ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Paper ID #44673

Developing a Writing Rubric to Answer Research Questions (not for Grading!)

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Abstract

Industry leaders emphasize that engineering students' technical communication and writing skills must be improved. Despite various institutional efforts, which include technical communication courses or engineering design projects aimed at enhancing students' communication abilities, many believe there has been only slow improvement in this area. There has also been a dearth of longitudinal studies that examine the development of engineering students' technical communication competencies from undergraduate to industry. This paper aims to contribute to this area through the creation of a rubric that specifically examines the writing competencies and technical communication ability of engineering students. This paper is part of a larger, NSF-funded research study that examines the quality of students' written and oral communication skills and seeks to understand their relationship to the students' spatial abilities.

First-year engineering students in their second semester at a large R1 Midwestern university were examined. Students were tasked with creating a written report responding to a set of questions that asked about their team-based engineering design project completed in their first semester. As this occurred months prior, this non-graded report became a reflection on their experience and innate abilities. While low stakes, it mimicked a more authentic writing experience students encounter in industry. Students' responses were examined collaboratively by

an interdisciplinary team which created a rubric through an iterative process. This rubric was distributed to the interdisciplinary team and outside evaluators composed of individuals in industry and engineering faculty. An inter-rater reliability analysis was conducted to examine levels of agreement between the interdisciplinary team and outside evaluators, and implications of this inter-rater reliability score and the process of rubric application were documented.

Results of this paper include details on the development of a rubric that examine students' technical communication and writing skills. Traditional rubrics utilized by engineering faculty usually address an entire project for engineering students, which includes students' content knowledge, writing capabilities, and the requirements of the project. Such rubrics are often used to provide feedback to students and evaluation in the form of grades. The narrower focus of the rubric being developed here can provide insights into communication and writing competencies of engineering students. Scores secured through the use of this rubric will aid in the research study's goal of finding correlations between engineering students' communication skills and spatial abilities (assessed outside of this current effort). Spatial ability has been well-documented as an effective indicator of success in STEM, and interventions have been developed to support development in students with weaker spatial skills. [23, 24]This has prompted this research to explore links between spatial skills and communication abilities, as validated spatial interventions may help improve communication abilities. These current results may also provide unique insights into first-year engineering students' writing competencies when reporting on a more authentic (non-graded) engineering task. Such information may be useful in eventually shaping guidance of students' communication instruction in hopes of better preparing them for industry; this is the focus of a planned future research study.

Introduction

ABET requires that students graduate from their engineering program with the ability to communicate effectively with a range of audiences.[1] These audiences can range from academic personnel, industrial leaders, teams on jobsites, and discussions with non-engineering stakeholders. When reviewing the literature on the communication abilities of engineers, while there appears to be a consensus that the skills are important, the exact skills that must be focused on seem to be varied. Particular research has focused on communication as a holistic component, where presentations, writing, and oral communication are covered by the umbrella term of communication. Others focus purely on writing ability or oral communication skills. The following sections provide a brief overview of some current trends in technical communication for engineers.

Technical Communication Skills in Engineers

Many of the studies regarding communication skills of engineers focus on technical communication, or the broad ability of engineers to create, write, and communicate with non-engineering audiences about projects or content. This skill is recognized as a core skill by ABET and academic institutions. [2, 3, 4] Engineering students have also stated this is a critical skill, as recent research found engineering undergraduate students self-identify the importance of soft-skills, which include empathy, listening, and active collaboration, regardless of their extrinsic factors of gender and major. [5] First-semester engineering students also state they think communication skills are important for engineers and value activities that mimic authentic communications they will encounter in industry. [6] And of course, industry continues to share concerns about engineering students' communication readiness for effective employment. [7,8]

Interventions and Training for Engineers' Technical Communication Abilities

The importance of communication ability is well accepted, and there has been a great deal of effort to utilize interventions and unique teaching strategies to teach communication more effectively for engineers. Situated and active learning have been advocated as an ideal approach for learning communication as they play a significant role in helping engineers develop transferable and effective communication skills. [9] This active role in teaching communication is critical as it combats misconceptions that communication is a non-iterative process or that the skills are not as critical as content knowledge, and a focus purely on correct grammar rather than the complexity of rhetorical writing. [10,11,12,13,14]

While situated and active learning are proven to improve communication abilities of engineers and address misconceptions prevalent about communication skills, not all institutions have the resources and workforce able to develop and effectively deliver communication-targeted courses or workshops. Furthermore, the sustainability of these courses or workshops may be an issue; if these are removed from curriculums to opt for a reinforced focus on engineering content, it can reinforce prior sentiments that content is more important than the communication ability of engineers. Engineering faculty may not feel fully able to effectively teach communication nor to provide feedback on students' writing. Thus rubrics can provide a helpful tool in these efforts. Alternatives beyond targeted interventions have been rubrics and evaluation tools that align the expected content-knowledge with transferable communication abilities expected of engineers in industry. [15] Other rubrics have also responded to oral presentation skills, soft-skill development, and general communication abilities. [16,17,18] These rubrics provide an alternative means to measure technical communication abilities in pre-existing class formats. Furthermore, if developed and tested for reliability through many institutions, they can be an effective way to pinpoint how the technical communication skills of engineers are developing as they progress through curriculums. This may provide deeper insights on where engineering students need practice beyond existing technical writing or lab report courses.

In engineering and technology education, there are many publications about the importance, strategies, and various models of assessment practices, but few published papers about performance measures and instruments that can be used by engineering and technology faculty for classroom assessment and evaluation situations. [19] Thus, while attention to communication assessment remains strong, relatively little has been developed or documented in terms of performance measures or assessment tools relevant for application in engineering learning at the course or classroom level.

Methodology

This research project is part of a larger study that examines potential links between spatial and communication skills of engineering students at a large R1 midwestern university. First-year engineering students in their second semester at a large R1 Midwestern university were examined. Students were tasked with the creation of a written report where they would respond to a set of questions about their engineering design project completed in their first semester. These written responses occurred months after the students completed their project, which created a more authentic, low stakes experience where the students reflected on their experiences of their design project. All students had practical experience in writing a report based on their final project submission from their previous semester. Students were given the following assignment:

For the writing portion of this study, reflect back on your robot from your first-year-engineering course and please write a document that describes:

- What problem were you trying to solve?
- What task was it supposed to do?
- What did it look like?
- How did it operate?
- What features of your robot solved the problem?
- How did your robot perform in the demo?

If you need to include a figure in your document, please use the blank sheets of paper provided and hand-sketch the figure. Do not spend a great deal of time trying to make a computer-generated sketch either in Word or elsewhere. Your document should be 2 pages maximum.

Students responded to these questions using a laptop and a word document. There was no time limit for the student responses. Students' written responses were stored alongside any drawings the student opted to create. Students' responses were examined collaboratively by an interdisciplinary team which consisted of experts in engineering education and technical communication.

The team developed a rubric to assess these student writing responses through an iterative process until a working version was finalized. The rubric contained 11 questions with a Likert scale of 1-6 (Unacceptable, Marginal, Adequate, Above average, Strong, Exceptional) for each question. For each question, the rubric provided a general description and specific details to aid the reviewer in determining the grade. Reviewers were offered a comment box area where they could elaborate on why they decided on specific scores for each question.

Table 1. ***Working version of Communication Task Rubric distributed to reviewers***

Q. #	**General Description**	**Specific details for question**
1.	Overall design project and goals identified.	"Big picture" of robot design project is shown. Problems to be solved are provided.
2.	Purpose / task of the robot provided.	Robot's specific goals / tasks to be accomplished are identified. Precise tasks to perform are clearly described.

3.	Robot's appearance described.	Overall appearance – size / dimensions / materials – is described. Specific attachments / appendages and their purposes are explained. The reader can envision what the robot looks like.
4.	Robot's operation explained	Basic operation and control mechanisms are clear. Student's control of robot is described. How robot functioned to complete various tasks is clear.
5.	How did the robot solve the problem?	Student's and robot's performance of required tasks is described. Reader can understand the processes described in relation to achievement of task. What features of the robot were involved in solving the problem?
6.	Overall performance or success of the robot during the demo.	Summarizes robot's performance / success in achieving assigned goals. Provides explanation of constraints that kept robot from fully achieving goals. Suggests specific upgrades or changes to improve future performance.
7.	Was sufficient detail provided?	Description of project purpose, robot, activities, and results is thorough and specific. Reader can fully envision the robot and activities performed. No gaps in explanation that confuse reader are present.
8.	Communication style effectiveness.	Organization is clear and effective; explanation develops logically. Phrasing is tight and specific *vs.* wordy and vague. Information seems accurate and correct.
9.	Document structure / layout supported reader understanding.	Layout of the response document helped with reader's understanding overall. Document's structure supported the logical development of the response. Visual structure of document helps reader stay interested and focused. *In comments, indicate the document structure (narrative, large blocks of text, lists, etc.) used.*
10.	Mechanics (grammar, spelling, punctuation, etc.) used appropriately.	Standard English usage supported reader's understanding of the response. No or minimal misspellings or punctuation errors. Word choices are correct; no or minimal subject/verb agreement errors or run-on sentences, etc.
11.	Drawings used to illustrate, explain	*Comment "N/A" below if drawings were not used.* *Comment if drawing(s) used as primary explanations / responses.* Drawing(s) helped explain and support points made in text. Drawing(s) were clearly drawn, labeled as needed, appropriately connected to related textual material.

Note that the rubric's first six questions correlate directly to the six questions the assignment directed the students to respond to. The next four questions were to assess students' writing and communication effectiveness. Question 11 referred to any optional drawings or schematic the student chose to include with their written responses.

After this version of the communication task rubric was finalized, the team created a sample of ten student writing responses from the over 90 written responses obtained. These samples were gathered specifically to provide a range of quality and usage of drawings for illustration.

Multiple reviewers were then identified and asked to serve as initial users of the rubric. A goal of having multiple reviewers use the rubric to rate the students' writing was to see if there was a general consensus on "good" vs. "poor" writing and to see if the rubric was effective in gaining that information. The rubric and samples were distributed to nine reviewers. These reviewers were chosen to represent populations that worked in engineering education academically or actively worked in industry, thus providing a range of expertise in different domains. A total of eight reviewers were able to successfully complete the review of the provided samples.

Inter-rater Reliability Analysis

An inter-rater reliability analysis was conducted to examine the reliability of the rubric based on results from each reviewer. In determining the type of inter-rater analysis to conduct, Cohen's kappa was found not applicable due to having more than two reviewers. A two-way random-effects intraclass correlation coefficient (ICC) was chosen as the reviewers were representative of a larger population of engineering educators. [20, 21, 22] Each reviewer completed one rubric per sample, resulting in 80 rubrics used for analysis purposes. An inter-rater reliability using RStudio (Build 2023.03.0-daily+82.pro2) with the *psych* library for intraclass correlation was utilized to analyze the responses. The intraclass correlation coefficient was computed to assess agreements between the eight reviewers using the provided rubric to rate communication abilities in ten students reports. ICC estimates and their 95% confident intervals were calculated.

There was found to be poor agreement between the raters at kappa = 0.39, $p < 0.05$ ($p = 1.48e-23$), $F(92,113)=7.93$ for the two-way model single-rater model. The RStudio guide indicates the following standards for rates of agreement: [kappa] below 0.50: poor; between 0.50 and 0.75: moderate; between 0.75 and 0.90: good; and above 0.90: excellent.

Discussion

While the results of the rating indicated poor agreement, the first iteration of the rubric resulted in an agreement that is nearing acceptable values and can benefit from future iterations. Several specific areas of revision and clarification were identified for the next round.

First, Question #11 presented problems in calculating the IRR. Because "N/A" was an option on Question 11 (but no other question) for the student writing samples without drawings, and only five of the ten responses had drawings, reviewers' responses varied widely. For example, one rater provided a value of 0, as they may have thought they were interchangeable. There was a discrepancy between the number of scores actually rated, as N/A for Question 11 on all 5 samples without images caused calculation errors. Future iterations may need to remove the question and ignore illustrations. Because illustration, as a graphic form of communication, may introduce another area of communication for engineers that may not be effectively represented through a single Likert scale question, the solution may be to account for this in another rubric separate from the main rubric (Question 1-10). Because the intraclass correlation through RStudio accounts for missing values inside of its calculation, Question 11 responses were simply opted as missing values. This means that future iterations can benefit from training for the raters and more specific directions.

It is also not unusual to have a low agreement score on a rubric's first iterations. Additionally, some trends between specific educators and industry reviewers were observed; these will figure into future revisions and use of the rubric.

The distribution of the samples, rubrics, and grading through rubrics occurred through a secure online folder provided by the university. While this may be the default, it may be an interesting area to determine differences in grades and if modality of the work impacts this (e.g., some reviewers preferred physically looking at the reports vs. working completely online to complete their rubrics). This is useful information as sustainability and shared resources of rubrics to improve the ability of engineering educators to help engineering students' communication was a main motivation behind this work, and this can further provide insights into modalities that should be used going forward.

Beyond the IRR findings, reviewers' comments provided useful feedback for further refining the rubric. In particular, some reviewers mentioned questions 8, 9, and 10. These were the questions specifically focused on areas of students' writing effectiveness: communication style, document structure, and basic English mechanics. Although guidance was provided on the rubric for reviewers for each of these questions, some reviewers perceived overlap or redundancy. The next revision of the rubric will address these concerns, perhaps reducing these three to two questions or at least providing further clarification.

Conclusion and Next Steps

This paper is part of a larger research study that examines the quality of student writing and communication skills and makes comparisons to students' spatial abilities. This rubric is one tool to help the team assess the students' communication skills, providing a score that can be compared to the student's spatial skills scores, addressing the current project's working theories. The rubric may also identify specific areas of writing concerns across this large group, e.g., explanation, organization, accuracy, or basic English mechanics. Such information may be useful in future studies hoping to provide guidance for improving communication abilities of engineering students in light of industry expectations. If academia seeks to graduate engineers that satisfy the expectations of industry personnel, then these research areas are vitally important to ensure a competent and effective graduate workforce.

The next step for this research team is another iteration of the rubric, addressing the areas of concern that may have prevented fully effective use of the first version rubric. This next version will be completed and tested during February, with those results shared at the ASEE NCS conference in March. Another intraclass correlation coefficient analysis will be performed. The team may also look more closely at ratings of the individual reviewers, seeking to determine if engineering educators tend to grade specific aspects of written reports differently in comparison to engineers currently in industry. This has value for the eventual application of findings from this overall study. The research team is excited to apply these results to the overall study.

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