Modalities and Learners: An NLP Analysis of Technical and Scientific Communication Instruction Across U.S. Engineering Curricula

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Engineering programs must balance curricular compression with rising demands for students to demonstrate professional communication competence, and ABET-supported learning outcome. This study examines how and for whom Technical and Scientific Communication (TSC) is taught across top U.S. engineering programs. Building on prior published typologies that include external, internal, and hybrid TSC instruction models, we extend the analysis to account for distinct learner trajectories within engineering: (1) entrepreneurial and innovation-oriented students, (2) management and leadership-track engineering students, and (3) broad STEM generalists. Prior research shows that engineering students value technical writing instruction that is tied to real-world problem solving and professional engineering conventions, with students appreciating instruction that distinguished technical writing from early-college composition courses. Using natural language processing (NLP) in Python, we analyzed course syllabi from various engineering programs to identify latent themes that signal experiential learning in TSC courses across five thematic domains: project-based learning; teamwork and collaboration; innovation and corporate focus; embedded communication; and stakeholder and community interface. Findings show that while hybrid and embedded modalities correlate with richer, project-based writing practice, most curricula do not differentiate instruction by student career orientation and interest. Entrepreneurial students encounter few authentic communicative contexts; management-oriented students seldom receive explicit rhetorical training; and generalists often experience communication as decontextualized writing with little conventional difference from traditional narrative composition. To address these gaps, we propose a best-practices cross-matrix linking student trajectories and interests, instructional modalities, and genre-based communication outcomes, with advantages and disadvantages for each. This framework enables programs to design adaptive, audience-specific TSC instruction that aligns communication-anchored learning opportunities with professional identity formation across engineering pathways.

Keywords: Technical and Scientific Communication (TSC); Engineering Education Curriculum Design; Natural Language Processing (NLP) in Education Research; Experiential and Project-based Learning; Professional Identity Formation.

Introduction

Employers expect engineers to be technically proficient and able to communicate their expertise to technical and non-technical audiences. Many careers in engineering involve team-based work (often with other disciplines), communication among other employees and customers, and to individuals and groups in higher positions. The Engineering Body of Knowledge (EBOK) by the National Society of Professional Engineers (NSPE) outlines several guiding principles to include "The increasing need to incorporate societal impact considerations in engineering decision-making will require better communication, management, leadership, and other professional practice skills on the part of engineers. Collaboration with non-engineers will be critical" [1]. Other discipline specific professional organizations have emphasized verbal and written communication skills for immediate and long-term career advancement [2], [3].

In spite of all the cited external drivers for proficiency in Technical and Scientific Communication (TSC), engineering students see writing as one of their least favorite academic tasks, often favoring hands-on activities than words to demonstrate proficiency. Students in the field of engineering are sometimes described as "people of action rather than of words" [4]. Also, TSC style and purpose differs from previous earlier academic writing instruction. Moreover, developing writing skills among engineering students is not one of the easiest tasks in the engineering curriculum. Many engineering faculty may not be trained to formally teach a TSC course, so they may reinforce TSC in a technical course as part of a writing intensive or writing in the curriculum program. A stand-alone TSC course may often be taught from non-engineering faculty (often from English departments) with a focus on clarity of communication to a non-technical audience. One study found that the typical technical writing course serves students from different STEM disciplines and interests and aims to prepare them for workplace communication [5].

Table 1 provides a conceptual overview of how TSC instruction is typically delivered across different engineering student trajectories. Drawing on prior typologies of TSC modalities and programmatic practices, the table links student goals, instructional formats, and common syllabus-level signal cues. This framing motivates the present analysis by making explicit the gap between differentiated student needs and largely generalized curricular signaling. Table 1 also highlights the motivations for differentiated learning trajectories, which in turn merits their inclusion in communication coursework designed to prepare a modern engineering workforce.

Our differentiated conceptual framing of TSC Instruction centers students interests and intended career trajectories rather than historical institutional and programmatic precedents, which have driven much of TSC implementation and scaling. Engineering curricula are typically structured around accreditation standards, institutional priorities, and generalized workforce competencies [6], [7] with less overt attention directed toward student professional aspirations. As a result, engineering communication instruction may be robust and broadly consistent across institutions while remaining maladaptive to distinct learner goals. This work, as framed in Table 1, attempts to identify distinct learner trajectories and map whether corresponding curricular language signals are present in TSC syllabi. By analyzing how and for whom communication instruction is described, curriculum stakeholders can assess whether formal curricular artifacts reflect trajectory-sensitive design or default to generalized models of communication competency.

Table 1: Modality, delivery, and comparison of TSC instruction

Student Type / Goal	**Educational Experience Sought**	**Typical TSC Modality Found**	**Advantages / Disadvantages**	**Illustrative Syllabus Signal Cues**
Entrepreneurial / Innovation-oriented	Applied, market-driven learning; emphasis on prototyping, pitching, and impact framing	*Hybrid or externalized.* Supported through entrepreneurship centers, partnerships, or	**Advantage:** authentic audience and applied contexts **Disadvantage:** limited engineering faculty	"pitch," "prototype report," "market analysis," "innovation challenge," "stakeholder communication"

		communication electives	integration, writing often peripheral.	
Engineering Management / Leadership-track	Integrative business + technical coursework; systems communication; business intelligence (BI) reporting (Power BI visualizations, or Tableau)	*Internal or hybrid.* Embedded documentation and team communication in project courses	**Advantage:** aligns with ABET teamwork outcomes **Disadvantage:** lacks rhetorical depth or explicit writing pedagogical practice	"team report," "project management plan," "client deliverable," "risk summary," "executive brief," KPI
STEM Generalist / Technical Specialist	Strong disciplinary identity; limited interest in business contexts	*Internal.* Discipline-specific lab or design reports	**Advantage:** strong technical rigor **Disadvantage:** genre / discipline or instructor confinement, limited transfer to interdisciplinary settings	"lab report," "technical memo," "simulation documentation," "data interpretation"
Applied Research / Graduate-bound	Emphasis on scholarly communication and technical documentation	*External.* Writing instruction via English or research writing courses	**Advantage:** explicit genre focus and research writing training **Disadvantage:** minimal integration with known engineering content	"research proposal," "literature review," "methods section," "poster abstract"

Research Questions

As part of an exploratory investigation of best practices for Technical and Scientific Communication, the aim of the collaborative work is to identify knowledge and skill gaps at the collaborators' institutions and promote continuous improvement of the engineering programs. Part of the investigative work was to benchmark other institutions TSC programs. Several questions the researchers wanted to answer include:

1. What instructional strategies are engineering programs using or requiring for technical and scientific communications?
2. Are there differences in TSC emphasis at peer institutions?
3. What are some promising practices for TSC instruction?

While TSC has historically been analyzed through multiple lenses that include fidelity to Composition and Rhetoric as self-authorizing disciplinary arbiters of technical communication; comparative technical rigor; workforce readiness; or research writing preparation, the present study focuses on differentiated learner trajectories, particularly entrepreneurial and leadership-oriented pathways, as a means of evaluating whether communication instruction aligns with emerging professional identity formations.

Methods

Data Collection and Corpus Construction

To examine how TSC instruction is positioned within U.S. engineering curricula, we compiled a corpus of publicly available syllabi, course descriptions, and program-level communication requirement documents from U.S. News and World Report's 2025 top-ranked undergraduate engineering institutions, with more to be included as part of an ongoing study. Initially, this sample included: Massachusetts Institute of Technology, Stanford University, Georgia Institute of Technology, University of California at Berkeley, California Institute of Technology, University of Illinois at Urbana Champagne, University of Michigan at Ann Arbor, Carnegie Mellon University, Purdue University, Cornell University and University of Texas at Austin, however, University of Illinois' technical writing requirement is met by general education coursework in Composition I and was excluded for the purposes of this study, as no publicly available information could be found for the course. University institutions were selected based on national rankings to capture exemplary engineering programs with established communication requirements. Source documents included standalone communication courses, embedded communication offerings linked to design or capstone experiences, and institution-wide engineering communication requirement descriptions.

Documents were aggregated into a single corpus and manually segmented by institution using a standardized delimiter ("Institution:"), enabling institution-level analysis while preserving within-institution variation in document length and format. The resulting corpus reflects formal curricular signaling about communication instruction rather than classroom enactment or student experience.

Analytic Approach: Dictionary-Based NLP

We employed a dictionary-based natural language processing (NLP) approach (please see Appendix) implemented in Python to identify and quantify thematic signals related to communication pedagogy and learner orientation. A dictionary-based NLP approach was selected as a deductive, theory-driven analytic strategy to enable structured comparison across institutions. While human coding can provide important context, it can also introduce coder-dependent variability and bias without reliability training, and human coding may also limit scalability when applied across a multi-institutional corpus. Unsupervised topic modeling is useful for an exploratory discovery of latent themes; however, it can also generate semantically diffuse clusters of ‘concepts’ that do not map to theoretically-defined constructs in TSC pedagogy. In contrast, a dictionary-based method allows predefined domains derived from engineering education and communication theory to be operationalized explicitly, thereby enhancing interpretability, reproducibility, and cross-institution comparability. As a limitation, this approach may underrepresent instructional practices that are implicit or described using institution-specific terminology. Findings should therefore be interpreted as indicators of formal curricular signaling rather than comprehensive representations of enacted pedagogy.

A custom thematic dictionary was developed *a priori*, organized into five domains:

(1) Project-Based Learning / Experiential Cues [8], [9]
(2) Teamwork / Collaborative Practice [10] – [12]
(3) Entrepreneurial / Corporate Partnership / Innovation Focus [13] – [15]
(4) Embedded Communication [16]
(5) Stakeholder and Community Interface [17]

Within each theme, terms were further classified into single-word lexical cues (W) and multi-word phrases (P) to capture both general activity descriptors and more specific instructional practices. Dictionary terms were derived from prior typologies of TSC instruction, engineering education literature on experiential learning and professional identity formation, and iterative review of sample syllabi to ensure face validity.

Text Processing and Matching

All documents were preprocessed through standard text normalization procedures, including lowercasing, normalization of punctuation and hyphenation, and whitespace consolidation. Phrase matching was implemented using rule-based pattern matching to identify exact and near-exact occurrences of dictionary terms and phrases. The analysis allowed for multi-label assignment, such that a single lexical instance could contribute to multiple thematic domains where conceptually appropriate.

Quantification and Normalization

Theme frequencies were computed at the institution level and normalized per 1,000 tokens to account for variation in document length across institutions. For the purposes of frequency normalization, a token is defined as a single word-level textual unit generated after preprocessing (which includes making all words lowercased). Tokenization in this approach was performed using delimiter-based segmentation (i.e., white space), essentially tokenizing each discrete word. Although full corpus-level lemmatization was not performed algorithmically, the dictionary was constructed to account for known morphological variation within thematic domains. This is an operational definition of tokenization that reflects conventional corpus-linguistic practice and is used as a normalization denominator (per 1,000 tokens) to account for variation in syllabi length across institutions. This normalization enables comparison of relative thematic emphases rather than absolute term counts. Results are interpreted as indicators of relative prominence and distribution of instructional themes within formal curricular artifacts.

Scope and Limitations

This method captures how institutions describe communication instruction in official curricular materials, not how instruction is enacted in classrooms or experienced by students. Dictionary-based NLP prioritizes transparency but may undercount instructional practices that are unstated but expected, or practices that are referenced using institution-specific language. Accordingly, findings are interpreted as patterns of institutional emphasis and omission rather than comprehensive inventories of classroom activities. The authors attempted to ensure validity and reliability of the findings by following human-in-the-loop best practices for NLP, including: (1) one cycle of dictionary refinement to consolidate unique concepts and approximate semi-exhaustive thematic coverage; (2) manual review of sample matched excerpts; (3) targeted false positive checking. This validation cycle still permits the occurrence of false classification errors; however, the aggregate thematic patterns remain stable and interpretable at the institutional level.

Results

Broad Trends

The interest in TSC is high among employers and echoed by Industry and Professional Advisory Boards. However, universities respond to this demand in different ways. Some have expanded course offerings to require TSC or variants in their curricular plans; some have chosen to teach it within a laboratory or design course; and some have chosen to provide writing resources and centers to assist students as needed. Across institutions, communication requirements appear structurally robust yet largely undifferentiated by learner trajectory. While programs vary in delivery modality, few demonstrate explicit curricular signaling that aligns communication instruction with distinct student professional orientations. This short study found that most universities treat TSC differently, but all seem to have the following characteristics:

- Serve as a complement to either an engineering degree by providing a stand-alone TSC course to, often taught by non-engineering faculty, with an emphasis on non-technical audiences, and clarity. These stand-alone courses allow more formal instruction and depth in TSC.
- Provide an array of in-curriculum opportunities to instruct and reinforce TSC. These may be lab or design courses and often emphasize technical content and organization using a variety of student assignments.
- Pair a stand-alone TSC course with an engineering course to take advantage of the depth of instruction and the precision required in an engineering discipline.

A scan of syllabi for a typical TSC course shows course learning outcomes similar to the following:

1. Clearly convey specialized information from a technical field to a non-specialized audience.
2. Identify and use appropriate formats and conventions derived from individual disciplines.
3. Develop strategies for information design, to include producing visually enhanced documents.
4. Summarize larger texts in clear, direct style for practical applications.
5. Design and produce a research project appropriate to the student's major and/or career interests.
6. Edit documents according to professional guidelines.

Corpus Characteristics and Analytic Scope

The analyzed corpus comprised compiled syllabi and program-level communication artifacts from ten top-ranked U.S. engineering institutions, segmented by institution and analyzed using a dictionary-based NLP approach. The analysis focused on the frequency and distribution of pre-specified thematic cues signaling experiential learning, collaboration, innovation orientation, embedded communication practices, and stakeholder or community engagement. All frequencies were normalized per 1,000 tokens to account for variation in document length, as shown in Table 2.

Table 2. Theme frequency by selected institution (per 1,000 tokens)

Institution	Project-Based	Teamwork	Entrepreneurial	Embedded Comm	Stakeholder / Community
MIT	6.10	0.00	0.00	12.20	1.22
Stanford	5.65	3.77	0.00	5.65	0.00
Georgia Tech	2.61	2.61	2.61	26.11	5.22
UC Berkeley	23.57	3.37	0.00	3.64	3.37
California Tech	11.93	4.77	0.00	2.39	2.39
U Michigan	10.20	0.00	0.00	51.02	0.00
Carnegie Mellon	1.29	1.29	0.00	15.15	0.00
Purdue	10.00	0.00	6.66	10.00	3.33
Cornell	1.29	1.29	0.00	0.00	1.94
UT Austin	3.76	3.76	0.00	0.00	3.76

Project-Based Learning

Project-based and experiential cues were prevalent across most institutions, with several exhibiting strong normalized signal density. UC Berkeley, University of Michigan, Purdue, Stanford, and MIT showed particularly high rates of project-oriented language, largely associated with capstone courses, design reports, and semester-long projects. These signals were dominated by procedural and activity-oriented terms (e.g., project, design, report, develop), indicating that experiential learning is a common structural feature of engineering communication instruction.

However, the analysis revealed little differentiation in project framing by student career trajectory. Project-based language was rarely paired with terms indicating authentic external contexts such as industry sponsorship, community engagement, or market-facing deliverables. Instead, “project” functioned primarily as an academic container rather than a proxy for professional communicative environments. Institutions with extensive communication requirements, such as Cornell University and University of Texas - Austin, exhibited comparatively weak project-based signaling, suggesting that formal communication instruction does not necessarily coincide with experiential framing—at least in discrete courses.

Teamwork

Collaborative practice cues appeared across nearly all institutions, though with substantial variation in intensity. Cal Tech, UC Berkeley, UT Austin, Georgia Tech, and Stanford demonstrated a strong teamwork signal, driven by explicit references to team-based assignments, peer feedback, and collaborative deliverables. Other institutions referenced teamwork more sporadically, often implicitly through course descriptions rather than as an explicit instructional focus.

Importantly, teamwork language was primarily operational rather than rhetorical. While students are frequently positioned as working in groups or teams, few curricula explicitly addressed leadership communication, persuasion, or managerial discourse as distinct communicative competencies. As a result, management- or leadership-oriented engineering students are exposed to collaborative structures without receiving commensurate instruction in the rhetorical practices that distinguish effective technical leadership from participation alone.

Entrepreneurial and Innovation-Oriented Communication Is Largely Absent

Across the corpus, entrepreneurial, corporate partnership, and innovation-focused communication cues were notably sparse. Purdue demonstrated some signaling in this domain as well as Georgia Tech, and several showed effectively no measurable presence using the defined dictionary. Where innovation-related terms did appear, they were rarely embedded within communicative instruction and were more often presented as abstract outcomes or institutional values. This pattern suggests a structural gap for students pursuing entrepreneurial or innovation-oriented trajectories. Although many engineering programs emphasize innovation rhetorically, few provide explicit communicative contexts involving customers, sponsors, markets, or technology commercialization. As a result, entrepreneurial students encounter limited opportunities to practice audience-specific, market-facing, or value-proposition-driven communication within formal curricula.

Embedded Communication Is Common but Assessment-Driven

Embedded communication cues, such as reports, presentations, proposals, and revision, were among the most frequent signals across the dataset. University of Michigan and Georgia Tech emerged as clear outliers, with extremely high embedded communication density, while MIT, Carnegie Mellon, and Purdue also demonstrated strong signals. In contrast, Cornell and UT Austin showed minimal embedded communication signaling despite extensive narrative emphasis on communication requirements.

Closer inspection of the lexical patterns indicates that embedded communication is predominantly framed as assessment activity rather than genre-based instruction. While students are required to produce multiple written and oral artifacts, few curricula explicitly distinguish technical genres from general academic writing or foreground rhetorical decision-making tied to professional engineering contexts. Consequently, students may experience communication as decontextualized writing practice rather than as discipline-specific professional action.

Stakeholder and Community Interfaces

While Georgia Tech referred to stakeholders and community-oriented communication, these cues were the least consistently represented theme across other institutions. Where present, stakeholder language was most often framed in ethical or normative terms rather than through interactive communicative practices. Explicit references to community engagement, user-centered design, or stakeholder input were rare. This suggests that while social responsibility is acknowledged rhetorically, few curricula provide students with sustained opportunities to practice communication with real or simulated external stakeholders.

Conclusion and Future Work

The importance of TSC skills to future engineers cannot be understated. These are not "soft" skills but a core competency. Technical and Scientific Communication is not just putting words on a page to convey data; it is about influencing understanding, driving action, and developing trust with an audience. This brief study reveals some opportunities for many programs to improve TSC instruction and student outcomes. There are many opportunities to support the engineering curricula and improve students' professional skills. TSC instruction, whether as a stand-alone course or situated in a technical course, and assessment are an important part of continuous learning and can be reinforced throughout the engineering curricula. However, the findings also suggest that current approaches often lack differentiation by student goals and career orientation. While a 'coverage model' that aims for disciplinary breadth has historically been used to meet internal institutional needs and accreditation requirements, evidence-based educational best practices should be considered to inform TSC course design, reinforcing that communication preparation is most effective when aligned with authentic professional practice. Studies of early-career engineers demonstrate that the gaps between educational preparation and engineering work in the context of scientific communication are best addressed by (1) industry or other subject matter experts in the classroom [17], and (2) systematic reviews consistently identify applied, collaborative problem-solving as competencies in industry contexts [18]. Together, this body of evidence supports the inclusion of authentic audience exposure, including engagement with industry or other subject-matter experts, as well as career trajectory-specific, project-based communicative tasks within TSC design. Without differentiated course design as the authors suggest here, students may experience communication preparation as compliance rather than professional identity formation.

Another effort of this project is to refine and expand the list of single-word lexical cues (W) and multi-word phrases (P) to capture syllabi descriptions of institutional TSC course descriptions (see Appendix). Since this project reviewed ten highly ranked engineering curricula, keywords associated with other institutions and contexts will likely broaden to include the thematic domains. The authors anticipate that expanding and validating the thematic dictionary across a larger corpus will allow for greater sensitivity to engineering sub-disciplinary nuance, emerging instructional models, and evolving communication practices, thereby strengthening the robustness and generalizability of the analysis.

Visual Communication

Although data visualization and visual analytic communication were not a primary focus of the present dictionary-based analysis, their relative absence across the sampled syllabi is nonetheless notable. With the exception of one institution, where assignments explicitly reference evaluating and presenting data, visual aids, and audience-appropriate visual communication, most institutions offered limited or implicit curricular signals related to data visualization as a distinct communicative practice. Given the centrality of visual analytics and data-driven decision-making in contemporary engineering work, this gap suggests a potential misalignment between professional communication demands and formal TSC instruction. The limited curricular signaling of visual analytics may reflect a broader emphasis on textual compliance rather than multimodal professional communication, despite the growing centrality of visual data interpretation in engineering leadership roles. Future analyses, particularly with an expanded institutional sample, will examine whether this pattern persists and how visual communication competencies are positioned within or adjacent to TSC curricula.

Future work in this area includes expanding and updating the number of schools with TSC in their engineering curricula to increase the sample size of engineering programs. In addition, the authors plan to identify the instructional pathways for TSC in each engineering discipline (stand-alone course, capstone, lab, etc.) at these institutions, and eventually map opportunities to reinforce and expand TSC instruction to specific engineering requirements at their own institutions.

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Appendix: Keywords for Python dictionary

1. Project-Based Learning / Experiential Cues
W: "project," "design project," "capstone," "prototype," "iteration," "implementation," "deliverable," "build," "develop," "create," "model," "test," "evaluate," "optimize"
P: "hands-on," "real-world application," "design challenge," "client project," "industry-sponsored," "semester-long project," "open-ended problem," "solution-oriented," "design-build-test"

2. Teamwork / Collaborative Practice
W: "team," "group," "collaborate," "peer," "interdisciplinary," "cross-functional," "partnership," "shared responsibility," "role," "leadership," "communication plan"
P: "team charter," "peer review," "group presentation," "collaborative deliverable," "team-based assignment," "interdisciplinary team," "leadership reflection," "project management"

3. Entrepreneurial / Corporate Partnership / Innovation Focus
W: "entrepreneurship," "innovation," "startup," "prototype," "pitch," "venture," "market," "customer," "sponsor," "stakeholder," "impact," "commercialization," "technology transfer"
P: "industry partner," "corporate collaboration," "sponsored project," "innovation challenge," "Horizon Challenge," "technology commercialization," "customer discovery," "business model," "value proposition," "engineering economics"

4. Embedded Communication
W: "report," "proposal," "memo," "brief," "presentation," "poster," "reflection," "documentation," "portfolio," "iteration," "revision," "feedback," "peer feedback"
P: "communicate results," "draft and revise," "reflective writing," "technical documentation," "project summary," "executive report," "oral presentation," "poster session," "data storytelling"

5. Stakeholder & Community Interface
W: “community partner,” “client,” “stakeholder,” “end user,” “policy,” “ethics,” “impact,” “sustainability,” “context,” “user needs”
P: “community-engaged,” “stakeholder input,” “societal impact,” “ethical considerations,” “user-centered design,” “human factors,” “inclusive innovation”