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Critical Discourse Analysis in Engineering Education: Developing Critical Technical Literacy Through International Standards Analysis

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ABSTRACT

International technical manuals and standards are commonly taught in engineering education as neutral and factual documents. This study aims to examine how such documents construct authority, obscure agency, and embed ideological assumptions, while also evaluating the effectiveness of a Critical Discourse Analysis (CDA)-based pedagogical module in developing students' Critical Technical Literacy (CTL). A two-phase mixed-methods design was employed. In Phase 1, systematic CDA was conducted on seven technical documents consisting of four ISO/IEC standards and three corporate manuals from Siemens, Autodesk, and Rockwell Automation using Fairclough's three-dimensional framework. In Phase 2, a 14-week instructional module was implemented with 87 fourth-year electrical engineering students across three semesters. Data were collected through a validated CTL pre-test and post-test, students' final analytical assignments, and semi-structured focus group interviews. The CDA results showed that technical documents frequently used passive voice, nominalization, agent deletion, and dominant deontic modality, particularly the word "shall," to construct authority and reduce visibility of human decision-making. The pedagogical intervention significantly improved students' CTL scores from pre-test ($M = 52.4$, $SD = 11.7$) to post-test ($M = 76.8$, $SD = 9.2$), with a large effect size, $t(86) = 14.26$, $p < .001$, Cohen's $d = 1.53$. The findings suggest that CDA can be integrated into engineering education to strengthen students' ethical awareness, critical reading ability, and sociotechnical understanding of technical standards. This study contributes an interdisciplinary model that connects critical discourse studies with engineering education and positions CTL as a measurable learning outcome for preparing socially responsible engineers.

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INTRODUCTION

Imagine an engineering student sitting in a library, opening an international standard on system safety. The document is thick, full of tables, diagrams, and sentences that sound absolute:

"The system *shall* be designed to withstand load X," or "The procedure *shall* follow step Y." The student learns to memorize and apply these rules. But were they ever taught to ask: *Who set this 'load X,' and based on what assumptions? Why is the language always passive, as if these rules descended from the sky rather than from human decisions? What values and interests are hidden behind that seemingly neutral word 'shall'?*

This is the starting point for our investigation. In the world of engineering, international manuals and standards like those from ISO or IEC are often treated as sacred texts: objective, neutral, and value-free. Traditional engineering education trains students to become obedient *users*: extract the specification, follow the protocol, apply the rule. This skill is essential, but it is not enough. This approach inadvertently teaches future engineers to accept the authority of technical texts without ever questioning the underlying assumptions, power structures, or worldviews (Downey et al., 2007). Yet, the technical decisions they will later make about infrastructure, digital technology, or energy systems will shape the lives of people globally. The inability to "read between the lines" of technical documents is not just an academic weakness; it is a real professional and ethical risk (Mendoza & Dorner, 2020).

Technical standards are increasingly recognized as political artifacts rather than neutral technical documents. Research has demonstrated that standards development is often "a political and conflict-laden process" involving diverse stakeholders with competing interests (Krupczak et al., 2019). Far from being purely technical, standards-making involves negotiation, power dynamics, and the selective inclusion of certain perspectives while excluding others (Roberts & Ziosi, 2026). As Schoechle (2003) argues, the discourse of standardization reconstructs practice through specific rhetorical strategies that legitimate particular institutional arrangements and interests. This political dimension of standards has profound implications for engineering education, as students who treat standards as immutable truths internalize the values and power relations embedded within them.

This research originates from the humanities, specifically from the field of Critical Discourse Studies. This field sees language not as an empty pipe conveying facts, but as a *social practice* a site where power is contested, ideology is reinforced, and certain realities are constructed (Fairclough, 2003). Through this lens, a technical standard is not just a collection of data. It is an *actor*. It employs specific linguistic strategies: passive sentences that erase the agent ("*shall be performed*"), abstract nouns that mask action ("*implementation*" instead of "*who* implements"), and rigid structures that make it seem like a law of nature. All of this functions to make human decisions appear impersonal, to render a particular cultural or corporate logic as natural and universal, and to turn complex ethical considerations into mere checklists (Gazzola et al., 2023). The "universal" language of standards often carries with it a Western technocratic worldview, which can subtly marginalize local knowledge or alternative ways of working in different parts of the world (Chen & Mason, 2018).

While CDA has been applied to professional discourse Hyland, (2005) and STS critiques of engineering are well-established (Riley, 2008), the combination of (a) systematic CDA of ISO/IEC standards as a unified corpus, (b) a pedagogical intervention with quantified outcomes, and (c) the Critical Technical Literacy (CTL) construct as a measurable learning outcome has not, to our knowledge, been previously reported. This study deliberately bridges two worlds that are usually separate: the critical-analytical world of language and literary studies, and the applied world of engineering education. This is an effort to inject critical-humanist thinking into the very heart of the engineering curriculum and also respond to a growing concern in higher engineering education: that students need to be trained not only to *calculate well*, but also to *question well* (The Royal Academy of Engineering, 2007). Technical literacy alone is insufficient; what is needed is critical literacy the ability to dissect how authority is constructed in a text, to recognize buried assumptions, and to understand the social consequences of the technical language they use. This ability forms the foundation for ethical and responsible communication.

The urgency of this pedagogical intervention is underscored by recent high-profile engineering failures that have been attributed, at least in part, to a lack of critical questioning and ethical reflection among technical professionals. From the Boeing 737 MAX crashes to the Grenfell Tower fire, these disasters reveal how uncritical acceptance of technical specifications and standards can have devastating real-world consequences. In each case, engineers followed the rules and protocols as written, but failed to question whether those rules were adequate, whether the underlying assumptions were valid, or whether the standards themselves embodied values that might conflict with broader social responsibilities (Herkert et al., 2020; Grenfell Tower Inquiry, 2024). This pattern suggests that teaching students to read standards critically is not merely an academic exercise but a matter of professional and public safety.

Recent work in engineering education has emphasized the need for critical literacy approaches that enable students to "think with, against, and beyond" engineering standards (Wilson-Lopez et al., 2017). Thinking *with* standards means using canonical texts to question practices that harm or exclude particular groups. Thinking *against* standards involves challenging assumptions that may perpetuate inequality, such as the profit motive driving technological development. Thinking *beyond* standards means considering perspectives of multiple stakeholders consumers, citizens, government officials who are affected by engineered products (Wilson-Lopez et al., 2017). This framework aligns with the growing recognition that engineering education must cultivate critical thinking about sociotechnical contexts (Krupczak et al., 2019).

Technical literacy alone is insufficient; what is needed is critical literacy the ability to dissect how authority is constructed in a text, to recognize buried assumptions, and to understand the social consequences of the technical language they use. This ability forms the foundation for ethical and responsible communication.

Therefore, this study addresses two research objectives:

Phase 1 Objective: To conduct a systematic Critical Discourse Analysis of a corpus of international technical standards (ISO, IEC) and corporate manuals to identify linguistic strategies (modality, transitivity, nominalization, intertextuality) that construct authority, obscure agency, and naturalize Western technocratic values.

Phase 2 Objective: To design, implement, and evaluate a 14-week pedagogical module for engineering students that teaches CDA-based critical reading skills, measuring its impact on students' Critical Technical Literacy (CTL) through quantitative (pre/post-test) and qualitative (artifact analysis, focus groups) methods.

The remainder of this paper is structured as follows: Section 2 describes the mixed-methods research design and corpus composition; Section 3 presents the CDA findings from Phase 1 and the educational outcomes from Phase 2; Section 4 discusses theoretical implications, limitations, and future directions; Section 5 concludes with recommendations for engineering education.

METHOD

This study employed a two-phase, mixed-methods research design, integrating qualitative Critical Discourse Analysis (CDA) with quantitative and qualitative educational assessment. The six-year research program (2018-2024) was conducted at Politeknik Negeri Medan, Faculty of Electrical Engineering. The study received ethical approval from the Institutional Review Board.Timeline of the Six-Year Research Program

1. **Timeline of the Six-Year Research Program**

Phase 1 (2018-2021): Corpus compilation and systematic CDA of all seven documents using Fairclough's three-dimensional framework. Results from Phase 1 informed the design of the pedagogical module. The 2018-2021 period was dedicated to theoretical development, instrument validation, and pilot CDA work. Phase 2 (2022-2023)**:** Implementation of the 14-week module across three academic semesters (Fall 2022, Spring 2023, Fall 2023) with fourth-year Electrical Engineering students. Participant breakdown: Fall 2022 (n=28), Spring 2023 (n=30), Fall 2023 (n=29), total N=87.

2. Corpus Composition (Phase 1)

The primary textual corpus for Phase 1 consisted of a purposive sample of international technical documents, selected based on their prominence in undergraduate engineering curricula and global industrial relevance.

Technical Standards

Four full-text standards were obtained from the official online portals of the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC).

These included:

1. ISO 13849-1:2015, *Safety of machinery, Safety-related parts of control systems. Part 1: General principles for design* (International Organization for Standardization, 2015).
2. ISO 9001:2015, *Quality management systems, Requirements* (International Organization for Standardization, 2015).
3. IEC 61508-1:2010, *Functional safety of electrical/electronic/programmable electronic safety-related systems. Part 1: General requirements* (International Electrotechnical Commission, 2010).
4. ISO/IEC/IEEE 12207:2017, *Systems and software engineering, Software life cycle processes* (International Organization for Standardization, 2017).

Technical Manuals

Three comprehensive equipment/software manuals from leading global technology providers were analyzed. These were publicly available installation/operation manuals for:

1. Siemens SIMATIC S7 PLC systems (Manual obtained from Siemens AG, Germany, Document ID: 6ES7398-8FA10-8BA0, 2019).
2. Autodesk AutoCAD Civil 3D software (User manual, Autodesk Inc., USA, Version 2022, Document ID: MFG-8721-2022).
3. Rockwell Automation Studio 5000 Logix Designer (Manual obtained from Rockwell Automation, USA, Publication 9324-UM006E-EN-P, 2020).

Pedagogical Materials

For Phase 2, a 14-week instructional module titled "Critical Reading of Technical Discourse" was developed. All teaching materials, including lecture slides, annotated text samples, worksheets, and assessment rubrics, were created by the research team.

Methods Phase 1: Critical Discourse Analysis of Corpus

The textual analysis followed the three-dimensional framework for CDA established by Fairclough (2003), which examines (1) textual features, (2) discursive practices, and (3) social practices. This framework has been widely applied in educational research to analyze how power and ideology are enacted through language (Mendoza & Dorner, 2020).

1. Textual Analysis: A close linguistic analysis was performed on the selected documents using the qualitative data analysis software NVivo 12 (QSR International). Coding focused on:
   a) Modality: Frequency and function of deontic modals (e.g., *shall, must, should, may*).
   b) Transitivity & Agency: Use of passive voice, nominalization, and agent deletion.
   c) Lexical Choice: Analysis of keyword clusters, technical jargon, and evaluative language.

d) Intertextuality: References to other standards, laws, or documents establishing authority.

2. Discursive Practice Analysis: This stage investigated how the documents are produced, disseminated, and consumed. It involved tracing the development history of selected clauses through published commentaries and committee notes, where available.
3. Socio-Practice Analysis: This interpretive stage connected linguistic patterns to broader issues of power, ideology, and professional culture in engineering, drawing on literature from science and technology studies (STS) and professional ethics.

Method Phase 2: Educational Intervention & Assessment

1. Module Development: Based on Phase 1 findings, the learning module was designed with weekly units covering: (a) Introduction to CDA concepts, (b) Analysis of modality and obligation, (c) Unpacking nominalization and agency, (d) Ideology in technical visuals (diagrams/charts), and (e) Ethics of technical communication. The module drew on principles of critical literacy that enable students to read the "designed world" and its embedded power relations (Hyland, 2005).
2. Participants: The module was piloted over three academic semesters with fourth-year undergraduate students (N = 87) majoring in Electrical Engineering at Politeknik Negeri Medan. Participation was voluntary, with informed consent obtained.
3. Procedure: The module was delivered as a 2-hour weekly seminar. Each session combined mini-lectures, guided group analysis of text excerpts from the corpus, and hands-on exercises where students analyzed documents from their own capstone projects.

Data Collection & Analysis:

1. Pre- and Post-Test: A validated Critical Technical Literacy (CTL) assessment was administered, featuring multiple-choice and short-answer questions designed to measure students' ability to identify discursive features and ideological implications in unseen technical text samples. The instrument assessed students' capacity to identify implicit and explicit assumptions, evaluate reliability of information, and understand the sociotechnical context of engineering texts (Luke, 2012).
2. CTL Instrument Validation: The CTL assessment was developed by the authors based on the CDA findings from Phase 1. Content validity was established through expert review by three engineering education researchers and two CDA specialists. The instrument was piloted with 15 engineering students not in the main sample; item analysis led to the removal of 4 ambiguous questions. For the final 25-item instrument (15 multiple-choice, 10 short-answer), internal consistency was acceptable (Cronbach's $\alpha = 0.84$).
3. Artifact Analysis: Students' final assignments a critical discourse analysis of a technical document of their choice were scored using a standardized analytic rubric (0-4 scale across five dimensions: Identification of Features, Interpretation, Connection to Context, Argumentation, and Ethical Reflection). Inter-rater reliability was established (Cohen's $\kappa > 0.85$).
4. Focus Groups: Semi-structured focus group interviews (n=6 groups, 5-6 students each) were conducted at the end of each semester to gather qualitative data on perceived learning outcomes and changes in perspective. Interviews were transcribed and analyzed using thematic analysis (Braun & Clarke, 2006).

Statistical Analysis

Pre- and post-test scores were compared using paired-sample t-tests. Correlation analysis was performed between final assignment scores and pre-test scores. Quantitative analyses were conducted using IBM SPSS Statistics, Version 28.

RESULTS AND DISCUSSION

The results are presented in two main sections corresponding to the research phases: (1) findings from the Critical Discourse Analysis of the technical corpus, and (2) outcomes from the educational intervention assessing its impact on engineering students.

Phase 1: Critical Discourse Analysis of International Technical Documents

Systematic analysis of the seven-document corpus revealed consistent discursive patterns that construct an aura of neutrality and authority.

Linguistic Features Constructing Authority and Obligation

1. Modality: Deontic modals, particularly *"shall,"* were overwhelmingly dominant. In the four standards analyzed, *"shall"* appeared an average of 42.7 times per 1000 words (range: 38.2–51.1), constituting 89% of all modal verbs. The use of *"must"* was rare (<2%), and *"should"* was reserved for non-mandatory recommendations. This lexical uniformity creates a powerful, monolithic sense of obligation. The overwhelming presence of "shall" constructs what Fairclough (2003) terms a "grammar of obligation" that naturalizes particular requirements as self-evident and beyond question.
2. Agency and Nominalization: Passive voice and agentless constructions were pervasive (present in ~78% of procedural and requirement statements). For example, "The safety function *shall be performed*" (International Organization for Standardization, 2015) or "Non-conformities *shall be addressed*" (International Organization for Standardization, 2015). The actors (designers, committees, corporations) who define the "safety function" or decide what constitutes a "non-conformity" are systematically erased. Furthermore, processes were consistently transformed into static things via nominalization (e.g., "design" becomes "the design," "evaluate" becomes "evaluation"), obscuring the human activity behind these concepts. This linguistic pattern aligns with the concept of "agent deletion" identified in CDA literature as a mechanism for obscuring responsibility and power relations (Fairclough, 2013).
3. Lexical Choice and Semantic Domination: Beyond modality and passive constructions, the standards employed specific lexical choices that reinforce particular professional hierarchies and knowledge systems. Terms such as "best practice," "state of the art," and "recognized principles" were used repeatedly to frame the standards' requirements as reflecting objective, universally accepted knowledge. However, these terms are semantically loaded they implicitly dismiss alternative approaches as inferior or outdated without providing substantive justification. This lexical strategy creates a "regime of truth" wherein the standards' prescriptions appear as the natural culmination of technical progress rather than as contested, historically situated choices (Downey et al., 2007).

Intertextuality and the Construction of a Closed System

The documents consistently referenced other standards within their own ecosystem (e.g., "in accordance with IEC 61508-2"). An average of 12.4 explicit cross-references to other ISO, IEC, or internal clauses were found per document. This creates a self-referential, closed system of knowledge that is difficult for outsiders to challenge or even fully access, as understanding one standard requires possession of several others. This intertextual web exemplifies what Foucault (1972) terms a "discursive formation"—a system of knowledge production that maintains its authority through internal consistency and specialized access requirements.

Visual-Graphical Discourse

Diagrams and flowcharts in the manuals (e.g., the PLC system architecture, software workflow) employed a "rhetoric of inevitability." Decision diamonds almost always led to a single, technically prescribed path labeled as "correct," while alternative pathways were absent or marked as leading to "error" or "system halt." This visually reinforces a worldview where technical problems have only one optimal, pre-defined solution, effectively delegitimizing alternative approaches or local knowledge. Such visual rhetoric functions ideologically by naturalizing particular technological choices (Wilson-Lopez et al., 2017).

Phase 2: Impact of the Educational Intervention

A. Quantitative Assessment of Critical Technical Literacy (CTL)

Eighty-seven students completed both the pre- and post-intervention CTL assessment. A paired-sample t-test revealed a statistically significant increase in critical reading competency.

Table 1. Pre-test and Post-test CTL Assessment Scores (N=87)

Assessment	Mean Score (Max 100)	Standard Deviation	Statistical Comparison
Pre-test	52.4	11.7	Pre–Post Comparison:
Post-test	76.8	9.2	$t(86) = 14.26$, $p < 0.001$, Cohen's $d = 1.53$

Note: The t-statistic, p-value, and Cohen's d refer to the paired-sample comparison between pre-test and post-test scores.

The large effect size (Cohen's d = 1.53) indicates a substantial educational impact. The greatest score improvements were in sections requiring students to identify hidden assumptions in requirement statements and explain the potential social consequences of agentless passive constructions. This finding is consistent with research showing that targeted critical literacy instruction can significantly enhance students' ability to recognize ideological dimensions in technical texts (Luke, 2012).

Analysis of Student Artifacts (Critical Analyses)

The final assignments (n=87) were scored using a 20-point rubric. The mean score was 16.3 (SD = 2.4), indicating successful application of CDA tools. A weak negative correlation was found between pre-test scores and final assignment scores ($r = -0.21$, $p = 0.048$), suggesting students with initially lower uncritical reading habits benefited most from the explicit discursive toolkit.

Table 2. Final Assignment Rubric Scores by Dimension (Mean, 0-4 Scale)

No	Dimension	Mean Score	SD
1	Identification of Features	3.6	0.5
2	Interpretation	3.4	0.6
3	Connection to Context	3.1	0.7
4	Argumentation	3.3	0.6
5	Ethical Reflection	2.9	0.8

While students excelled at identifying linguistic features (Dimension 1), Dimension 5 (Ethical Reflection) had the lowest average score, indicating the challenge of moving from analysis to normative ethical reasoning. This finding resonates with research showing that engineering students often struggle to connect technical analysis with ethical implications, despite demonstrating competence in critical technical skills (Zhuang & Xu, 2018).

Qualitative Themes from Focus Groups

Thematic analysis of focus group transcripts yielded three primary themes:

1. Awakening to the "Politics" of Technical Text: Students repeatedly described a "shift" or "eye-opening" moment. One student noted, *"I used to read 'shall' as a fact of nature, like gravity. Now I see it as a human command. It makes me ask, 'Who benefits from this command?'"* This transformation reflects the process of "denaturalization" that critical literacy aims to achieve revealing the constructed and contingent nature of texts previously perceived as neutral (Wilson-Lopez et al., 2017).
2. Empowerment and Agency: Students reported feeling more confident and "less intimidated" by standards. They framed their new skill as a form of professional agency: *"Before, the manual was the boss. Now I feel I can have a conversation with it, even argue with it if I have a better reason."* This sense of empowerment aligns with the goal of developing engineers as

"critical, ethical agents" who can think "with, against, and beyond" standards (Wilson-Lopez et al., 2017).

3. Tension with Traditional Engineering Identity: Several students expressed initial cognitive dissonance, questioning if this "critical" approach was "allowed" in engineering. One participant stated, *"We're trained to find the right answer. This teaches there might not be one right answer, just different choices with different consequences. It's unsettling but important."* This tension highlights the challenge of introducing critical perspectives into engineering education, where dominant discourses often prioritize technical competence over sociotechnical reasoning (Zhuang & Xu, 2018).

Discussion

Synthesis of Key Findings

The CDA revealed that international technical manuals and standards are not neutral vessels of information but are linguistically engineered to project objective authority, conceal human agency, and constrain interpretation. The educational intervention demonstrated that this "hidden curriculum" can be effectively made visible to engineering students. The significant gains in CTL scores and the qualitative feedback confirm that students can transition from passive recipients to critical, engaged readers of the foundational texts of their profession. The large effect size (Cohen's d = 1.53) indicates that the CDA-based instructional approach was not merely statistically significant but educationally meaningful, transforming students' orientation toward technical texts.

Theoretical Implications

Synthesizing the Phase 1 and Phase 2 findings, this study makes three theoretical contributions. First, it provides empirical linguistic evidence (quantified frequencies of "shall," passive voice, and nominalization) supporting Winner's (1980) classic argument about the "politics of artifacts" and Latour's (1987) concept of delegation to non-human actors. Technical standards are not merely neutral tools but are discursively engineered actors that shape engineering practice. The linguistic patterns we identified particularly the dominance of "shall" and agentless passive constructions demonstrate how standards function as "inscribed" political decisions that appear as natural requirements (Schoechle, 2003).

Second, the self-referential intertextuality observed (12.4 cross-references per document) demonstrates what Foucault (1972) termed a "discursive formation" a closed system of knowledge that is authoritative because it is internally consistent and difficult to penetrate without specialized access. This intertextual web creates barriers to participation and reinforces the authority of standards bodies. As research on AI standards-making reveals, the robust procedures of ISO/IEC committees can create "insulated ineffectiveness" while also enabling uneven participation (Roberts & Ziosi, 2026).

Third, the significant CTL gains demonstrate that this "hidden curriculum" can be effectively surfaced, supporting Luke's (2012) argument that critical literacy is not an innate capacity but a teachable set of analytical practices. The intervention demonstrated that engineering students can develop the capacity to "think against" and "think beyond" institutionalized standards, moving from compliance to critical engagement (Wilson-Lopez et al., 2017).

Several limitations of this study must be acknowledged. First, the sample was a convenience sample drawn from a single institution (Politeknik Negeri Medan), which limits generalizability to other engineering education contexts, particularly those outside Indonesia. Second, the study used an uncontrolled pre-post design without a control group; therefore, causal claims about the module's effectiveness cannot be definitively established, as maturation or history effects cannot be ruled out. Third, focus group responses may be subject to demand characteristics, where students reported perceived learning gains they believed the researchers wanted to hear. Fourth, the corpus, while purposively selected, included only documents from Western standards bodies (ISO, IEC) and Western corporations (Siemens, Autodesk, Rockwell). Non-Western technical standards (e.g., from Japan, China, or ASEAN countries) were not analyzed, limiting claims about the universality of the discursive patterns observed. Research on "New Engineering Education" in China suggests that different national contexts may construct engineering education through distinct technological imaginaries (Zhuang & Xu, 2018). Fifth, the study measured short-term learning outcomes immediately post-intervention; longitudinal follow-up is needed to assess retention of CTL skills over time.

Based on the limitations above, future research should address the following directions. First, replication of the pedagogical module with a randomized controlled trial design, including a control group receiving traditional technical reading instruction, would strengthen causal inferences about the module's effectiveness. Second, longitudinal studies (e.g., 1-year and 2-year follow-ups) are needed to assess whether CTL gains persist and whether students apply critical reading skills in professional workplace settings after graduation. Third, the corpus should be expanded to include technical standards from non-Western standard-setting bodies (e.g., Japanese Industrial Standards [JIS], Chinese National Standards [GB], or ASEAN standards) to examine whether similar discursive patterns of authority and agency-obscuration appear, or whether alternative discursive strategies are employed. Cross-national comparative studies would illuminate how different cultural and institutional contexts shape the discourse of standardization (Zhuang & Xu, 2018). Fourth, the validated CTL instrument should be tested in cross-institutional and cross-national samples to establish its generalizability and to enable comparative studies. Fifth, future research could investigate whether CTL training influences students' subsequent ethical decision-making in capstone design projects or workplace internships. Research on assessment of sociotechnical thinking suggests that critical thinking about engineering contexts can be measured through targeted exercises (Krupczak et al., 2019).

CONCLUSIONS

This study demonstrates that international engineering standards and corporate technical manuals should not be treated merely as neutral technical documents, but also as discursive texts that construct authority, regulate professional action, and shape how engineers understand responsibility. The Critical Discourse Analysis revealed that these documents commonly rely on strong deontic modality, especially the repeated use of "shall," agentless passive constructions, nominalization, and self-referential intertextuality. These linguistic features help create an impression of objectivity and inevitability while often obscuring the human, institutional, and cultural decisions behind technical requirements.

The 14-week pedagogical intervention showed that Critical Discourse Analysis can be meaningfully integrated into engineering education to develop students' Critical Technical Literacy. The improvement in students' pre-test and post-test scores indicates that explicit instruction in modality, agency, nominalization, intertextuality, and visual discourse can strengthen students' ability to identify hidden assumptions and question the social implications of technical language. The qualitative findings also suggest that students began to shift from passive users of technical documents toward more reflective and critical readers who could engage with standards as human-made texts rather than unquestionable rules.

However, the findings should be interpreted with caution. The study was conducted in a single institution with a convenience sample and did not include a control group. The corpus was also limited to selected ISO/IEC standards and corporate manuals from mostly Western institutional and industrial contexts. Therefore, future studies should replicate the intervention using a stronger experimental or quasi-experimental design, include more diverse technical documents from non-Western standard-setting bodies, and conduct longitudinal follow-up to examine whether students retain and apply Critical Technical Literacy in capstone projects, internships, and professional engineering practice.

Overall, this study contributes to engineering education by showing that critical literacy is not an optional addition to technical training, but an important component of responsible engineering formation. Future engineers should not only be trained to understand and apply technical standards, but also to question the assumptions, power relations, ethical consequences, and social values embedded within them. Integrating Critical Discourse Analysis into engineering curricula can therefore help prepare engineers who are not only technically competent, but also critically aware, ethically responsible, and socially engaged.

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AUTHOR CONTRIBUTION STATEMENT

AIK contributed to the conceptualization of the study, research design, supervision, and preparation of the original manuscript draft. SAN contributed to corpus selection, Critical Discourse Analysis coding, and development of the pedagogical module. N contributed to the implementation of the instructional intervention, participant coordination, and validation of the learning materials. WS contributed to quantitative data analysis, statistical interpretation, and preparation of tables and results. IAH contributed to focus group facilitation, qualitative data analysis, and interpretation of student learning outcomes. AAM contributed to manuscript review, editing, project administration, and final manuscript preparation. All authors reviewed and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

AI DISCLOSURE STATEMENT

The authors used AI-assisted language tools only to support grammar checking, sentence clarity, and manuscript editing. AI tools were not used to generate research data, conduct statistical analysis, perform qualitative coding independently, fabricate references, or make substantive interpretations of the findings. All AI-assisted outputs were reviewed, verified, and revised by the authors. The authors take full responsibility for the accuracy, integrity, and originality of the final manuscript.

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