Technical communications in an environmental engineering curriculum: a framework for analysis and continual improvement

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Abstract

The ability to effectively communicate technical information is an important skill for engineers, especially young engineers entering the workforce upon completion of their education. Undergraduate environmental engineering programs normally address technical communications, but some do not provide intentionally placed discipline-specific technical communication experiences designed to progressively increase communication skills through the curriculum. Conducting a crosswalk of graded events with a technical communication component across a curriculum can help an institution understand the placement of technical communication graded events and identify opportunities for improvement. This study presents a survey-based approach for gathering information about all technical communication graded events within an environmental engineering curriculum and a method for analysis using a longitudinal crosswalk of all applicable courses from freshman to senior year. Results from this study indicate that the number of graded technical communication events in our program increases longitudinally from freshman to senior year. Further, the number of individually completed events and written events were highest in the sophomore year, with team events and oral communication events increasing in the junior and senior years. Additionally, the weighting of graded events shifted longitudinally through major courses. Graded events worth < 5% of the course grade were most prevalent in the sophomore year, and events worth ≥ 5% occurred most frequently in the senior year. Implications for our university's environmental engineering program are discussed, to include opportunities for scaffolding events across courses. The methods presented in this study can be used by other environmental engineering programs to identify gaps in technical communication education and methods for improvement within their curriculum.

1. Introduction

1.1. Background

Engineers need strong communication skills to effectively convey ideas to a range of audiences (Kamarudin et al. 2012). Many studies have identified communication as one of the most important transferrable employment skills – one that often influences job performance and career advancement (Grant and Dickson 2006; Leydens et al. 2008; Poe et al. 2010; Lopes et al. 2015; Bercich et al. 2018; Young and Ashman 2019). Despite the importance of communication skills, several studies have identified communication-related shortcomings in recent graduates, such as convoluted writing, imprecise or inaccurate content, and an inability to meaningfully

communicate technical conclusions (Paretti 2006; Craig et al. 2008; Mohan 2009; Conrad 2017; Fletcher et al. 2017).

While most engineering curricula include some technical communication components, a possible cause of the aforementioned shortcomings could be a lack of emphasis on discipline-specific communication skills. General communication literacy can be addressed using language (e.g., English) courses, guest lectures, or centralized institutional-level writing services; however, these approaches often focus on generic academic writing style and grammar (Wingate 2015). Additionally, several researchers have concluded that discipline-specific communication education can be more effective in teaching communication skills, especially for engineers (Lea and Street 1998; Lillis 2003; Lillis and Scott 2007; Kokkinn and Mahar 2011; Maldoni and Lear 2016). Approaches that align general and discipline-specific engineering technical communication skills can enhance student appreciation for effective communication (Brinkman and van der Geest 2003; Paretti 2008; Vampola et al. 2010); however, not all engineering programs have deliberately examined opportunities for enhancing discipline-specific technical communication skill education within their curriculum (Pfluger et al. 2020).

Several approaches to coupling general communication skills and discipline-specific technical communication skills exist. Examples include required technical communication courses within engineering curricula, or deliberate inclusion of technical communication graded events within existing courses. At the time of this study, there were 98 ABET accredited environmental engineering programs (86 in the United States; 12 outside of the United States). Each of these programs must support ABET's Student Outcome 3, which states that students must have "an ability to communicate effectively with a range of audiences" for accreditation (ABET 2020). A full examination of approaches to teaching technical communication skills in all accredited programs is outside the scope of this study; however, Table 1 provides examples of approaches for addressing technical communication skill education at ~10% of ABET accredited environmental engineering programs in the United States (i.e., 10 of 98 accredited programs were randomly selected and examined). As shown, the majority of programs use a combination of English literature and/or composition courses and technical communication skill education interwoven into major courses. Several universities offer technical communication courses at the university level (e.g., Clarkson University's Professional Communication (COMM 313) course, or the University of Michigan, which offers numerous technical communication courses). Fewer institutions offer technical communication courses specific to environmental engineering (or civil & environmental engineering). An example is the Georgia Institute of Technology's Engineering Communication (CEE 6754) course. A more complete examination of technical communication courses that engineering students in ABET accredited universities in the United States is found in Donnell et al. (2011).

Table 1. Sample representation of approaches to teaching technical communication in several ABET accredited undergraduate (B.S. or B.S.E) environmental engineering programs in the United States. Approximately 10% (n = 10 of 98) of ABET accredited environmental engineering programs in the United States were examined. Programs were randomly selected. Table 1 shows all programs reviewed in this study.

Institution	Description and Website
Bucknell University	Students must satisfy a university-level writing requirement, which includes three writing courses (normally completed in the first year). No separate technical communication course is required; technical communication skill education is interwoven into the engineering curriculum. https://coursecatalog.bucknell.edu/collegeofengineeringcurricula/areasofstudy/environmentalengineeringeveg/#text
Clarkson University	No separate technical communication course is required; technical communication skill education is interwoven into the engineering curriculum. A course in Professional Communication (COMM 313) and a course in Environmental Communication (COMM 428) are available. https://www.clarkson.edu/environmental-engineering-bs-curriculum
Colorado School of Mines	No separate technical communication course is required; technical communication skill education is interwoven into the engineering curriculum. University-level courses, such as Professional Oral Communication (LICM501) are available. https://cee.mines.edu/bs-environmental-engineering/
Georgia Institute of Technology	Students complete two semesters of English (ENGL 1101 and ENGL 1102 Composition, total 6.0-credits) during the freshman year; however, no technical communication specific course is required in the environmental engineering curriculum. Engineering Communication (CEE 6754) is a 3.0-credit offering. http://www.catalog.gatech.edu/programs/environmental-engineering-bs/#text
University of Michigan	No separate technical communication course is required; technical communication skill education is interwoven into the engineering curriculum. https://cee.engin.umich.edu/academics/undergraduate/bse-environmental-engineering/ University of Michigan also offers a number of technical communication courses: https://bulletin.engin.umich.edu/courses/techcomm/
Missouri University of Science and Technology	Students are required to take Exposition and Argumentation (English 1120) during the freshman year. Students are also required to take one of four communication-related courses: Engineering Communications and Computations (CIV ENG 2003), Writing and Research (English 1160), Technical Writing (English 3560), or Principles of Speech (SP&M S 1185). http://catalog.mst.edu/undergraduate/degreeprogramsandcourses/environmentalengineering/
Northwestern University	3.0-units of Design and Communication are required as part of the McCormick Core. These include Engineering Design and Communication (DSGN 106-1,2), Writing in Special Contexts (ENG 106-1,2), and one of three other courses (Public Speaking (COMM ST 102), Analysis and Performance of Literature (PERF ST 103), or Performance, Culture, and Communication (PER ST 203). https://www.mccormick.northwestern.edu/civil-environmental/academics/undergraduate/environmental-engineering/
United States Military Academy (West Point)	Two courses, Composition (EN101) and Literature (EN102) are required. No separate technical communication course is required; technical communication skill education is interwoven into the engineering curriculum. https://www.westpoint.edu/academics/academic-departments/geography-and-environmental-engineering/environmental-engineering
University of Southern California	Composition / writing requirements include Writing and Critical Reasoning (WRIT 150) and Advanced Writing (WRIT 340). No separate technical communication course is required; technical communication skill education is interwoven into the engineering curriculum. https://cee.usc.edu/academics/undergraduate-program-environmental/

1.2. Institutional Support at the United States Military Academy

The United States Military Academy (West Point) emphasizes general communication skills by providing strategic guidance regarding the importance of effective communication and by resourcing activities that enhance general communication skills for students. Specifically, our university's academic program goal #1 states "graduates can communicate effectively with all audiences." Sub- components of this goal include effective listening, reading, speaking, and writing with a clear purpose and intent to diverse audiences using appropriate forms and media.

Resourced activities designed to enhance student communication center on the West Point Writing Program (WPWP), which works across our university's curriculum to help students improve composition, critical thinking, academic argument, writing pedagogy, and professional communication in all disciplines. Part of the WPWP is the Mounger Writing Center, which employs staff, postgraduate writing fellows, and student volunteers, to conduct one-on-one consultations, group workshops, and special events for all students working on writing and communications projects for any academic course, personal interest, or professional opportunity.

The WPWP interfaces with more than 50 courses within our university's curriculum in several different ways. The most relevant interface for this study is the Writing in the Major (WiM) program. The WiM program stresses the in-depth study and practice of discipline-specific writing within one course in each academic major. For environmental engineering majors at our university, the course associated with the WiM program is Environmental Science for Scientists and Engineers (EV301). Additional information concerning the WPWP, the WiM, and the Mounger Writing Center can be found at our university's website.

1.3. Environmental Engineering Curriculum

West Point's environmental engineering curriculum consists of a robust set of core courses (required for all academic majors), as well as environmental engineering courses, and other courses that support the environmental engineering major. In total, environmental engineers take 22 core courses, 11 courses in the major, 4 electives, and 5 supporting courses. Table 2 depicts courses taken by environmental engineers at West Point. For simplicity, core courses are depicted are not shaded or bolded, and courses outside of the core required by environmental engineering majors are shaded. Courses examined in this study are bolded and italicized.

1.4. Purpose of Study

The purpose of this study was to: (1) conduct a crosswalk of all technical communications graded events within West Point's environmental engineering curriculum to identify the placement of graded events with a technical communication component (oral or written); (2)

identify gaps in the curriculum stemming from a lack of graded events with an assessed technical communication component; (3) identify opportunities to enhance our programs' curriculum with respect to graded events with a technical communication component. The results of this study, to include the survey used to gather information and the methods used to conduct the crosswalk, can be employed in environmental engineering undergraduate programs.

Table 2. The courses depicted are required for graduation from our university with a degree in Environmental Engineering. Courses in unshaded boxes are our university's core courses, while those in shaded boxes are specific to the environmental engineering program. Bolded and italicized courses are those that were included in this study. *(EV and XS = Department of Geography and Environmental Engineering, MA = Department of Mathematical Sciences, MC = Department of Mechanical and Civil Engineering, CH = Department of Chemistry and Life Science, PH = Department of Physics and Nuclear Engineering).*

Freshman Year					
1st Semester			*2nd Semester*		
Course Number	Course Name	Credit Hours	Course Number	Course Name	Credit Hours
MA103	Math Modeling & Intro to Calculus	4.5	MA104	Calculus 1	4.5
CH101	General Chemistry 1	4.0	***CH102***	***General Chemistry 2***	***4.0***
EN101	Composition	3.0	EN102	Literature	3.0
HI105	History of the United States	3.0	HI108	Regional Studies in World History	3.0
IT105	Introduction to Computing & IT	3.0	PL100	General Psychology	3.0
Sophomore Year					
1st Semester			*2nd Semester*		
EV301	***Env Science for Eng and Scientists***	***3.0***	***XS391***	***Prin. and App. of Env. Chem***	***3.0***
MA206	Probability and Statistics	3.0	***MA366***	***Applied Engineering Math***	***3.0***
Lx203	Foreign Language 1	4.0	PH205	Physics 1	4.0
SS201	Economics	3.0	Lx204	Foreign Language 2	4.0
PY201	Philosophy	3.0	SS202	American Politics	3.0
EV203	Physical Geography	3.0			
Junior Year					
1st Semester			*2nd Semester*		
MC311	***Thermal-Fluid Systems 1***	***3.5***	***EV396***	***Env and Biological Systems***	***3.5***
PH206	***Physics 2***	***4.0***	***EV397***	***Air Pollution Engineering***	***3.0***
Elective	General Elective	3.0	***EV401***	***Physical and Chemical Treatment***	***3.5***
CY305	Cyber Foundations	3.0	Elective	Engineering Elective 1	3.0
SS307	International Relations	3.0	***EV481***	***Water Resources Planning and Design***	***3.0***
			PL300	Military Leadership	3.0
Senior Year					
1st Semester			*2nd Semester*		
EV394	***Hydrogeology/Hydraulic Systems***	***3.5***	***EV488***	***Solid and Haz Waste Treatment and Remediation***	***3.5***
EV402	***Biochemical Treatment***	***3.5***	***EV491***	***Advanced Engineering Design***	***3.0***
EV490	***Env Engineering Design***	***3.5***	Elective	Engineering Elective 4	3.0
Elective	Engineering Elective 2	3.0	HI302	History of Military Art	3.0
LW403	Constitutional & Military Law	3.0	MX400	Officership	3.0

2. Methods

The number, arrangement, and attributes of technical communication graded requirements within West Point's environmental engineering curriculum were assessed through a comprehensive multi-part survey. The surveys were completed in the winter of 2019-2020 by the instructor for each of the required courses in our environmental engineering curriculum for year group 2022 graduates (Table 2). All required courses (i.e., core courses and major courses) were initially considered for inclusion in this study based on the following criteria: (1) topic of course and graded events (i.e., STEM); (2) structure of the event (i.e., was the event formatted in a scientific writing style); and (3) were events designed to enhance technical communication skills (and not just general communication skills). Each environmental engineering major is required to take four engineering electives. These courses were not included in this study as there are over 25 choices from 6 different departments. All surveyed courses are bolded and italicized in Table 2.

Part I of the survey was completed by all faculty teaching required courses (note: when more than one faculty member taught a course, the survey was completed by the lead faculty member (i.e., the course director)). Part I of the survey asked faculty to report the total number of technical communication events for their course. These were binned into the following categories: lab reports, technical reports (i.e., those ≤ 5 pages in length), full reports (i.e., those > 5 pages in length), oral presentations, and other. Part I of the survey also asked whether each event was an individual or a team assignment, and the percentage of the total course grade that each event contributed. Part II was a slightly more detailed examination of each graded event and was only completed by the 11 required environmental engineering courses that are organic to our university's department Geography and Environmental Engineering (EV301, EV396, EV394, EV397, EV401, EV402, EV481, EV488, EV490, EV491, XS391; course numbers are defined in Table 2). This portion of the survey asked whether the events were broken into multiple parts, required progress reviews or back-briefs prior to final submission, the method used for instructor assessment, formatting requirements, the emphasis placed on reference quality, and a qualitative instructor assessment on a Likert scale of 1 to 5 (with 1 indicating the event needs to be completely rewritten, and 5 indicating that event needs no improvement). The survey is available by request from the authors. Next, a crosswalk of technical communication graded events was mapped out to determine how graded technical communication requirements are balanced from freshman to senior year, including term placement.

3. Results and Discussion

3.1 Placement within the Curriculum

A visualization of the of the technical communication crosswalk for West Point's environmental engineering program is seen in Figure 1. At the time of this study, there was a

total of 79 graded events with a technical communication component for environmental engineering majors at West Point. The quantity of technical communication graded events consistently increased in volume over the course of a student's four years (Figure 2). Of the 79 total events, 31 occurred in a student's senior year (9 lab reports, 10 written events, and 12 oral presentations). The remainder of technical communication events were divided between the first three years and gradually increase in each subsequent year (4 during the freshman year, 18 during the sophomore year, and 26 during the junior year). At West Point, students do not formally declare their major until the spring semester of their freshman year; therefore, the required environmental engineering curriculum courses were placed in the latter three years of study. Only four technical communication events located in General Chemistry 2 (CH102) were examined during the freshman year. CH102 is a required course for environmental engineering majors but can be taken prior to student major declaration. While other required core courses, such as English (EN101), History of the United States (HI105), Literature (EN102), and American Politics (SS202) have communication components, these courses focus on general communication competencies and did not meet baseline criteria for inclusion in this study.

Concerning technical communication offerings for environmental engineers, this study found that the majority of the technical communication events offered outside of our department were concentrated in the freshman and sophomore years (100% and 50% of technical communication events in those respective years). During the first two years of study, students take many foundational math and science prerequisites. Accordingly, the number of technical communication events completed outside of the department dropped substantially in the junior and senior years (35% and 0% respectively), as these years are filled with upper-level environmental engineering courses (Figure 3).

While the sequencing of courses over an environmental engineer's academic program is highly controlled and meticulously planned, the precise balance and succession of technical communication requirements between semesters and years was previously unexamined. For example, communication events in the sophomore year are primarily comprised of technical and full reports with only one lab report, while in the junior and senior years there are fewer technical and full reports but several more labs and oral presentations (Figure 2). Further, the total number of technical communication events is well balanced between semesters and is proportional to the total number of environmental engineering classes taken. For instance, there are 18 total events scheduled during the sophomore year split evenly between the first and second semesters. Likewise, there are 26 total events scheduled during the junior year - nine during the first semester and 17 during the second semester. Finally, the 31 technical communication events scheduled during the senior year are divided into 19 in the first term and 12 in the second (Figure 2).

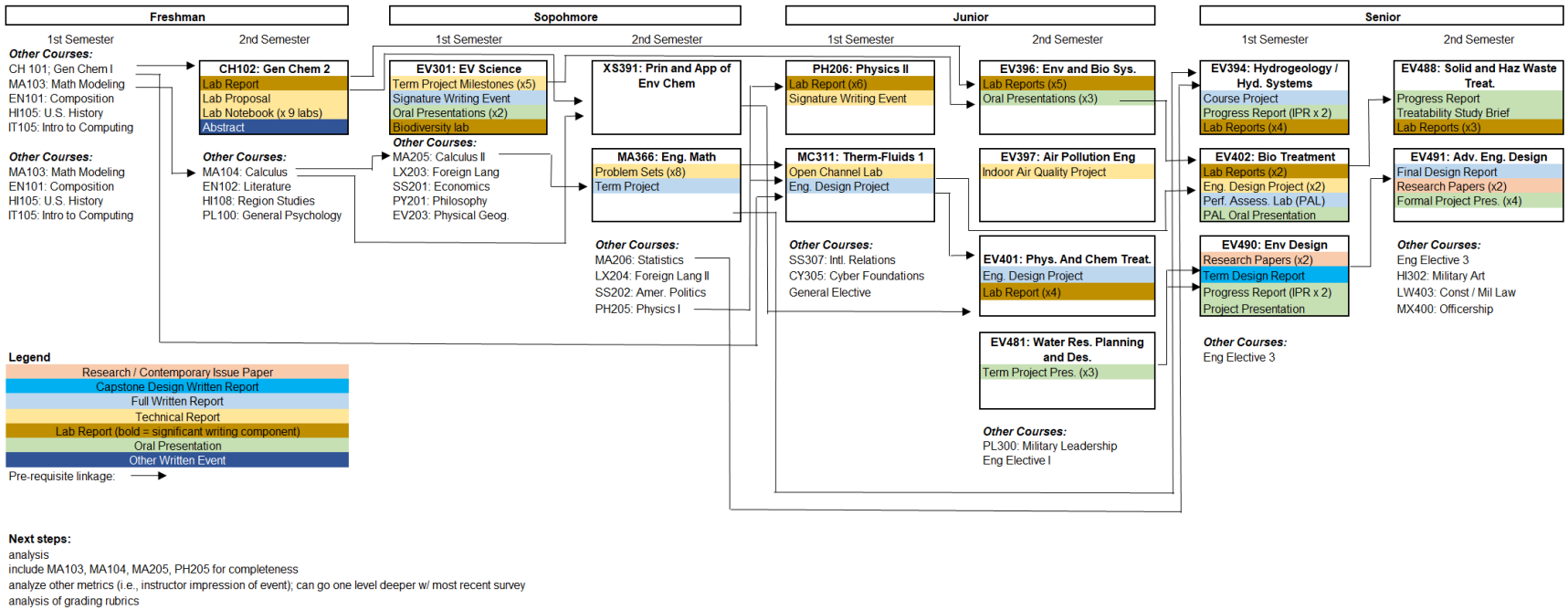

Figure 1. Crosswalk map depicting graded technical communication events for an environmental engineering major at our university. Freshman year is shown to the left and senior year to the right. The arrows indicate pre-requisite links between courses. The quantity and topic of each course's technical communication events are shown within each respective course listing. The colors indicate the type of communication event (*color coded key is provided in the bottom left*).

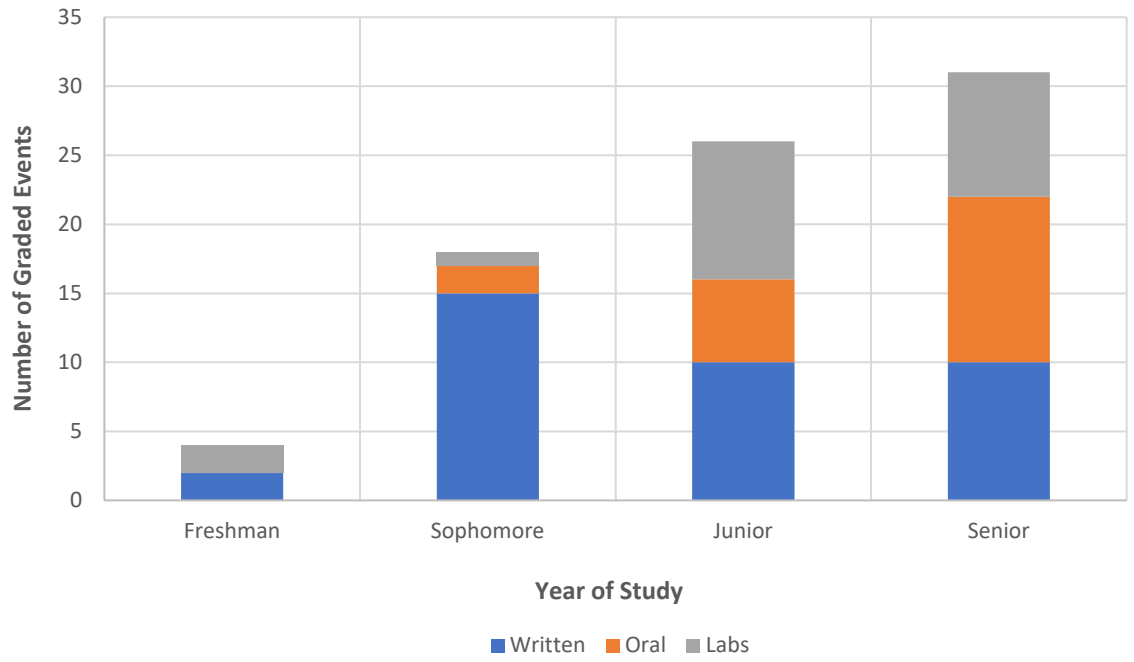

Figure 2. Graded technical communication events by type and by class year for students majoring in environmental engineering. Events were categorized as lab reports (gray), oral presentations (orange), or written events (blue).

Analysis of the placement of technical communication graded events suggests that few near-term changes are required. The number of graded events with technical communication components increases each year and become more concentrated in environmental engineering courses. The number of graded events also increases from freshman to senior year. The number of written events stays approximately the same from sophomore through senior year, while the number of written labs and oral communication events increases.

3.2 Weighting of Graded Technical Communication Events

The weight of graded technical communication events transitions as a student progresses through the program. Specifically, the majority of the technical communication events (15 of 18, or ~83%) in the sophomore year comprise less than 5% of the total course grade. Technical communication events receive a higher proportion of their course's weight in later years with only 12 of 26, or ~46% and 8 of 31, or ~25% of graded events encompassing less than 5% of the total course grade in the junior and senior years, respectively (Figure 4).

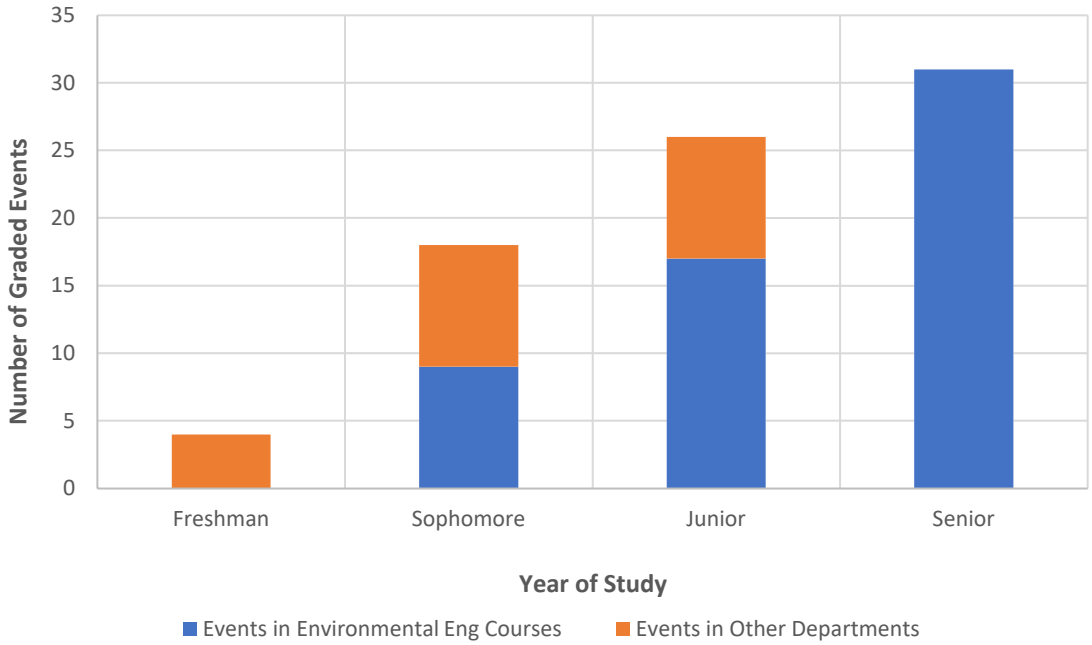

Figure 3. The total number of technical communication graded events from courses within the department compared with events offered from classes outside of the department. Of the 79 recorded events, 22 were from other departments, (*9 of which were from one course (MA366) applied engineering math, which is typically taken in the sophomore year*).

As students approach graduation and transition to the workplace, the events become more heavily weighted to emphasize the realistic conditions that they will experience as an environmental engineer in the public or private sector.

3.3 Group vs. Individual Technical Communication Events

Most (50 of 79 or ~63%) of the graded technical communication events within the environmental engineering curriculum are group, or team, events. Survey results show a change from individual events (100% and 78% of total events in the freshman and sophomore years) to group events (70% and 84% of total events in the junior and senior years) in the later academic years (Figure 5). Throughout the curriculum, term projects and labs are typically group events, while technical reports, full reports, and response essays are usually individual assignments. However, event types are not consistently binned as individual or group. Rather, the dominant trend is to assess technical communication at the individual level in lower-level courses and then within group contexts in higher-level courses. This sequencing of assessment provides an opportunity for students to enhance individual technical communication skills prior to entering group work scenarios. In the higher-level courses, students should have the skills needed to function in team environments, preparing them for the realistic demands of environmental engineers in the work force.

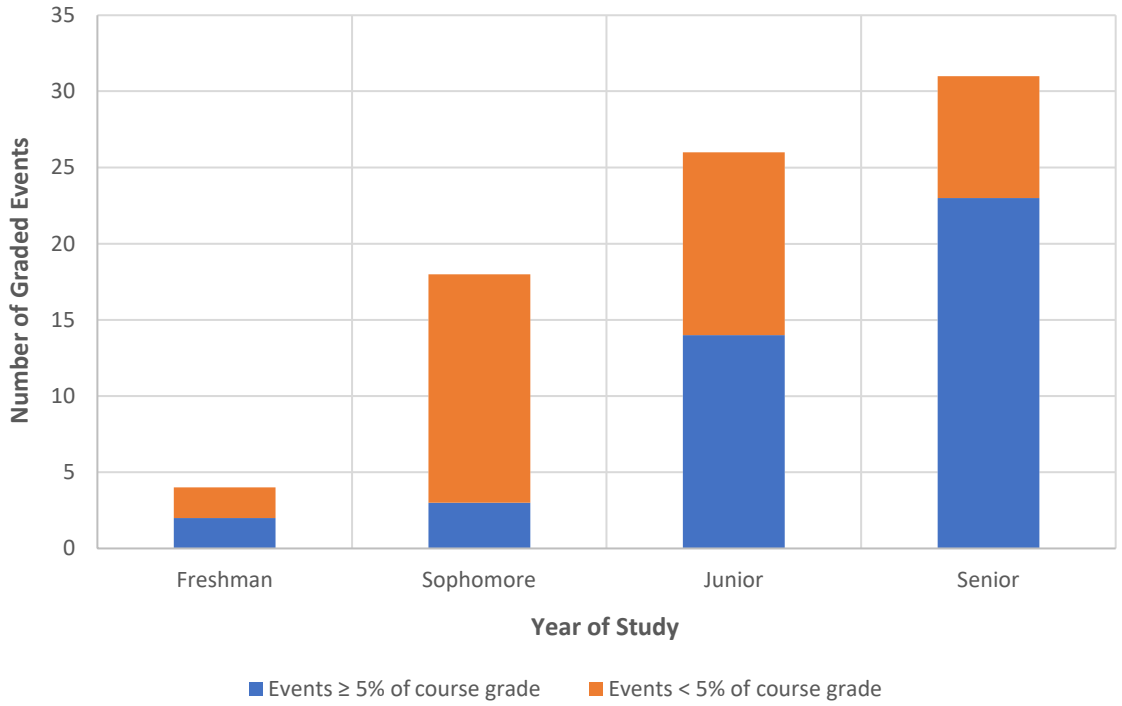

Figure 4. Technical communication events compared by their respective weight (%) of the total course grade. Graded events with a technical communication component are relatively low stakes (< 5%) in the sophomore year. Technical communication consistently becomes more weighted as students mature in the major and prepare for graduation and the real-world application of gained skills.

Frontloading individual events within courses taken early in the major can have disbenefits. First, the relatively higher number of individual assignments in earlier courses requires more instructor time for grading and adequate feedback. Early courses within STEM degrees can have higher enrollments, which may mean that more faculty are necessary to properly engage and assess individual student assignments. Second, teamwork generally allows for diversity of thought and experience in decision-making processes. Exposing students to diverse approaches to problem solving early in the major can allow for students to incorporate new ideas and norms early on.

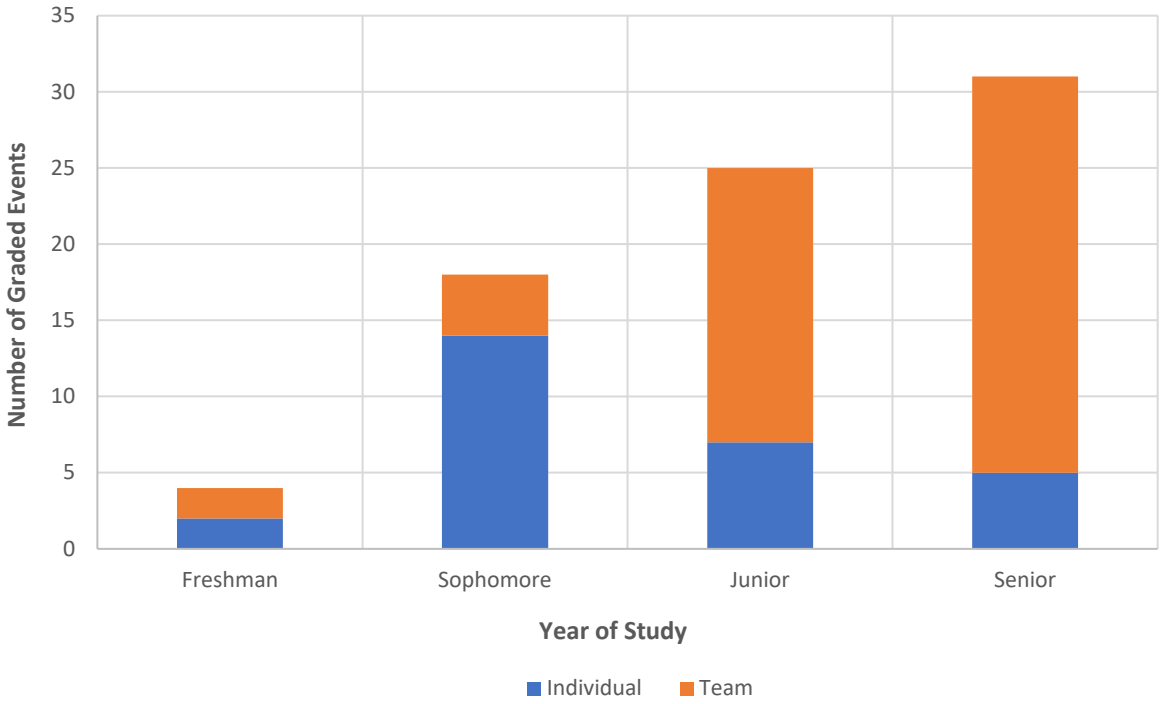

Figure 5. Technical communication events compared as individual work or group/teamwork. Students are assessed with mostly individual communication events in the sophomore year. This trend transitions to a majority of graded group work as students near graduation and a transition to the work force.

3.4 Assessment of Technical Communication Events

Technical communication events within our program were assessed in two ways for this study: (1) environmental engineering faculty were asked to provide their assessment of the quality of events within their respective courses using a Likert scale (1 to 5); and (2) data collected for ABET assessment purposes was examined.

The second part of the survey asked environmental engineering faculty to assess technical communication events within their respective courses using a Likert scale (1 to 5, with 1 indicating that the event needs to be completely rewritten, and 5 indicating that event needs no improvement). All written events and lab events received a score between 4 and 5, with written events receiving the highest average score (4.49) followed closely by lab reports (4.42). Oral events were rated the lowest with an average score of 4.36 (event scores ranging from 3 to 5). While faculty assessments of technical communication events suggest that most events within the curriculum needed little or no improvement, the study did identify opportunities for improvement with some oral presentations. For example, the lead instructor for EV490 (Environmental Engineering Design) and EV491 (Advanced Environmental Engineering Design), a two-course capstone sequence, rated the preliminary design brief (an event with an oral communication component) as a 3 out of 5. The rating was primarily due to the mediocre quality of briefings produced by the students. Since this study's survey was issued, the instructor

examined the placement of the preliminary design brief in the courses (at the end of the first course, EV490) and realized that groups needed more time to adequately produce conceptual design, and subsequently a preliminary design. Thus, the conceptual design brief was moved to the end of EV490, and the preliminary design brief moved into the second course, EV491; both communication requirements are now expected to be of more value. This anecdote demonstrates that proper timing and sequencing of communication events is critical if they are to have the greatest efficacy.

Data collected for assessment of our program's attainment of ABET Student Outcome 3, which requires graduates to have "an ability to communicate effectively with a range of audiences" was also examined. Specifically, our university's environmental engineering program uses direct indicators, which are student scores on selected graded events in environmental engineering courses, to assess student outcome attainment. Courses selected for student outcome assessment are those required for all environmental engineering majors. The indicators are more prevalent in higher-level courses. A weighted average of embedded indicators (indicators on graded events placed within courses) is computed based on points associated with each assignment. Then, direct indicator mean scores are converted to a 1-5 scale for evaluation of student outcomes. The following defines the direct indicator performance ratings (1-5) for our student outcomes:

- **Outstanding:** Rating of "5": meets or exceeds all established performance measures.
- **Very Good:** Rating of "4": meets or exceeds most established performance measures.
- **Good**: Rating of "3": meets or exceeds at least half of the established measures and any shortfalls are considered minor.
- **Fair**: Rating of "2": meets or exceeds less than half of the established measures or there is at least one serious shortfall.
- **Poor**: Rating of "1": fails most established measures or there are multiple serious shortfalls.

Table 3 shows the evaluation of graded events supporting ABET Student Outcome 3. Three courses support the assessment: EV301 (Environmental Science for Engineers and Scientists), EV396 (Environmental Biological Systems), and EV491 (Advanced Environmental Engineering Design). For assessment of Student Outcome 3, student scores on nine events with strong technical communication components were used to directly assess student ability. For academic year 2019-2020, our university's program scored a 4.25 on a 5.0 Likert Scale, which is congruous with results of the faculty survey, and indicates that our program meets or exceeds most established performance measures concerning ABET Student Outcome 3. As seen in Table 3, the nine events selected represent a diversity of environmental engineering topics. At present, 8 of the 9 events assessed are team events, which may impact results; however, further assessment and consideration of this point is required.

Table 3. Evaluation of graded events in support of ABET Student Outcome 3, "an ability to communicate effectively with a range of audiences".

Activity	Pts Total	Pts Earned	Average	5-Pt Scale Score
EV301 Environmental Science for Engineers and Scientists				
Term Project Milestone 1: Research Question, Null Hypothesis, Initial Statistical Test & Engineering Design	30	23.83	79.43%	
Term Project Milestone 2: Introduction, Refined Hypothesis, Methods, References	40	32.48	81.20%	
Term Project Milestone 4: Results (Figures & Tables), Refined Methods & Engineering Design	20	16.88	84.40%	
Signature Writing Event: Scholarly Journal Submission for General Audience	120	97.88	81.57%	
Total	210	171.07	81.46%	4.07
EV396 Environmental Biological Systems				
Deployment Brief - Medical Threat Analysis Brief to Army Commander	45	41.80	92.89%	
Lab 2 Presentation on Political, Environmental, Economic, Health of Genetic Engineering	5	4.67	93.40%	
Total	50	46.47	92.94%	4.65
EV491 Advanced Environmental Engineering Design				
Presentation - Final Detailed Design via Briefing on Projects Day	75	66.50	88.67%	
Final Report - Communication Quality of Final Detailed Design	50	40.00	80.00%	
Poster - Final Detailed Design via Poster Presented on Projects Day	100	88.67	88.67%	
Total	225	195	86.74%	4.34
Overall Assessment				
Total	485	413	85.09%	4.25

3.5. Opportunities for Continuous Improvement, Future Work, and Application at Other Universities

Results from this study suggest that technical communication events within our university's environmental engineering curriculum progress from individually assessed, low stakes written assignments to more heavily weighted group assignments that include written and oral technical communication components. Self-assessment spurred by this study led program faculty to conclude that only minor adjustments should be made to our program's curriculum regarding technical communication skill in the near-term. First, several graded events with oral communication components will benefit from continued assessment and improvement. The refinements to EV490/EV491 (discussed in Section 3.4) provide an example of the continuous

assessment and improvement process. Additionally, our program could benefit from comprehensive relook and revision of grading rubrics for technical communication related graded events in the near term.

Second, our university's environmental engineering program can explore the use of scaffolding technical communication events across courses. Scaffolding centers on intentionally connecting graded events (e.g., capstone projects or research papers) with technical communication components across courses, either within the same semester or longitudinally across semesters. Scaffolding events across semesters offers several advantages, to include the ability for students to benchmark against previous performance and continually add to a body of increasingly complex work while simultaneously enhancing technical communication skills (Bercich et al. 2018). Currently, all technical communication graded events in our program's curriculum occur discretely within one course except for our senior design capstone courses (EV490/EV491), which cover two semesters. However, there are other scaffolding opportunities within the program's curriculum. For example, our program's Environmental Biological Systems (EV396) course is a pre-requisite for the Biochemical Treatment Course (EV402). EV402 builds on many environmental biotechnology and microbiology concepts introduced in EV396. Currently EV396 has five written lab reports and three oral presentations, while EV402 has two lab reports, two engineering design projects, and a performance assessment lab (i.e., and open-ended design lab focused on biochemical treatment topics). To scaffold, our program could introduce an engineering design project in EV396 that serves as an introduction to EV402's engineering project, which currently centers on design of a wastewater treatment facility and dissolved oxygen sag curve modeling using the Streeter-Phelps model. Doing so could help students draw connections between the two courses while simultaneously building writing skill by asking students to modify and improve their design report from EV396.

Before a program decides to scaffold graded events, however, it should conduct an in-depth examination of the placement and quality of existing technical communication events within their overall curriculum to identify gaps and potential opportunities. While implementing a scaffolded event could be beneficial for students, there is a likely increase in faculty time requirements and coordination between instructors in different courses. The costs in terms of time and coordination must not outweigh the potential student learning benefit.

This study can be a useful tool and applied within environmental engineering programs at other universities. The approach used, to include the survey, the crosswalk of technical communication graded events, and the data assessment approaches can help programs identify shortcomings or opportunities for improvement. Opportunities for scaffolding, such as the one described in this study, could also be identified.

4. Conclusions

This study assessed the placement, sequencing, and critical features of the 79 technical communication events assessed within the fifteen required courses for environmental engineering majors (11 courses from our department, and 4 from other departments). A crosswalk map was constructed to highlight how graded events are leveled through a student's academic career (Figure 1). We found that the number of graded events with a technical communication component incrementally increase each year through a student's academic progression within the major. Further, the body of technical communication events within the major transition from individually assessed, relatively 'low stakes', primarily written events in the earlier academic courses, to team assessed, relatively 'high stakes,' oral and written capstone presentations in the later academic courses. This trend shows a methodical progression within the department, which is designed to develop foundational communication skills, and then put those skills into practice. A possible area for improvement within the curriculum is identifying course linkages and then intentionally scaffolding them through synchronized grading rubrics. This would serve to improve long-term retention by building upon specifically assessed technical communication skills. Continued improvement of grading rubrics and introduction of a technical communication course could also serve to enhance student technical communication skills.

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