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Design of an Aerospace Industry-Informed Technical Writing and Communication Course

Glen Roderic Coates, Pennsylvania State University

Glen R Coates received his B. S. degree in Environmental Engineering from Penn State University. He then went on to receive an M. S. degree in Mechanical Engineering at Penn State and a second M. S. degree in Management of Technology from Rensselaer Polytechnical Institute. Working in the Aerospace industry as a Senior Analytical Engineer for the past 45 years, he also has taught undergraduate mathematics and physics at several institutions as an adjunct professor. These experiences fueled his passion to bring real world engineering into the classroom. Mr. Coates is currently teaching at Penn State for the Aerospace Engineering Department.

Dr. Alyson G. Eggleston, Pennsylvania State University

Alyson Eggleston is an Associate Professor in the Penn State Hershey College of Medicine and Director of Evaluation for the Penn State Clinical and Translational Science Institute. Her research and teaching background focuses on program assessment, STEM technical communication, industry-informed curricula, and educational outcomes veteran and active duty students.

Dr. Robert J. Rabb P.E., Pennsylvania State University

Robert Rabb is the associate dean for education in the College of Engineering at Penn State. He previously served as a professor and the Mechanical Engineering Department Chair at The Citadel. He previously taught mechanical engineering at the United States Military Academy at West Point. He received his B.S. in Mechanical Engineering from the United Military Academy and his M.S. and PhD in Mechanical Engineering from the University of Texas at Austin. His research and teaching interests are in mechatronics, regenerative power, and multidisciplinary engineering.

Design of an Aerospace Industry-informed Technical Writing and Communication Course

Many engineering disciplines recognize the need for cross-functional skills such as technical writing and communication (TWC) in addition to the engineering-specific knowledge gained in an undergraduate education. Industry constituents expect engineering graduates to communicate technical content efficiently and effectively to disseminate technical information.

Specifically, the aviation industry requires a considerable amount of documentation to support the design, development, maintenance, and safety of operations; as such, skill in technical writing is required to accomplish these activities effectively. However, in traditional, humanities-based writing courses, (which are often the main source of writing preparation for engineering students) the focus of such writing courses is not on technical writing. Instead, students are taught rhetorical, argumentative, and analytical style writing, when technically-oriented writing is required.

While focus on rhetorical positioning can result in more careful student writers, this paper calls for a return to education that will encourage the ability to create work products that can effectively communicate technical information to both technical and non-technical readers. TWC includes published research, reports, as well as presentations; and all of these require structure, format, and organization that differ from the conventional writing style than is taught in the humanities.

This paper presents a Project-based Learning (PBL) approach to the design and implementation of a Technical Writing and Communication course that is embedded in an Aerospace Engineering curriculum. PBL focuses on writing assignments that are authentic, situational assignments in response to real project demands rather than responding to hypothetical situations. To generate enthusiasm for the course, the topics chosen for each of the writing assignments were selected to be of personal and/or professional value to the students.

Based on the results of student surveys, this paper documents the improved capability for students to present technical information and convey meaning more precisely by using a PBL approach. This improved capability is the result of students being exposed to situational, professional and STEM-specific writing tasks. Both quantitative and qualitative results from a case study are presented in this work. Finally, this paper makes recommendations for a technical writing course design and implementation.

Background: Cross-disciplinary engineering focus on communication

The engineering disciplines receive guidance in communication standards and curriculum development from regional accrediting bodies and ABET. ABET has revised directives for engineering communication in recent years to include an increasing focus on course assignments, projects, and extracurricular experiences that convey awareness of appropriate cultural factors (ABET criterion 2); audience awareness (ABET criterion 3); and collaborative teamwork and leadership (ABET criterion 5). Engineering programs are free to engage with and build capacity in ways that align with their own curricular strengths and limitations, and programs accomplish these goals in a variety of ways [1-4].

To address sensitivity of cultural factors and increase awareness, the assignments for (TWC) were evaluated by the instructor and were peer-reviewed as well. Peer reviews were structured as a double-blind evaluation – that is, the writer and reviewer were both kept as anonymous. In this way, any portions of the assignment that were unclear to the peer reviewer were open for comment.

Curricular change in engineering communication emerged on two fronts: top-down from ABET, and bottom-up from individual institutions seeking to better meet industry needs. In the first case, ABET's motivations for these program outcome revisions came in response to noted gaps in early career engineers' skillsets, documented for over two decades. At the same time, as advisory boards saw improved representation from local industry leaders, individual institutions aligned engineering program learning outcomes and curricula to address early career skill gaps in team-based projects, improve multicultural fluency, and produce technical writing that is appropriate for supervisors, clients, subject matter experts, and community members.

Historical changes to engineering communication

In the last twenty years, expectations for improved Engineering Communication (EC) have risen as a consequence of the need for increased technological literacy, as reported by the National Academy of Engineers and the National Research Council [5-6].

New pedagogical approaches to EC include an increasing focus on topic-specific procedural writing; engineering-specific templates and citations; and highly structured assignments with clear applications and a team-based component. Studies have shown that engineering students in particular respond best and perform better in technical writing tasks with clear deadlines, expectations, peer review phases, and rubric-based assessments [5].

EC pedagogy is also changing as a result of the overall importance of engineering technical work rises in industry. Calling it the Communication Coefficient (CC) method, researchers advocate that engineering students' experiences in the communication classroom can be improved if they are advised in three so-called philosophies [7]:

Philosophy 1: The way that we communicate affects how others perceive our work. They perceive our work as more valid and useful when we communicate it well and less so when we communicate it poorly.

Philosophy 2: Individuals judge communication quality based on a host of personal factors, including their experiences, preferences, technical background, linguistic background, and membership in professional groups.

Philosophy 3: Communication matters during all interpersonal interactions, to varying degrees.

Aviation industry changes in communication

The advent of new technology from military necessity has often been a catalyst for TWC. Prior to World War II, technical writing suffered from a lack of disciplinary identity or an administrative home inside academia. At that time, the status and credibility for TWC and those who taught it were often looked down upon by instructors of literature in English departments [8]. During and after World War II, there was a new interest in technical communication as a profession to explain weapons, space flight, and the accompanying advanced technology to the military workforce [9]. Eventually, many of the military technologies transitioned to peacetime uses, to include aviation.

Thanks to the Servicemen's Readjustment Act of 1944 (GI Bill), universities began to adapt to the new student populations in their classrooms and engineering programs, which improved accessibility to higher education. Due to the larger number of students in colleges and universities, TWC education saw increased development and a wide range of instructional options. Technical communication classes were growing in the post-war years, and were developed and taught initially by instructors with their own military and industry experience. As these instructors began to retire, the field of technical communication became more recognized by industry and new texts began to appeal to a wider range of disciplines. Professional societies for technical communications formed. Science, Technology, Engineering, and Math (STEM) professional organizations began to recognize the need for professional as well as technical skills [8].

At the same time, national accrediting bodies were moving toward a universal standard of excellence in TWC for engineering students. Achieving technical communication skills in rigorous engineering curricula can be challenging, but these are requirements sought by many beyond academia. ABET, the accreditation board for engineering programs in the US and abroad, identifies communication as a key student learning outcome: "(3) demonstrate an ability to communicate effectively with a range of audiences" [10]. Likewise, industry and academia have uniformly acknowledged the need for engineering graduates to improve their communication skills [11-12]. For example, the American Society for Civil Engineering (ASCE) states that "Civil society will become increasingly demanding in granting the "social license" required for our built projects. Stakeholder communication and collaboration will be as important as technical content" [11].

Further, the American Society of Mechanical Engineers (ASME) in their Vision 2030 study found from industry managers that "entry level mechanical engineers need strengthening in how devices are made and work and in communication," recommending curricular design that supports "effective communication, persuasiveness, diplomacy, and cultural awareness" [12]. The Aerospace industry also recognized as early as 1965, that "there is overriding importance placed on accuracy, and that effective communication that must take place between writer and reader. Equipment has grown so complex that it must be accompanied by instructions in its use" [13].

As recently as 2016, the American Institute of Aeronautics and Astronautics (AIAA) noted at their Workforce Summit the concern that "even the most highly educated STEM graduates were inadequately prepared in cross-functional skills such as writing, management, and interpersonal communication." One recommendation from the Summit was to recruit company employees for programs and mentorships that foster stronger connections between academic and business cultures and teach workplace and communication skills in addition to STEM [14].

The TWC course described here emerged in 2023 from collaborations between a retired aviation industry professional and the Department of Aerospace Engineering at Penn State University. Technical writing instruction has long been sustained by experienced industry professionals wherein lived, vocational knowledge is a unique form of expertise that becomes available to the students [15]. As field-specific requirements increase, more advanced students benefit from the unique insights of an industry insider-turned-instructor.

The Aerospace engineer teaching the TWC course began with a survey of current technical communications courses offered from another college, then developed a needs-based assessment for the course described here. The instructor sought to identify opportunities for the program, which apply real-life experience that would be of value to the students using a Project-Based Learning (PBL) approach. It should be noted that the course design also provided for potential scaling of the course for larger course sections and retooling stated learning outcomes.

PBL approaches across engineering

PBL is an instructional approach that platforms a student-centered classroom dynamic, and requires teamed students to propose solutions for open-ended, discipline-specific problems and processes. Students produce results that can be assessed with outcome-based standards. As a final project phase, students are invited to reflect on their problem-solving posture, identifying opportunities and gaps in their knowledge [16]. As supported by findings in cognitive science, true learning requires higher energy cost for the brain. Connecting old and new information supports deeper integration, learning, and memory retrieval, a consolidation process that is strengthened by self-reflection. Additionally, studies in STEM-PBL show that PBL works—initially low-performing and intermediate-performing students and minorities benefit most, though the drivers for these gains are still being investigated [16].

STEM pedagogy studies have long agreed that STEM students, particularly engineering majors, prefer active experiential approaches to learning and visual input [17]. The Kolb model of experiential learning focuses on process-based methods that connect old knowledge with new domains. Students begin learning through the uncomfortable process of linking lived experience with the immediate, lived environment. Felder's Index of Learning Styles [18-19] further validates this approach, noting that engineering students prefer and thrive in solutions-focused learning spaces that allow them to be active learners. This approach is contrasted with more conceptual and theoretical approaches, though Felder et al. concede that as students mature in their disciplines, they become gradually more comfortable with more passive, global approaches to learning and connecting new information [18-19].

Professionals in the technical writing and communication space have long called for authentic document and media to be used and produced in TWC classroom [20-21]. A PBL approach to TWC ensures that students learn by doing and creating those authentic documents [22-23]. Numerous benefits ensue for teaching engineering communication courses from a PBL perspective; foremost among these is the incentive for students given assignments that apply to real-world applications. Furthermore, the real-world applications being taught can be designed to have both personal and professional relevance for the students.

In addition, PBL assignments can be structured not only to enhance student communication skills, but also to increase the knowledge base by assigning topics that are fundamental to a particular course of study. To further enhance student communication performance and track progress, feedback from both peers and instructors has been provided as part of each assignment. This peer feedback benefits both the evaluator and the student being evaluated.

New TWC course design needs in Aerospace Engineering

The Aerospace industry encompasses many written forms of communication, and the information communicated can be critical to safety and design. The variety of information communicated is extensive, and the means used for writing also varies. Written communication in Aerospace can include: regulations, procedures, technical drawings, manuals, performance graphs and tables, and accident reports.

The technical writing course for STEM students also fulfills a general education requirement and is taught outside of the College of Engineering. With a high enrollment and high demand technical writing course for all STEM students at Penn State, engineering students were seldom learning technical writing relevant to their chosen major nor reinforcing authentic technical writing in any engineering discipline, according to student self-reporting. Numerous students were taking the specified technical writing class out of sequence, often during one of their last semesters. Many of the assignments in the general education TWC course are generic and focused on organization rather than content and accuracy. Many of the English Department instructors had very little background in technical communications and writing outside of a week-long preparation before the semester started. Several of the engineering departments needed a technical writing and communications course relevant and timely to their majors.

The Aerospace program at Penn State is a nationally ranked and well-respected program that has high interests among the students choosing the major. At an R1 institution, many of the faculty are focused on the research mission while acknowledging the need for better written communications in the discipline. Technical communication skills can play an important part in the career of an engineer, and developing these skills in engineering students can be difficult when engineering curricula tends to focus on technical content. Aerospace Engineering was fortunate to have a retired Aerospace industry professional in the area who observed the need within the Department of Aerospace Engineering and volunteered to develop and teach a new technical writing course to the Aerospace Engineering students. Beginning as a pilot in the Fall 2023 term, the course has seen very positive feedback and interest.

Aerospace Engineering lab-based TWC course

This course is a different type of technical writing course in which the instructor creates content through in-class demonstrations and experiments. Here, students receive feedback both on the precision and clarity of their writing. In addition, students also receive feedback on highlighting the most important details.

While many proponents of PBL in engineering scaffold major projects as preparation for a final major capstone effort, the course design featured here adopts a more modular approach. Each Engineering Communication (EC) skill is introduced and reinforced through mini-projects, allowing adequate opportunities for students to reflect on their strategy and ultimate performance and benefit from instructor and peer-based evaluation and feedback. Table 1 provides an overview of the assignment topics, their focus, and the engineering communication skills involved.

The projects for the course were structured into 12 project-based writing assignments; five of which involved classroom demonstrations. Project assignments were selected by the instructor and approved by the Aerospace Department. For each project, students were tasked with explaining the mathematics, physics and the relevance involved in these topics. Each of the projects were chosen to be practical topics that are of value and of interest to Aerospace Engineering students. Finally, each successive writing assignment required an increase in writing skills and complexity. The writing assignments were as follows:

Table 1. Assignment, Topic Focus, and EC Application

Assignment	Topic	EC Skill [20]
Assignment 1	Safe Driving – Assessment of Reaction Time & Braking Distance to Improve Driver Safety.	Executive Summaries; Organizing Ideas and Explaining Data; Making Recommendations
Assignment 2	Wiser Use of Money – Personal Finance, Regarding Investment and Debt; Planning for a Comfortable Financial Future.	Technical brief; Explaining Data; Making Recommendations and Persuasive writing
Assignment 3	Casinos, Warranties, and Insurance – Probability, Statistics and Expected Value as Applied to Business Models Based on Events that are Probabilistic in Nature	Quantitative Analysis; Explaining Data; Audience Selection; Persuasive Writing to a Non-Technical Audience

Assignment 4	Understanding Aircraft Trailing Edge Vortices – Causes and Effects	Quantitative Analysis; Technical Reporting and Explaining Observations & Application
Assignment 5	Column Buckling – Enhanced Structural Capability by Using Impulse Force Loading	Quantitative Analysis; Explaining Data and Observations & Application
Assignment 6	Understanding Ground Effect for Fixed Wing Aircraft and its Impact on Flight Performance	Analysis of Aerodynamic theory; Explaining Observations & Application
Assignment 7	Understanding Ground Effect for the Application to Formula 1 Racecars and its Impact on Vehicle Performance.	Analysis of Aerodynamic theory; Explaining Data & Application
Assignment 8	Energy Transducer – Problem Solving through Energy Conversion	Technical Reporting; Collaborative Problem Solving; Writing to a Non-Technical Audience.
Assignment 9	Understanding the Physics, Fluid Mechanics and Thermodynamics of Hurricanes	Analysis of Aerodynamic and Thermodynamic Theory; Explaining Data
Assignment 10	Understanding the Acoustics of Helmholtz Resonators and their Use for Aircraft Noise Reduction.	Analysis of Acoustic Theory; Explaining Data & Application
Assignment 11	Understanding how Air Jet Impingement Can Perform to Generate a Local Vacuum.	Analysis of Aerodynamic Theory; Explaining Data and Observations
Assignment 12	Career Planning – Personality Testing & Feedback from University-Based Career Services to guide career-related decisions.	Pre-Professional Training; Professional Documents & Planning for a More Rewarding Career.

This approach relies on three pillars: (a) problem-solution pairings; (b) practicing creativity and solution-finding; (c) documenting and reflecting on the process. Because the course is divided into mini-projects, this ambitious skill acquisition and practice is feasible through repeated time-on-task iterations. Students become accustomed to the problem-solution orientation of the class and come prepared to practice problem-solving together. Writing with precision is an important aspect that distinguishes engineering writing from general writing.

Course Approach

In the first part of assignment 1 (Safe Driving), students work in pairs to perform an exercise that measures their reaction time. The second portion of this assignment determines the stopping distance of a typical vehicle given its initial velocity. With data from reaction time and vehicle stopping distance, the students then calculate the total stopping distance of their vehicle. Finally, given the maximum viewing distance of typical vehicle headlights, the students must calculate whether they can stop their vehicle from hitting an object that suddenly appears in view of their headlights.

In the second exercise, (Wiser Use of Money) students are given the exponential equation of compound interest that applies equally to accumulation of investments (and similarly, the accumulation of debt). After assuming typical growth rates of salary and of long-term investments, the students then perform an exercise to calculate their accumulated savings over a career and compare that with their projected salary increases. They must then decide what percentage of their salary that should be invested such that the growth of their accumulated assets outpaces their salary growth near the end of their career. Comfortable retirement for the engineer is possible if the investment plan is carefully implemented.

An additional implementation of Wiser Use of Money exercise has the students calculate the rapid growth of short-term debt if they carry an increasing balance on their credit cards. It becomes very apparent to the students that the consequences of carrying significant balances on their credit cards will severely impact their financial health and credit rating.

In the third exercise, (Casinos, Warranties, and Insurance), students conduct an experiment that generates a random outcome to demonstrate the typical profile for a probabilistic event. From this demonstration, it becomes very apparent to the students that there is a central tendency for binary events (those with success or failure outcomes). The central tendency of these probabilistic events then determines the basis for business models in such fields as insurance, warranties and gambling. Finally, given the central tendency of outcomes in probabilistic events, the students can then calculate the expected value (how much money will be won or lost) for decisions that are made in these various business models. The Mathematics invoked in this exercise exposes the utter foolishness of trying to “win big” by involvement in gambling.

In the fourth exercise, students must explain the formation and performance impact of wingtip vortices on aircraft performance. As part of understanding the physics of the vortex, the students must explain the mechanism and the physics involved in the formation of condensation trails that are sometimes seen at the core of wingtip vortices.

In the fifth exercise (Column Buckling), students are presented with a seemingly impossible challenge regarding structural performance; they must then determine how to improve the penetration of a shaft into a solid object. Once the demonstration is completed, the students must consult the literature to explain the physics involved in their successful demonstration.

In the eighth exercise (Energy Transducer), students are again presented with a seemingly impossible task involving concepts in statics and dynamics. With some prompting, the students discover that the solution to the task is to create an energy transducer. And then, to the surprise of all, the use of an energy transducer is demonstrated in class as a solution to the problem; it is “out-of-the-box” thinking on full display.

In assignments six, seven, and nine through eleven, students are tasked with consulting literature to explain the physics of various topics that are of interest to Aerospace Engineering students. These are all topics that must be well understood by a successful Aerospace Engineer.
In the final exercise of the course, students are instructed to take a personality test (Myers-Briggs Type Indicator, MBTI) to determine their behavioral tendencies or preferences. Given the results from the MBTI test, the students then meet with the staff at the University's Career Center to help guide some aspects in their choice of a career path; with some coaching, their career path is intended to build on their identified strengths and preferences. This final exercise allows the opportunity for the students to reflect on their writing assignments over the course of the semester and to acknowledge the development of their technical writing skills as they gain proficiency in their ability to adapt their work to a range of readers.

Discussion

Part of the feedback received from this new Aero TWC course was the fact that throughout the course, student attendance was excellent. During the class, students consistently maintained eye contact with the instructor because they were engaged in the presentation of the material. Students very much liked the course content and the way in which it was presented, but probably very few students could put into words why they liked the pedagogy used in Aero TWC. The answer as to why the course content was well received is that the teaching of the course was done in such a manner that every class had features of the presentation style that appealed to their various learning styles.

Also, during the academic year 2022-2023, the Aero TWC instructor was a Teaching Assistant (TA) for an Aerospace laboratory course (which had the English Department's TWC version as a prerequisite). Periodically through the Aerospace lab, the instructor asked the lab students for their input and their reaction to the English TWC and make comments about their experience; some common themes emerged.

Comprehensive feedback from discussions with Aerospace lab students on their experiences with a traditional English-Department focused, non-experiential TWC course included criticisms of both the assignments and the course structure, ultimately questioning its utility. Many comments were as follows:

- Peer evaluations were not done consistently
- Writing topics were not of any interest to me
- Writing resumes and cover letters was a part of [English Department TWC] and it was wasted time – that kind of material is readily available online and at the Career Center on campus.
- Mostly we just did in-class busy work: from start-to-finish for the course
- I had an 8:00 AM [English Department TWC] class (with only 10-15 mins of lecture). The class time was wasted…
- Many of my classes were cancelled. Class time was generally useless

- As an engineer, I felt like a "fish out of water" in the English Department [TWC] class.

In contrast, when students of the Aero TWC were asked in a formal, after-completion-of-the-course evaluation, "to what degree did the overall structure of the course (content, materials, assessments) promote a meaningful learning experience; the average was 4.56 on the on a 5-point Likert scale. This evaluation result showed a very positive reception of the course". The scale used for the evaluation was based on: 1=Strongly Disagree to 5 = Strongly Agree. The rating or 4.56 of 5.00 is significant, and it clearly shows that the students felt the course was valuable. Further, the numerical results were reinforced by student's free text comments in reference to their course rating:

- "The teacher made the class more alive and made use of the time to teach us concepts of technical writing [sic] that will be used in aerospace engineering writing.
- "Instead of just assigning reports or memos, he creates a narrative and background to each one, making them seem less like assignments and more like something requested in the workplace."
- "the instructor's lectures and demonstrations keep my attention well. Each topic has real world applications for general use and this specific career. instructor is always energetic."
- "Writing multiple memos helped me master this technical format. Also, the class assisted in organizing thoughts before beginning to write."

A career as an Aerospace engineer requires people who can express the value and meaning of their work and communicate their information effectively. Unfortunately, many engineering students tend to undervalue their need to be able to write in a clear, concise, effective manner for a variety of audiences of both non-technical and engineering experts. As discussed in earlier sections, the Aerospace future will rely on Aerospace engineers who have stronger technical communication skills.

Conclusions and Future Work

Adequate communication skills are necessary to serve as an engineer. Enhanced communication skills reinforced with discipline specific work add value to industry and will make a difference to engineers' careers and with whom they interact. Industry requirements are further formalized through ABET [10] student outcomes, particularly (3): "an ability to communicate effectively with a range of audiences." Connecting academic program outcomes with industry requirements is essential to many stakeholders. Academic institutions should view technical communications as an investment in their students and industry constituents.

Finally, looking further into the future with Aero TWC, there may come a time when this course will be offered to engineers of all stripes. Anticipating that change in the student demographic, new demonstrations and new writing assignments will be offered which will appeal to the various engineering specialties of students enrolled in the course. While it is true that many of the current assignments were intended to appeal to a general technical audience (Safe Driving, Wiser use of Money, Probability and Expected Value in insurance, warranties, and gambling), other topics will be crafted to appeal to a wider spectrum of engineers. Many of the topics have relevance to multiple engineering disciplines, and continuous exploration of these by discipline experts can help in replicating this type of course to other academic programs. A longitudinal assessment involving several stakeholders is planned to include:

- 1-year course run, feedback received,
- "Best part", "more relevance" – ask students these types of questions
- Assessment for effectiveness (industry, academic – compared with results from English TWC)

With course structures similar to Aero TWC, discipline-specific examples and instructional strategies can be applied in the classroom to enhance critical skills desired by industry. In addition, highlighting the relevant content for the students reinforces the importance of technical writing principles and the value of professional communication.

Use of real-world demonstrations drives student engagement. While incorporating more material into an Aerospace engineering curriculum is challenging, in the end, program directors will soon realize the benefits for the students, all the while aligning the requirements of the educational institution with the goals of their particular discipline.

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