 ± 6          | 0.61006               | NO                      |
| 7          | Asphalt plant visit                 | 96 ± 4              | 97 ± 4          | 0.1096                | NO                      |
| 8          | Asphalt test                        | 98 ± 2              | 91 ± 5          | <0.00001              | YES                     |
| 9          | Final formal report                 | 93 ± 5              | 95 ± 4          | 0.42952               | NO                      |

Figure 5. Results of students’ perception of their technical writing skills with and without assigning team leaders.
Figure 6 plots the score trend. Comparing the first lab report score with the final report score, the average lab score increases from 81 to 93 for students who were not assigned team leaders during TBL, while the average lab score increase from 83 to 95 for those who were assigned team leaders during TBL modules. A paired t-test is further conducted to compare the score of Report No. 1 with that of Report No. 9, with the results showing: \( p \)-value of w/team leader-TBL = 0.000013, and \( p \)-value of w/o team-eader-TBL = 0.00078, indicating that regardless of assigning team leaders or not, students were able to develop their technical writing skills significantly, due to extensive training and technical writing TBL activities. Assigning team leaders in TBL instructional modules does not affect students' writing skills in a small group of three persons, most likely because students were able to intrinsically figure out the team leader on their own, which facilitated their communications in small groups.

![Figure 6. Lab report score trend comparison between TBL with and without assigning team leaders.](image)

5.3. Discussion

It was the intent of this study to develop four standalone TBL technical writing modules and integrate them into the current lab curriculum to enhance engineering students’ technical writing skills. Overall, it appears that students who participated in TBL modules improved their technical writing skills.

We were also interested to see whether there would be a difference between male and female students’ perceptions of their technical writing skills. Figure 7 compares lab report scores for male and female students who participated in TBL modules. Overall, it is observed that female students appeared to exhibit better performances in their first two lab reports, but the advantage became lesser with more writing assignments. Gender does not significantly affect technical writing skills, which is consistent with the findings by Maharaj and Banta [21] and Hartberg et al. [33].

This study was based on civil engineering students, which resulted in a limited number of participants. The results of this study may not be conclusive for other engineering students. In addition, the students’ perceptions of their own technical writing skills and instructors’ perceptions of students’ technical writing skills were not assessed in the same way, as students’ perceptions were assessed through qualitative Likert scale questions, while instructors’ perceptions were based on more objective laboratory report grading using the same rubrics.
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Figure 6. Lab report score trend comparison between TBL with and without assigning team leaders.

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Figure 7. Comparison of lab report scores between male and female students who participated in TBL.

In addition, the complexity and difficulty of technical content in each of the nine lab report assignments may be different, which may shadow the evaluation of specific technical writing skills. For example, the lab reports based on field visits show higher grading than other reports based on laboratory experiments. Those limitations may be addressed by future studies.

6. Conclusions
This study evaluated the effectiveness of applying TBL instructional modules in improving engineering students’ learning experience and outcomes of technical writing. Four standalone TBL modules were designed and implemented throughout a laboratory course, which specifically covered four major technical writing topics. A cycle of TBL in-class activities included a mini-lecture, individual readiness assurance test, team readiness assurance test, appeal, application, and peer evaluation.

Based on students’ own perceptions, receiving TBL modules has improved their technical writing skills. Based on instructors’ evaluation of students’ lab reports, it is found that students who have experienced TBL instructional modules exhibit better technical writing performances than those who have not. There is also a strong correlation between students’ perception and instructor perception of students’ technical writing skills.

Assigning team leaders in TBL instructional modules does not significantly improve engineering students’ technical writing. The same happens with gender.

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Appendix A. Example of iRAT Module I: Introduction and Technical Language

1. Which of the following is inappropriate statement about technical writing?
   A. Technical writing should be neutral and unbiased.
   B. Technical writing is to educate students.
   C. Technical writing should be fact-based and fact-driven.
   D. Technical writing can express authors’ opinion from technical point of view.
   E. Using third-person and passive tense makes technical writing objective.

2. _____ introduces a formal list, long quotation, equation, or definition.
   A. Comma (,)
   B. Dash (-)
   C. Semi-Colon (;)
   D. Colon (:)
   E. Period (.)

3. Run-on is _____.
   A. two or more independent clauses that are joined properly
   B. two or more independent clauses that are not joined properly
   C. group of words that either is missing a subject or a verb or does not express a complete thought
   D. group of words with a subject and a verb that expresses a complete thought
   E. group of words that neither is missing a subject nor a verb but express a complete thought

4. Read the sentences below: “To conclude this report, I think we had different numbers in each. We have learned the aggregate testing, the specific gravity, and absorption. We used the equations that we took in lecture.” Which is major issue for the above sentences?
   A. Faulty parallelism
   B. Unclear pronoun reference
   C. Vague definition
   D. Tense inconsistency
   E. Inappropriate use of number and unit

5. For the sentence below, which one is grammar error free?
   A. Table 1 shows the data of compressive strength and modulus for concrete.
   B. Smith (2019) shows that lower water-cement ratio result in higher compressive strength.
   C. Once the drying was completed, we weigh the sample and recorded the amount.
   D. Future work is needed to work on the correlation between strength and modulus.
   E. Three different types of recycled materials are studied in this project, recycled glass, recycled steel, and recycled woods.

Appendix B. iRAT Answer Sheet

Instructions: Each question is worth 5 points. You should assign a total of 5 points on each line. If you are uncertain about the correct answer you may assign points to more than one box.

For example: where is the capital of United States?
A. Washington, D.C.
B. Washington state
C. New York
D. New York State
E. Columbia

The answer is A. If you placed 5 points on A, you receive 5 points; If you placed 2 points on A and 3 points on B, you receive 2 points. Similar rule is applied to other scenarios.

Table A1. iRAT answer sheet.

| Q # | A | B | C | D | E | Individual Points |
|-----|---|---|---|---|---|-------------------|
| 1   |   |   |   |   |   |                   |
| 2   |   |   |   |   |   |                   |
| 3   |   |   |   |   |   |                   |
| 4   |   |   |   |   |   |                   |
| 5   |   |   |   |   |   |                   |
|     |   |   |   |   |   | Total             |

Appendix C. Peer Evaluation during TBL Application in Class

Give your honest evaluation of this person’s performance and contribution in the TBL, using Table A2.

Table A2. Peer evaluation questions.

| Scale                                                                 | Never | Sometimes | Often | Always |
|-----------------------------------------------------------------------|-------|-----------|-------|--------|
| Arrives on time and remains with team during activities              |       |           |       |        |
| Demonstrates a good balance of active listening & participation     |       |           |       |        |
| Asks useful or probing questions                                     |       |           |       |        |
| Shares information and personal understanding                        |       |           |       |        |
| Is well prepared for team activities                                 |       |           |       |        |
| Shows appropriate depth of knowledge                                 |       |           |       |        |
| Identifies limits of personal knowledge                              |       |           |       |        |
| Is clear when explaining things to others                            |       |           |       |        |
| Gives useful feedback to others                                     |       |           |       |        |
| Accepts useful feedback from others                                  |       |           |       |        |
| Is able to listen and understand what others are saying              |       |           |       |        |
| Shows respect for the opinions and feelings of others                |       |           |       |        |
Appendix D. Survey Questions on Students’ Perception of Their Technical Writing Skills

Table A3. What is your current level of proficiency in putting together a technical report?

| No. | Proficiency Statement                                                                 |
|-----|---------------------------------------------------------------------------------------|
| 1   | I am able to write a project report using the correct format.                          |
| 2   | I am able to write technical documents with correct grammar.                           |
| 3   | I am able to write technical documents with correct spelling.                          |
| 4   | I am able to write technical documents with correct capitalization (capital and small letters). |
| 5   | I am able to write technical documents with correct punctuation.                       |
| 6   | I am able to construct concise objectives for a project.                               |
| 7   | I am able to conceptualize a problem                                                  |
| 8   | I am able to compose an abstract in a report.                                          |
| 9   | I am able to illustrate a process                                                     |
| 10  | I am able to construct figures that present data clearly and precisely.                |
| 11  | I am able to construct tables that present data clearly and precisely.                 |
| 12  | I am able to interpret graphic presentations such as figures and tables.               |
| 13  | I am able to analyze data of a research project accurately.                            |
| 14  | I am able to collate research data                                                    |
| 15  | I am able to qualify claims based on gathered data                                    |
| 16  | I am able to transpose verbal data to non-verbal materials and vice versa.             |
| 17  | I am able to define technical terms in my own words.                                   |
| 18  | I am able to construct conclusion from research findings in a project report.          |
| 19  | I am able to propose recommendations from research findings                            |
| 20  | I am able to write references for a project report using a correct way.                |
| 21  | I am able to differentiate the features of technical reports                          |
| 22  | I am able to distinguish an opinion from a fact                                        |
| 23  | I am able to spot errors in a technical report                                        |
| 24  | I am able to analyze content of technical reports                                     |
| 25  | I am able to recognize classification of terms according to methods and functions      |
| 26  | I am able to distinguish the differences between technical writing and other forms of writing. |
| 27  | I am able to write using various technical writing styles.                             |
| 28  | I am able to distinguish between formal and informal English in technical writing.     |
| 29  | I am able to show that proper ethics are followed in my report.                        |
## Appendix E. Evaluation Rubrics on the Technical Writing Reports

### Table A4. Report evaluation rubrics.

| Criteria                  | Poor 3 pts                                                                 | Fair 6 pts                                                                 | Good 8 pts                                                                 | Excellent 10 pts                                                                 |
|---------------------------|-----------------------------------------------------------------------------|-----------------------------------------------------------------------------|-----------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| **Content & Development** (20%) | Content is incomplete. Major points are not clear, not persuasive. Equation, figure and table are inappropriate. | Content is not comprehensive or not persuasive. Major points are addressed, but not well supported. Most points required by the assignment are covered. Content is inconsistent with regard to purpose and clarity of thought. Equation, figure and table are inappropriate. | Content is somewhat comprehensive, accurate, and persuasive. Major points are mostly clear and supported. Most of the points required by the assignment are covered. Content and purpose of the writing are mostly clear. Equation, figure and table are almost correct. | Content is somewhat comprehensive, accurate, and persuasive. Major points are mostly clear and supported. Most of the points required by the assignment are covered. Content and purpose of the writing are mostly clear. Equation, figure and table are correct and appropriate. |
| **Organization & Structure** (20%) | Organization and structure detract from the message of the writer. Paragraph is disjointed and lack transition of thoughts. | Structure of the paragraph is not easy to follow. Paragraph transitions need improvement. | Structure of the paragraph is mostly clear and easy to follow. | Structure of the paragraph clear and easy to follow. |
| **Format** (20%) | Paper lacks many elements of correct formatting. Paragraph is inadequate in length. No citation. | Paper follows some of guidelines. Paper is under word length. Citation is inappropriate. | Paper follows most of designated guidelines. Paper is the appropriate length as described for the assignment. Citation is correct. | Paper follows all the designated guidelines. Paper is the appropriate length as described for the assignment. Correction is correct and include all components. |
| **Grammar, Punctuation & Spelling** (20%) | Paper contains numerous grammatical, punctuations, and spelling errors. Language uses jargon or conversational tone. | Paper contains few grammatical, punctuations, and spelling errors. Language lacks clarity or includes the use of some jargon or conversational tone. | Rules of grammar, usages, and punctuations are mostly followed; spelling is mostly correct. Language is mostly clear and precise; sentences display good structure. | Rules of grammar, usages, and punctuations are followed; spelling is correct. Language is clear and precise; sentences display consistently strong, varied structure. |
| **Conclusion** (20%) | There is a 1-2 sentence that does not include all the necessary elements of a closing paragraph. | The conclusion is recognizable, but does not tie up several loose ends. Does not include all the necessary elements of a closing paragraph. | The conclusion is recognizable and ties up almost all the loose ends including restating the thesis. Include all the necessary elements of a paragraph. | The conclusion is strong and leaves the reader satisfied. The thesis statement is restated. Sums up the main topic successfully and leaves a potent final statement. |
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