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Understanding Industry's Expectations of Engineering Communication Skills

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UNDERSTANDING INDUSTRY'S EXPECTATIONS OF ENGINEERING COMMUNICATION SKILLS

by

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ABSTRACT

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Excellence in communication is a highly desirable competence in engineering. However, research has indicated the dissatisfaction of employers when it comes to the performance of engineers as communicators in the workplace, revealing an apparent gap between communication instruction in engineering programs and expectations from professionals. This gap provides opportunities for additional research to identify the specific communication skills required for engineers to succeed in the workplace so that new educational interventions may be carefully tailored according to employers' expectations. In order to obtain a deeper understanding of industry's expectations of engineering communication skills, a qualitative approach was implemented. Four industrial segments (High-Tech, Automotive, Aerospace, and Manufacturing) that make up a significant percentage of engineers in the United States were selected as case studies. Their perspectives were explored to determine the communication requirements of practicing engineers within these industrial segments. Engineers in leadership positions from each of the selected industrial segments participated in in-depth interviews and discussed the expected engineering communication skills in industry. The results revealed that: 1) oral communication is prevalent in the engineering profession; 2) engineers need to tailor their messages to multiple audiences and to select the most appropriate type of communication medium; 3) written communication is expected to be clear, concise, and precise; 4) global communication is an increasingly demanded requirement in industry.

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PUBLIC ABSTRACT

Understanding Industry's Expectations of Engineering Communication Skills

Lilian Maria de Souza Almeida

The importance of communication in the engineering profession is widely acknowledged by various stakeholders, including industry, academia, professional engineers, and engineering students. Even though alternative strategies to help students improve their ability to communicate professionally have been approached by many engineering programs across the country, research indicates a continued dissatisfaction of employers when it comes to the performance of engineers as communicators in the workplace. This perspective suggests efforts to improve students' communication skills in universities may be inconsistent with workplace needs, revealing an apparent gap between what is taught and what is expected from engineering professionals. This gap provides an opportunity for additional research to identify the specific communication competencies required for engineers to succeed in the workplace. Particularly, the requirements of industry concerning engineers' communication skills need to be understood more deeply, so that new educational interventions may be carefully tailored according to employers' expectations and that both communication and engineering faculty can revisit their strategies to teach students to become better communicators. In order to obtain a deeper understanding of industry's expectations concerning engineering communication skills, a qualitative research study was implemented to provide a detailed description of the communication skills practicing engineers need while working in industry. The exclusive focus on industry was pursued through the development of case studies. Four industrial segments (High-Tech, Automotive, Aerospace, and Manufacturing) that employ a significant percentage of engineers in the U.S. were selected. Engineers in leadership positions from each of the selected industrial segments participated in in-depth interviews and discussed about the expected engineering communication skills in industry. The results revealed that: 1) oral communication is prevalent in the engineering profession; 2) engineers need to tailor their messages to

multiple audiences and to select the most appropriate type of communication medium; 3) written communication is expected to be clear, concise, and precise; 4) global communication is an increasingly demanded requirement in industry.

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INTRODUCTION

Communication is recognized as an important skill for many professional disciplines and is a highly desirable competence in engineering. According to Werner, Dickert, Shanmugaraj, Monahan, and Wallach (2017) even though communication competence is not an exclusive concern of the engineering profession, given that the central role of engineers involves working with public health and safety, its significance becomes magnified. Engineers have an impact in the world, and the nature of engineering uses different forms of communication, including oral, written, and visual (Dalinova & Pudlowski, 2009). Therefore, effective communication is essential in engineering (Bjekic, Bjekic & Zlatic, 2015).

According to Wren (2018), communication skills continue to be a top priority from both academic and industry's perspectives. In a systematic review including 52 studies (27 quantitative and 25 qualitative) addressing competencies engineers need and which are the most important, Passow and Passow (2017) indicated communication is among the 16 generic competencies that are essential to engineering practice, and engineers spend more than half of their work day (55% - 60%) communicating. These results are consistent with what was revealed by recent engineering graduates almost two decades earlier about their experience in the workplace (Sageev & Romanowski, 2001). Their study indicated that 64% of the overall time of practicing engineers was spent on some form of communication: written, oral presentations, and discussions. In another investigation, engineering graduates considered communication as one of the most important skills demanded in their work, along with other competencies listed by the

Accreditation Board for Engineering and Technology (ABET), such as teamwork, data analysis, and problem solving (Passow, 2012). Nathans-Kelly and Evans (2017) added that not only is communication essential, but it can no longer be seen as a distinct element of the engineering practice as proposed by the misleading dichotomies hard skills versus soft skills, or technical skills versus professional skills. Hynes and Swenson (2013) argued the use of the term 'soft skills' may have a pejorative connotation when compared to 'hard skills', which includes the technical aspects of engineering often represented in engineering's mathematical and scientific roots. They described six humanistic disciplines relevant to the practice of engineering, using the term 'humanistic' to refer to what are termed 'soft skills'. Communication is included in these humanistic disciplines. They suggested that design and development of engineering solutions requires multiple forms of communication, using different representations, and interacting with end-users, suppliers, manufacturers, and interdisciplinary teams.

Even though engineering students have been exposed to different opportunities to become proficient communicators in academic settings, employers and executives still convey the need for novice engineers to have better communication skills, which suggests the communication currently learned in academia is not necessarily the same used on the job (Norback, Leeds, & Kulkarni, 2010). According to Hanson et al. (2017), multiple factors may be keeping engineering students from developing communication skills during course work. Thus, there appears to be a gap between recent graduates' actual preparation and their expected performance. This apparent gap provides opportunities for additional research on identifying the specific communication skills required for engineers to succeed in the workplace. Particularly, the requirements of industry concerning engineers' communication skills need to be understood more deeply, so new educational interventions may be carefully tailored.

Problem

Graduating engineers are considered skillful and knowledgeable in their technical expertise, but many lack the communication skills needed in the work environment. This raises the question of whether university education is too focused on producing substance expertise and not focused on humanistic skills (Lappalainen, 2009).

In 2000, ABET placed an enhanced emphasis on communication skills as one of the desired outcomes of engineering education (ABET, 2018). However, the need to improve future engineers' performance as communicators continues to be a topic of concern. From industry's perspective, communication skills of engineering graduates tend to be weak, even though engineering departments have worked specifically at improving communication competence of their students (Donnell, Aller, Alley, & Kedrowicz, 2011). This perspective suggests efforts to improve engineering students' communication skills in the universities may be inconsistent with the workplace's needs. A possible explanation for this mismatch was suggested by Paretti (2008) who addressed the idea of school and work as different activity systems. Paretti explained the primary goal of the classroom experience is the students' learning (mastery of the subject matter) while the desired outcome in the workplace is a product or process that generates profitability. The distinctions between these two activity systems are critical because it influences the way faculty react to students' work, which can, in turn, limit students' communication advances. Key differences between the classroom and the workplace activity systems are provided in Table 1.

Table 1

Comparison of Classroom and Workplace Activity Systems (Paretti, 2008)

	Classroom	**Workplace**
Primary system goal	Student learning	Corporate profitability
Primary document function (mediating activity)	Evaluation of student learning	Decision-making to insure project profitability

The scientific research that captures what industry says about the communication skills of engineering graduates is very limited, especially when compared with studies describing what engineering departments should do to teach communication (Donnel et al., 2011). While there are many studies supporting the claim that communication skills are important for engineers, little systematic research from industry representatives providing descriptions of the types of communication skills that are consistent with industry needs can be found (Darling & Dannels, 2003). Additionally, available studies have some limitations. Some are part of broader projects and not exclusively focused on communication skills of engineers (Nicometo, Anderson, Nathans-Kelly, Courter, & McGlamery, 2010). Others are focused only on writing skills (Conrad, 2017; Kmiec & Longo, 2017; Winsor, 1996) or oral communication skills (Dannels, 2002; Darling & Dannels, 2003). Some investigations are based on just one type of engineering discipline (American Society of Mechanical Engineers, 2011; Conrad, 2017). Additional studies available are limited to the perspectives of executives (Norback, Leeds, & Forehand, 2009; Norback et al., 2010) with the main focus on the hiring process and the early years of engineers at the workplace (Norback & Hardin, 2005).

Therefore, a more precise research investigation of the specific communication skills required by industry could help develop future educational interventions in engineering programs and potentially help both communication and engineering faculty to revisit their strategies to teach students how to become better communicators.

Purpose and Objectives

This study seeks to provide a detailed description of the communication skills practicing engineers need while working in industry. Understanding the current expectations of these skills in the workplace is of importance since a significant portion of an engineer's time is spent in communication interactions.

Based on information collected from multiple sources (Bureau of Labor Statistics [BLS], 2018a; Data USA, 2018; Universum, 2017), four industrial segments that make up a significant percentage of engineers in the U.S. were identified. These include the High-Tech, Automotive, Aerospace, and Manufacturing industries. Their perspectives were explored in this study to determine the communication requirements of practicing engineers within these industries.

The following objectives were the focus of this study in an effort to answer the research questions:

1. Identify the specific communication skills necessary for practicing engineers to succeed in contemporary industry settings.
2. Identify the common communication challenges of practicing engineers in industry settings.

3. Verify if there are differences in the specific engineering communication requirements across the four industrial segments investigated.

Research Questions

The study is guided by the following research questions:

1. How are the specific communication skills expected from practicing engineers in industry described?
2. What are the communication challenges of practicing engineers?
3. In what ways are engineering communication requirements different across varying industrial segments?

Positionality

Since in qualitative studies researchers are considered integral instruments in the research design and data collection process (Creswell, 2013), it is important to position the researcher of this study in the context of this work. The researcher has a M.S. in production engineering and developed her thesis with focus on industrial-specific means of communication as an instrument to improve quality control in companies. For 10 years, she worked as an instructor of marketing and business in engineering and other programs in a higher education institution in Brazil. Currently, she is a Ph.D. candidate in the Engineering Education Department at Utah State University (USU). In this role, she has combined her past experience teaching engineering students and her prior research to better understand the different communication requirements varying industries have for their engineers.

Methodology and Methods

The engineering education research community acknowledges no particular method (quantitative, qualitative, or mixed-method) is privileged over any other, and the choice must be driven by the research questions (Borrego, Douglas, & Amelink, 2009).

An increasingly diverse range of qualitative methods has been implemented in the field of engineering education (Walther et al., 2017). Qualitative research is the ideal approach when the intention is to explore and understand individuals' or groups' meanings with respect to social or human problems. It is an approach characterized by data collection performed in participants' settings through emerging questions and procedures, inductive analysis, and the researcher's interpretations of the meaning of the data (Creswell, 2014).

In order to obtain a deeper understanding of industry's expectations concerning engineering communication skills and to address the research questions proposed for this study, a qualitative approach was implemented. Koro-Ljungberg and Douglas (2008) argued that qualitative research has the capability to capture the complexity of human behaviors in ways not possible when studies are based on prediction and randomized controls. They also added the use of qualitative research methods in engineering education has been recognized and penetrated several areas of study as an alternative way of knowing and viewing the empirical world. This qualitative study is based on an epistemological paradigm and on a constructivist interpretive framework.

An exclusive focus on industry as the group of stakeholders responsible to describe in detail the communication skills required in the engineering profession was pursued through the development of case studies. In the field of communication specifically, qualitative case studies are widely adopted, well-established and considered a rigorous research method (Paretti, 2008). Voss, Tsikriktsis, and Frohlich (2002) added that case studies can have a high impact on research as it can lead to new and creative insights and the development of new theory and validity with practitioners because of its very nature of being unconstrained by rigid limits of questionnaires and models.

Data collection included qualitative interviews with engineers in leadership positions in industry. This procedure is among the four main types of data collection suggested by Creswell (2014). Interviews with engineers for communication research purposes have been successfully used as a method of data collection (Darling & Dannels, 2003; Nicometo et al., 2010; Williams, Longo, & Kmiec, 2016; Winsor, 1996).

Limitations of the Study

The limitations of this study are:

1. The cases were purposefully selected according to pre-established criteria (industrial segments with the highest engineering employment rates in the United States), but access to the participant companies relied mainly on contacts from USU's database, which limited the research to companies located in the state of Utah.
2. Since the number of engineers in each participating company is unknown, it is not possible to draw conclusions about the extent to which the communication practices in the organizations are affected by the percentage of engineers in the group of employees. Additionally, participant engineers were selected through purposeful and convenience sampling.

3. Due to time and availability limitations, participant engineers limited themselves to answer the interview questions of the research protocol.

Assumptions of the Study

This study was conducted with the following assumptions:

1. Engineers from industry who participate in the research do so voluntarily and may have specific interest in the topic engineering communication.
2. Participants from industry are open and honest when being interviewed and discussing their communication experiences in the workplace.
3. The researcher administers the qualitative data collection in the same way in all eight interviews.
4. Participants have practical engineering communication experience in the industry they work.

Definition of Terms

- *Qualitative research*: an approach used to explore and understand the meaning individuals or groups ascribe to social or human phenomena (Creswell, 2014).
- *Engineering education* (EED): an emerging discipline based education field of study through which research initiatives and cross-disciplinary collaborations are applied and evidence-based curricula is implemented (Benson, Becker, Cooper, Griffin, & Smith, 2010).
- *Engineering communication*: communication skills according to the conventions of the engineering profession (Knisely & Knisely, 2015).

CHAPTER 2

LITERATURE REVIEW

Initiatives to understand the communication practices of engineers in the workplace do not represent a new topic of scientific research. However, improved engineering communication is consistently mentioned by employers as an important element of an engineer's skill set, which creates an opportunity for a continued research with focus on different communication methods. Additionally, the constant evolution of communication competence makes room for further exploration.

Since engineers spend much of their time collaborating with other people and disciplines, communication is an essential part of their professional life. Despite this reality, there are some misconceptions about the importance of communication, especially when it comes to the perceptions of engineering students and novice engineers. According to Trevelyan (2014), one of these misconceptions is that good communication skills will be required only in management positions. Research has shown engineers need to work with and influence people from the beginning of their careers, and their ability to communicate will determine their ability to collaborate. Another misconception is students and novice engineers already have good communication skills. This is based on their past grades on written assignments, technical reports, presentations, and other activities during the engineering course work. The reality is employers frequently complain about the unsatisfactory communication skills of graduates and novice engineers. A third misconception is that communication skills cannot be taught, and they are learned by practice. Research has revealed engineers who have been exposed to communication instruction or training have greater confidence in their communication abilities (Trevelyan, 2014).

In the workplace, engineers can be involved in an extensive list of different activities such as conducting research, designing, developing products, and managing. All these activities demand resources including time, staff support, technologies, information, and communication. Tenopir and King (2004) provided a framework that illustrate the engineers' communication cycle as shown in Figure 1.

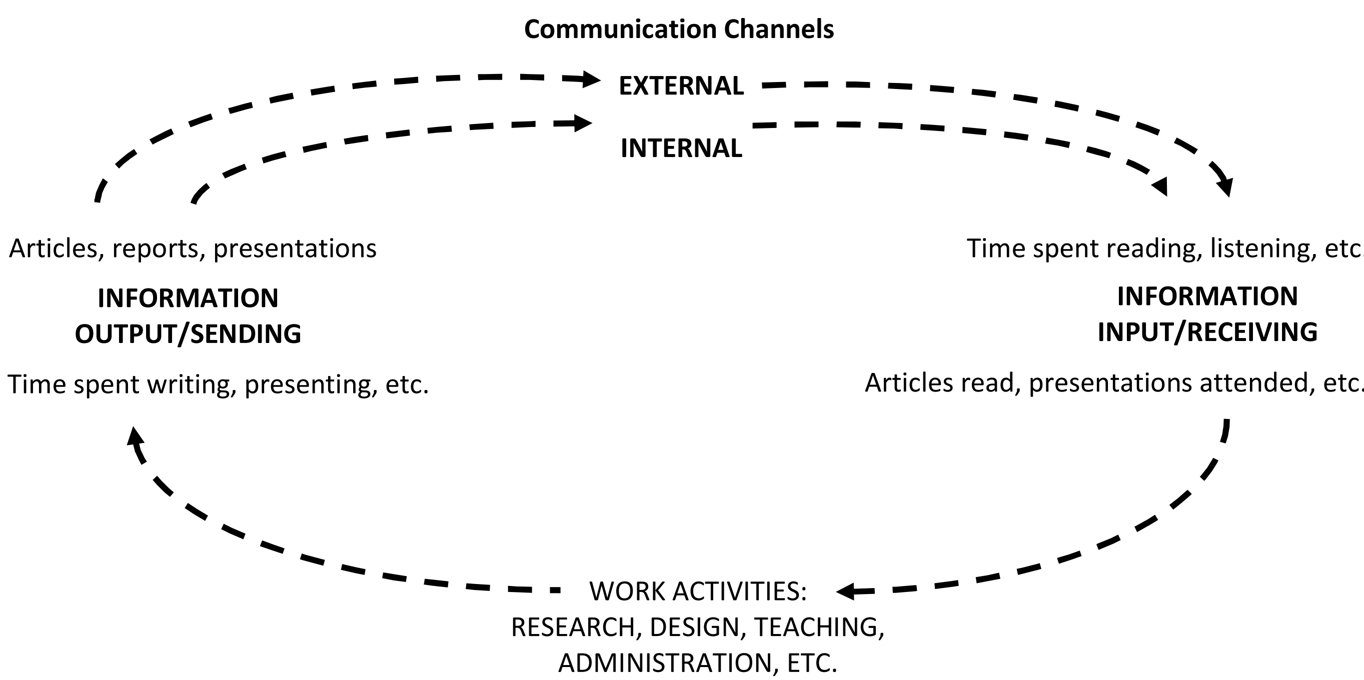

Figure 1. Engineers' communication cycle. Adapted from "Communication Patterns of Engineers", by C. Tenopir and D. W. King, 2004. Copyright 2004 by IEE Press.

As explained by Tenopir and King (2004), at the heart of the communication cycle are the activities performed by engineers. The cycle also considers how work is affected by information. Information input is defined as the effort or time spent reading and listening, as well as the amount of reading or number of interpersonal interactions made. Information output is the time and effort demanded for writing, making presentations, and other activities, as well as the quantity of items written and presentations made. Additionally, how engineers communicate, and the channels selected to do so, are both important aspects of the communication cycle. According to Wang (2008), the selection of the right communication channel or a suitable medium is a key factor to obtain the desired communication results.

One of the classic references on engineering communication frequently mentioned by many contemporary authors is the longitudinal research performed by Winsor (1996), which describes the perceptions of four engineering students about their own progress on writing skills as they moved from the undergraduate education experience to their career in industry. One of the key points of this study was the dynamic nature of engineering communication. This research highlighted what represents competent writing for an engineering student is different from what constitutes effective writing for an engineer with many years of seniority and a different kind of responsibility (Winsor, 1996). In a study aimed at gathering information about the communication routines of young graduate engineers at work, one of the most significant findings was the acknowledgment of the problems caused by ineffective writing and its cost implications for industry (Keane & Gibson, 1999). The impact of the actual workplace experience in the development of writing skills was also addressed by Aller (2001), who suggested that, even though some academic initiatives may contribute to engineering students' readiness for writing in the workplace, new engineers are more likely to learn about writing while professionally working and having a broader participation and immersion in all aspects of the engineering life. With a different perspective, Bjekic et al. (2015) argued university courses enable students to start their professional workplace careers with the same level of communication as more experienced engineering professionals.

While the writing skills of engineers as one of the most important communication modalities are frequently explored by researchers, some studies seeking to understand the skill set engineers need to become competent in the workplace include a more general picture of the communication abilities expected from industry. Nicometo et al. (2010), for example, summarized what can be considered the ideal engineering communication skills in the industry setting in three main themes: 1) the ability to effectively speak, write, and interact with audiences outside of engineers' specific discipline, work group, or focus; 2) the willingness and self-motivation to initiate communication with others and to seek out resource information through informal interactions; and 3) the ability to listen carefully to others in order to do the best work and achieve results valued by different stakeholders (clients, managers, coworkers).

Some insights from industry's executives revealed the search for engineers competent in communication skills starts in the hiring process, but is also critical for the professional advancement (Norback, Leeds, & Forehand, 2009). A summary of the most important communication aspects emphasized by these executives is provided in Table 2.

Table 2

Executives' Insights on Communication Skills of Engineers (Adapted from Norback et al., 2009)

Communication theme	**Communication expected competencies**
The concept of communication	• Persuasive communication: ability to sell the engineer's idea. • Active listeners: able to repeat, clarify, and summarize information. • Audience analysis: understand the perspectives of audience members. • Conciseness: the use of as few words as possible to get the message across. • Correctness: correct spelling and grammar; • Sense of trust over time.
Communication with senior management	• Strategic selection of factors that can facilitate decision-making process. • Clear information about actions to be taken and fact-based recommendations. • Details saved for later clarifications if needed.
Presentation	• Well-planned, succinct, and tailored according to the audience. • Clear agenda and results up front. • Messages supported by slides. • Insights and recommendation.; • Free from grammar and spelling errors.
Business writing	• Documents that communicate with management rather than technical reports and manuals. • Market analyses, product/service descriptions, business plans, and proposals.
Messaging	• Reviewed and prioritized e-mail messages. • Briefness and courtesy in voice mails. • Personal notes and letters are still very important in the engineering workplace.
Face-to-face Communication	• Meetings as the primary setting for face-to-face communication. • Required preparation concerning the purpose of the meeting and individuals in the audience.
Cross-cultural communication	• Avoidance of idioms, slangs, and acronyms. • Need for sensitivity to intercultural differences.

Engineering Communication Challenges

While engineers can be considered erudite and intelligent, when it comes to putting their ideas publicly, they can be perceived as uncertain and apologetic, in such a way their message can be misunderstood or even ignored (Scott & Billing, 1998). Engineers are typically not gifted communicators, which can impact their ability to produce high-quality work (Tenopir & King, 2004).

According to Gunn (2013), simply complaining about the lack of communication skills demonstrated by engineers is not productive, while it is important that interested parties in engineering departments investigate the actual deficiencies and concerns of those affected. By trying to understand in more detail the inadequacies of communication skills from both engineering students' and faculty perspectives, Gunn (2013) found the main areas of concern were grammar, spelling, lack of organization, unclear expression of ideas, poor verbal skills, difficulty with writing introductions and conclusions, and weak logic.

The results of a four-year development program using the capstone design course as a driver for developing engineers' communication skills revealed several deficiencies in students' performance. It was observed they had challenges presenting a big-picture view of their projects, thinking and talking about technical specifications, and appropriating material for their audience. In particular, students showed difficulty in selecting content and paring down information to fit within a 15-minute presentation, establishing a context at the beginning of the presentation, and organizing the presentation's components (Ford & Teare, 2006).

In a recent study comparing the writing performance of engineering students and practitioners, Conrad (2017) concluded students had more complicated sentence structures, less accurate word choice, more errors in grammar and punctuation, and less linear organization. Another set of problems found in the study included ignorance about genre expectations, weak language skills, and failure to appreciate that written descriptions of calculations are needed. According to Wren (2018), students' difficulties are normally related to lack of writing experience in general, including text knowledge, such as genre, structure of the text, what belongs to the introduction and conclusion, and differences between description and interpretation.

Some common challenges related to engineering students' communication skills were also observed by Soto-Cabanare, Selvi, and Avila-Medina (2011) during in-class presentations of research and design projects. Observations such as lack of preparation or rehearsal, ineffective use of presentation software and tools, excess of information on a single slide, reading from the screen or handouts, and inadequate use of graphics and images. These common mistakes found during the engineering students' presentations provided insights about what engineers still need to learn to better communicate in this context.

In addition to understanding the communication challenges faced by engineers and engineering students, it is important to identify the communication requirements they will encounter in the professional setting. Future engineers require more than technical skills and must have the creativity and communication abilities to innovate across disciplines (Benson et al., 2010).

Engineering Communication Requirements

From the perspective of executives, the communication competencies expected from engineers include effective description of tasks and ideas expression, successful interaction with high-level management, preparation and delivery of effective presentations including high-quality written materials, selection of the most effective medium to communicate the message, effective dyadic face-to-face communication, and appropriate communication with individuals with different cultural backgrounds (Norback et al., 2010).

Wisniewski (2018) summarized characteristics of effective engineering communication from the perspective of managers:

1. ability to interact with varied audiences (upstream, midstream, downstream, external) by addressing audience needs and using audience preferred medium (memo, reports, e-mail, text, phone, face-to-face, visuals).
2. ability to apply communication strategies by using appropriate structure and message focus, using clarity, concision, and a professional tone.
3. ability to apply interpersonal skills by delivering information confidently and working as a team.

Wisniewski (2018) also provided insights about engineering communication skills that could be improved from the perceptions of managers. The areas of communication improvement indicated in this study included:

1. provide a big picture context before describing technical details in both written and oral communication: engineers should tell a story to provide a larger picture of the project.

2. develop clear, appropriate written and visual material: this includes awareness of the audience, conciseness, direct communication, and the use of appropriate jargon and conventions of the profession.
3. provide confident, timely content to the audience: demonstrate interpersonal skills, confidence and assertiveness at meetings, initiative when seeking and sharing information, and initiate conversations with others using proper etiquette in-person and via e-mail.
4. increase interactions with downstream audiences such as technicians and operators: since engineers will interact with all levels of professionals, they must learn strategies to deal and solve interpersonal conflicts.

When it comes to the communication skills engineers will be required to use during their professional careers, different modalities can be addressed. Modern engineers are expected not only to produce technically appropriate designs, but to communicate these designs in written, oral, and graphical form to a variety of audiences ranging from their technical peers to the general public (Troy, Essig, Jesiek, Boyd, & Trellinger, 2014).

While engineers are professionally exposed to different communication methods, a significant part of their communication activities may be clustered in two main groups (Knisely & Knisely, 2015): technical writing (e-mails, white papers, site visit reports, operating manuals, literature reviews, feasibility studies, business letters, memos, project proposals, design reports, engineering specifications) and oral communication (meetings, telephone conversations, one-to-one conversations, presentations to technical and non-technical audiences).

Technical writing

There is an increasing demand for writing skills especially in the workplace, which requires the ability to express oneself in different situations and for more heterogeneous recipients than in the past (Wren, 2018). Writing is a visual form of communication that relies on literacy and attention of readers who interpret what is being read. Workplace writing is frequently evaluated by its functionality, or to what extent the text enables someone to accomplish a task (Kmiec & Longo, 2017). Writing as a professional activity is a way to be part of, and to manifest, their group membership. Additionally, writing is culturally conditioned and should always be considered in relation to the specific contexts in which it is used (Wren, 2018).

According to Knisely and Knisely (2015), what distinguishes technical writing from other written categories is the goal to inform rather than entertain the reader. Additionally, engineers must be able to write for non-technical audiences, making sure the message is understandable for the intended public. Another difference is the common use of passive voice to communicate actions, measurements, processes, devices, and procedures. Finally, another distinguishing aspect of technical writing is the tone, which is expected to be factual and objective. A list of characteristics of good technical writing is provided in Table 3.

Writing like an engineer or a technical professional requires the communication of specialized information that allows people to adopt and implement technologies for practical purposes (Kmiec & Longo, 2017). Kmiec and Longo (2017) also discussed four writing communication models that could be implemented in the engineering practice:

Table 3

Characteristics of Good Technical Communication (Knisely & Knisely, 2015)

Good technical writing is	**Good technical writing**
Clear and precise	Addresses the needs of the audience
Concise	Adheres to standards of the profession
Well organized	Uses correct and appropriate units
Well designed and laid out	Contains effective graphics
Grammatically correct	Avoids slang, clichés, and verbosity
Factual and objective	Makes appropriate use of passive voice

In the transmission model, writing is comprehended as a transaction in the everyday workplace environment where the worker encodes and transmits a message in writing, while the recipient receives and decodes it. The recipient's understanding of the message will depend on how accurately it was encoded. The channel used to transmit the message might be complex. For example, if there is a third person involved, the fidelity may be affected.

The correctness model assumes there is one best way to use language and quality writing is a process that matches certain universal criteria. According to the correctness model, strong writers are masters of preexisting patterns, so even though the writer is still responsible to make decisions, his or her choices are constrained by some external standard of what is correct. The Publication Manual of the American Psychological Association (APA) and the Chicago Manual of Style are examples of guides to a generally correct form of writing.

Cognitive/behavioral models consider how behavioral and cognitive psychology can be used to understand the production and reception of written communication. The goal is to consider how human communication such as writing can be designed to best suit physiological and psychological needs of humans. Cognitive researchers also investigate the readability of texts. In this sense, the ability of readers to read and comprehend a text is considered to be affected by many aspects such as visual elements (style, size, spacing of type) and linguistic ones (complexity of vocabulary and the length of sentences).

The social/rhetorical models assume writers make choices based on their understanding of what is appropriate in their context and within their community. Writing becomes a strategic process, requiring the analysis of the situation, the values of the community, and the observation of the community member's relationship and personalities. The adoption of the social approach requires the ability to articulate features of an audience or the social situation of text.

Each of these models has its own contribution to the hybrid model proposed by Kmiec and Longo (2017) for making writing decisions. They argued that writing in the workplace setting is a process of making strategic decisions about arguments, forms, and words that will best allow the communicator to achieve his or her goals. A robust technique for making writing decisions can be a combination of a rhetorical approach, considering how one could present an argument persuasively given one's sense of the social situation, and a pragmatic approach, observing the communication environment and imitating the forms, arguments, and words that match your communication conditions. When using a combination of the rhetorical and the pragmatic approaches, the following parameters should be considered:

1. *Purpose*: the reason why the document is being written, what is expected from the audience in response to the document, and what is intended to be accomplished through the document. A well-defined purpose can be an efficient instrument to evaluate specific writing decisions.
2. *Audience*: the person or multiple people targeted by the written communication. Audience is a complex term because it is never completely predictable how people will read a text, what associations will be made with certain arguments, approaches, or phrasings. For many workplace documents, multiple people can be addressed at once, and they have different interests and concerns. One of the strategies to deal with this challenge is to prioritize audiences systematically. Knisely and Knisely (2015) added that regardless of the medium, engineering messages need to be tailored to the audience, which may be another engineer, a company executive, a client, an entire engineering department, and technicians.
3. *Identity*: the identity of an author is related to the audience's views and expectations about the author. The trustworthiness of a writer shapes how the document is produced, received, and used. One of the largest influences on the audience's perception of one's identity is the relationship established with them.
4. *Context*: involves the various environmental and macro-social considerations that affect the way the audience receives and perceives communication. Context can include a larger corporate culture, requirements for publishing in a trade magazine, governmental and legal regulations. In considering the

writing situation, it is necessary to evaluate the professional and societal context of which the document will be part.

5. *Community*: is the observable organization of people around a set of workplace and communication practices, beliefs, and goals. A community of people may be formed around skills, such as professional engineers, around a common mission or goal, such as a corporation or labor union, or around common beliefs, practices, or approaches, such as political or religious groups.
6. *Genre*: types of written materials such as final reports to clients (Kmiec & Longo, 2017).

The most important types or genres of written materials indicated by practicing engineers and supervisors for use in the workplace include: instructions, meeting minutes, project work plans, proposals, technical reports, technical specifications, and status reports (Norback & Hardin, 2005). Kmiec and Longo (2017) classified the common written materials in categories: informative documents (e.g., reports, specifications), instructions and guidance (e.g., manuals, procedures, tutorials, training materials, policies), persuasive documents (e.g., proposals, business plans), and correspondence (e.g., e-mails, letters, announcements).

Teaching of writing skills arguably can be the most difficult communication skill to teach. Engineering students need to unlearn some of the writing skills they acquired before entering an engineering degree in order to learn how to write succinctly and objectively (Milke, Upton, Koorey, O’Sullivan, & Comer, 2013). From the perspective of Linsdell and Anagnos (2011), engineering students write best and become more engaged when they are interested in the topic and able to see the assignment assisting in their career or day-to-day life.

Knisely and Knisely (2015) argued that reading can be used as a catalyst to improve writing if students pay attention to word choice, logic flow, patterns of organization, and format. Even though reading by itself does not produce quality writing, its combination with writing practices serves to accelerate the writing development of students.

Troy, Jesiek, Boyd, Trellinger, and Essig (2016) suggested the approaches of 'write to learn' and 'learn to write'. They argued that writing exercises in technical courses can benefit students not only by improving their communication skills (learn to write), but also by developing critical thinking and a deeper understanding of technical concepts (write to learn).

According to Lord (2009), engineering educators can build on constructivist and knowledge transformation frameworks in order to promote successful writing experiences in engineering in the form of 'writing to communicate'. She proposed five guidelines for integrating the 'writing to communicate' experience into a typical engineering course:

1. Authentic investigation: students are motivated by having a clear purpose for writing such as communicating their own experimental results.
2. Tying the writing to the technical content: students are more likely to see the value of writing when it is tied to the technical content.
3. Authentic well-defined audience: the 'writing to communicate' experience is enhanced by specifying a particular audience.

4. Providing useful practice for an engineering career.
5. Not being overly burdensome to the engineering faculty instructors: since engineering educators may object to the time required to evaluate or grade writing assignments, it is important to ensure this activity does not become onerous to engineering faculty members. However, if engineering faculty tell the students writing is important, but do not include it in grading, they send a mixed message.

Lord (2009) also suggested that although including writing into a typical engineering course may be challenging due to the already full curriculum and numerous competing demands on faculty time, effective writing can be integrated into a variety of courses in engineering programs. Collaboration with colleagues with expertise in technical writing can be helpful in this sense.

In the perspective of Yalvac, Smith, Troy, and Hirsch (2007), simply integrating writing training into engineering courses is insufficient to help students acquire more advanced writing skills when considering the demands they will encounter as professionals. The authors argued that writing instruction in upper-level science and engineering courses can - and should - incorporate the skills and applications that students normally do not receive in general courses in English and composition (Yalvac et al., 2007).

In addition to writing, oral communication is considered another important part of engineers' professional routines. When it comes to oral communication skills necessary to succeed in the workplace, engineers must build rapport with all types of people. Engineers need to learn to display an honest interest in getting to know other people from their first interactions and treat everybody with respect and courtesy. Engineers need to understand individuals with different attitudes and perspectives due to their diversified backgrounds (Mohd Radzuan et al., 2008).

Oral communication

According to Dannels (2002), many technical disciplines, including engineering, have recognized and explored the role of oral communication in their curricula. She argued that speaking like an engineer is a process of translation, which can be the translation of technical material for non-technical audiences, translation of design results into visual information, translation of numbers into results-oriented structure, or translation of design results into sales discourse. She found five main features of effective oral presentation performance of engineers: simple, persuasive, results-oriented, numerically rich, and visually sophisticated.

Knisely and Knisely (2015) also provided general principles for successful oral presentations as follows:

1. The presenter takes into consideration the knowledge level of the audience while preparing the visuals and delivery.
2. The presenter establishes a good rapport with the audience.
3. The presentation is organized, focused, and coherent.
4. The audience feels satisfied and with the impression they have learned something new.
5. The visuals are simple, clear, and contribute to keep the audience focused in the important points.

Oral presentations tend to be much more selective in their content. The introduction is expected to capture the audience's attention, explain the motivation for the work, provide background information on the subject, and clarify the objectives of the work. The body is condensed and contains only the details necessary to emphasize and support the speaker's conclusions. If the intention is to highlight the results, the speaker can spend less time on the methods and more time on the visuals that support the findings. In the presentation closing, the speaker should summarize the objectives and results, state conclusions, and emphasize the take-home message for the audience (Knisely & Knisely, 2015).

A complete list of exceptional oral competencies in presentations was provided by Kerby and Romine (2009). A high-level of competence in oral communication is characterized by the use of eye contact that enables the presenter to read the audience reaction, be aware of the audience understanding of the topic, and interact with the audience.

Darling and Dannels (2003) presented a list of the most important oral communication genres for practicing engineers: public speaking, meetings, interpersonal or informal communication, training, and selling. The authors also indicated the types of oral communication skills reported as important by engineers: concise, clear, with organized and logical message construction, interpersonal and teamwork type interactions, confident public speaking delivery, listening, and honesty. The main audiences of oral communication identified in this study were peers inside the company, non-technical audiences outside the company, management, customers, government agencies, and employees. The perceived consequences of oral communication in the workplace were advancement in job, instrumental support, and job performance. Finally, the relative importance of oral communications skills such as audience analysis, persuasion, confidence, and teamwork, are considered a higher priority than the importance of writing skills. For the particular professional discourse community of engineers, the work gets done more through the communication practice of speaking than through writing (Darling & Dannels, 2003).

Formal versus Informal Written and Oral Communication Practices

Both written and oral engineering communication can happen in formal or informal ways. Waller and Gowen (2002) provided a framework for the understanding of how formality and informality can be related to written or oral communication. Formality considers whether communication is rehearsed or previously prepared and also takes into consideration the risk involved in the engineering communication process. A final design report is an example of formal written communication because it should be developed in advance, edited, and rewritten as it carries a high risk for the student submitting it. On the other hand, circumstantial e-mail messages among students as they draft and edit the report is considered informal, since the e-mail messages are composed spontaneously. If the audience does not understand the meaning of these e-mails, they easily have the opportunity to ask for clarification and, since the students share the same power position, there is lower risk to the writer of the e-mail than the risk associated with the formal report submission. Formal oral communication is frequently associated with giving speeches or performing oral presentations, while informal oral communication normally includes teamwork, team dynamics, group interactions, etc. (Waller & Gowen, 2002).

While formal communication such as writing and presenting are good ways to start developing interpersonal skills, other types of human relations are especially important for engineers in an increasingly interconnected world (Goldberg, 2006). Therefore, engineering communication at workplace requires engineers to develop a more holistic set of interpersonal communication skills.

Interpersonal Communication Skills

Interpersonal communication competence can be generally understood as the ability of an individual to manage interpersonal relationships in communication settings (Rubin & Martin, 1994). Huang & Lin (2018) explain that listening is one of the first components of effective interpersonal communication. Through active listening, the speaker is taken seriously and the listener shows interest in what the speaker is saying. Another characteristic of interpersonal communication skills is empathy, or the ability to identify with and understand someone's situation and feelings. The ability to communicate expressively with others is another important component as well as social relaxation. In sum, interpersonal communication can be segmented in four basic skills: listening, empathy, expressiveness, and social relaxation (Huang & Lin, 2018).

Engineers are constantly required to use their interpersonal communication skills at workplace. In the engineering context, interpersonal communication has been addressed as one of the components of a set of competencies termed performance skills (Seat, Parsons, & Poppen, 2001). The performance skills represent a topic of concern to both industry employers and engineering educators and include communication abilities, interpersonal interaction, conflict management, team performance, understanding of technical culture, and sensitivity toward diverse populations. In response to the need for the development of interpersonal communication skills of engineers there has been a call for communication instruction approaches that go beyond the training in oral presentations. In fact, there is a call for instruction in the oral genres of interpersonal interaction, small-group decision making, teamwork, negotiation, and interviewing skills (Dannels, 2001).

Whitcomb and Whitcomb (2013) provided a six-step cycle for interpersonal and technical engineering communication. The advantage of this approach, according to the authors, is that it balances technical and interpersonal communication and it can be repeated if necessary over the life cycle of a design development or project execution. The six-step cycle includes:

1. Context identification: establishment of rapport and understanding of the space, face, and place spectrum in which people are interacting.
2. Problem definition: definition of concerns or issues (what to talk about - primary technical, a balance of technical and interpersonal, or primary interpersonal). Attention to interpersonal dynamics that may be obscuring technical solutions.
3. Goals determination: communication expectations.
4. Alternates generation: alternates of more effective communication and behavior.
5. Action: choice of an action and follow through.
6. Iteration: repetition of the cycle as necessary.

Independent of the specific modality, educators may have doubts about the extent to which all these communication skills are teachable. Shuman, Besterfield-Sacre and

McGourty (2005) concluded that the set of professional skills listed by ABET among the outcomes to be reached through engineering education can be taught and assessed. They indicated that it is possible to teach these competencies, including communication skills, although not necessarily in the traditional lecture format, but as part of a modern engineering education approach such as active and cooperative learning.

Since ABET established and maintained as one of the outcomes engineering students need to achieve before graduation is “the ability to communicate effectively” (ABET, 2018, p. 3), countless educational interventions aimed at incorporating communication skills into engineering programs have been proposed and tested. Obtaining awareness about some of the educational initiatives to improve communication skills of engineering students may provide insights on which alternatives have the potential to offer positive results.

Educational Initiatives to Improve Communication Skills in Engineering Programs

Ford and Riley (2003) provided a list of the main types of efforts on integrating communication skills in engineering programs. These include writing across the curriculum approaches, interdisciplinary courses, integrated programs, and a variety of support systems such as writing and communication centers, and online resources. Kedrowicz and Blevins (2011) explained that through writing, speaking, or communication centers, not only students are provided with tips on how to complete writing or speaking assignments, but also faculty are instructed on how to evaluate said assignments. Donnel et al., (2011) argued that even though engineering faculty are often considered not sufficiently prepared to give communication feedback, recent collaborations between engineering and communication educators has strengthened many engineering faculty’s ability to provide useful and informed assessment on communication.

Another compilation of educational initiatives on developing communication skills in engineering programs was provided by Donnel et al. (2011). These include communication intensive courses in engineering departments co-taught by departmental communication faculty or taught by engineering faculty with help of communication specialists, technical writing courses in English departments, speaking courses in communication departments, and technical communication courses in engineering departments taught by communication specialists.

In addition to the teaching approaches mentioned above, several innovative learning experiences have been offered to engineering students in order to improve their communication skills in different contexts. According to Kedrowicz and Blevins (2011), the best model to infuse communication among engineering students is to couple it with actual engineering projects so they are able to see how communication is intricately linked with engineering problem solving and design. Donnel et al. (2011) added that coupling communication with situated project activities is a strategy that can be enhanced when the individuals teaching and advising these projects are themselves skilled communicators, aware of industry expectations for professional communication requirements.

Communication instruction is often placed in the senior capstone courses of engineering programs since such courses are most likely to engage students in activities similar to the reality in industry as well as to get feedback from industry representatives on students’ communication skills (Darling & Dannels, 2003). Paretti (2008) argued that because design courses typically involve students in authentic engineering tasks, these courses also offer the ideal context to allow students to experience authentic engineering communication to foster situated learning. While developing a design project, student teams need to communicate with colleagues, advisors, and outside experts to succeed, and each of these interactions offers opportunities for situated learning because students understand how their documents and presentations function in the design activity.

Norback and Hardin (2005) argued several reasons for introducing communication education in capstone design courses. Firstly, students work with industry and other employers to solve real-life problems. Secondly, the students are typically about to start their first jobs, which make the workforce communication instruction more relevant. Finally, senior design courses offer the opportunity to give students feedback in small groups. Fries, Cross, Zhou, and Verbais (2017) found that students were able to improve their written communication skills significantly during an industry-sponsored capstone design course. They concluded that industry participation was an additional motivation for improvement compared to a course without industry participation. Students improved especially in the areas of grammar, spelling, and organization of content.

A different combination between design and communication courses was described by Hirsch et al. (2001). Through the Engineering Design and Communication (EDC) initiative, students studied the design process as well as the communication process, while working on conceptual design projects for real clients. With collaboration between engineering and arts and sciences faculties, students were coached in oral, written, and graphical communication while studying the design process. Their training also included meeting with clients, interviewing users, running focus groups, and presenting design reviews. Additionally, students were regularly involved with team process checks and learned about interpersonal communication. The expected outcome from this initiative was not only conceptual design, but well-conceived documents and persuasive oral proposals. The general evaluation of EDC from faculty and students was considered positive as an interdisciplinary venture (Hirsch et al., 2001).

Communication and design, explored together in engineering programs, has remained as an alternative to develop communication skills of students. Mullin and VanderGheynst (2018) described an elective class offered to all engineering students at the University of California Davis, regardless of their class standing or major. The goal was to provide connections between engineering content, oral communication skills, and creative problem-solving. In the implementation of the course in 2017, a new design project was incorporated. Twice weekly, hour-long lecture sessions were attended by all students where several communication and engineering design topics were presented. The majority of students enrolled in this course included sophomores, followed by freshman, juniors, and one senior. Different engineering programs such as aerospace, civil, electrical, mechanical, and other engineering disciplines were represented among the students. The communication-focused lectures addressed topics such as active listening, developing verbal arguments, teamwork, communicating as an engineer, and rhetorical elements. These topics were combined with design-specific lectures. Design topics included key stages of the engineering design process such as identifying needs, background research, problem definition, brainstorming, product benchmarking, prototyping, and testing, among others. Preliminary course results included gains in students' design self-efficacy and confirmed the potential for integrated communication and design course(s) in undergraduate engineering curriculum across engineering majors and years.

Based on the premise that engineers engage more in the process of developing their communication skills by learning from real marketplace executives about the specific kinds of communication competencies they will need in their careers, Norback et al. (2010) described the successful initiative of incorporating executive panel interaction into a capstone design course to align student skills with employers' expectations. An executive panel can be defined as a group of specifically selected industry leaders who devote time to provide expert opinion and real-life experience in the field. The direct benefits derived from the executive-student interactions were emphasized in this study, as well as the chance of obtaining other advice from executives such as inputs to a more advanced communication instruction. The executive panel experience not only allowed students to be exposed to the business community and the real-world scenario, but also increased students' awareness of the importance of communication skills, provided an understanding of the concept of communication from executive's perspective, about how communication with senior management occur, what are the workplace's expectations regarding presentations and business writing, communication mediums, face-to-face communication, and cross-cultural communication (Norback et al., 2010).

Even though many experts agree the capstone design experience is the most appropriate time to develop professional competencies, including communication skills, among engineering students, Kedrowicz and Blevins (2011) argued that setting the tone for the importance of communication to future engineers should start at the beginning of the program. They described a successful case of integration of communication skills in a freshman civil engineering class with more than 100 students. This integrated communication program incorporated communication, teamwork, and ethics instruction into undergraduate students' required core classes. Two communication instructors were assigned to team-teach with an engineering professor in designated classes. This split-class model was developed to accommodate individualized attention on speaking and writing. Overall, the feedback of this educational initiative indicated students' satisfaction with instruction on writing, speaking, and teamwork. Students pointed out that information about grammar and style was particularly helpful for writing improvement. In terms of oral communication instruction (speaking), students liked the tips on how to organize and deliver a presentation. With respect to teamwork, students found it very helpful to learn how to communicate effectively, and how to cooperate with their team members (Kedrowicz & Blevins, 2011).

Another approach was described by Harichandran, Adams, Collura, Erdil, and Harding (2014) through the Project to Integrate Technical Communication Habits (PITCH) in the University of New Haven. The project spanned seven engineering and computer science undergraduate programs, with the general goal to develop written, oral, and visual communication skills, and professional habits in engineering students. PITCH activities began in the students' first semester and continued during all four years of each program, having senior design as the culminating experience in which students were expected to demonstrate the skills and habits acquired through PITCH courses. The learning outcomes for the project were established based on surveys involving employers, alumni, and faculty. Specific courses within all four years of each program were targeted for implementation and assessment of technical communication skills so that competencies could be developed at deeper levels as students progressed through the years. The technical communication skills were fully integrated into the content of regular engineering courses, and were taught by regular engineering faculty, which made the project sustainable over the long term. Faculty members were trained by an external consultant through summer workshops to deliver and assess the technical communication instruments in their courses.

After two years of PITCH implementation, improvement in student writing was achieved. There was difficulty in consistent grading of writing made by different engineering instructors because the ability to assess technical writing and provide effective feedback was widely different. Faculty commitment to advancement in technical communication was a challenge. Strong leadership and support at the college and institutional levels, partnerships with technical communication consultants or faculty members, and a sufficient number of core faculty members who believe in the value of effective technical communication were critical factors for success (Erdil et al., 2016).

From the perspective of Linsdell and Anagnos (2011), motivating students to practice and improve their communication skills is much easier when they understand and experience the future workplace applications. By describing the successful experience of combining classes of communication skills with an environmental course, the authors concluded this strategy provided an ideal context for the types of writing tasks engineering graduates would engage in the workplace. The results of this initiative were optimistically evaluated in terms of goals achievement, and the use of the same model for other engineering programs was suggested.

Eggleston and Rabb (2018) proposed that communication instruction could benefit from being anchored in the Project-based Learning (PBL) approach. They reported engineering students' improved abilities to present information and convey meaning more precisely through the combination of this approach with communication instruction. They also concluded that designing a technical writing and communication class with the PBL approach offers engineering students exposure to and mastery of situated, professional, and STEM-specific writing and presentation tasks, resulting in a positive impact on engineering classes and positive perceptions from students regarding their own professional skills development.

Paretti, Eriksson, and Gustafsson (2019) explored how communication instruction can provide benefits that go beyond the improvement of engineering students' communication skills. In this case study, both faculty and student participants identified learning gains associated with engineering content from integrated communication practices. Additionally, faculty noticed that integrated writing and presentation assignments helped students to appropriately recognize and prioritize relevant components of their work, particularly in large and complex open-ended situated projects. The study also suggested that, by identifying and selecting important information or attending to the ideal level of details, students engaged in communication tasks within their technical courses learned not only what the discipline values, but also what potential audiences value. Finally, it was observed that the integration of disciplinary communication assignments required students to justify decisions in ways that reflected the types of logic and reasoning valued by the engineering discipline or potential stakeholders.

Mottart and Casteleyn (2008) argued that before proposing a teaching rationale that would successfully integrate communication training to engineering courses, it is important to define the characteristics of a good communicator. They suggested that communicating effectively is a rhetorical approach to communication, and if educators want to train students to communicate effectively, they should confront them as much as possible with the audience perception. In the perspective of Bercich, Summers, Cornwell, and Mayhew (2018), the intentional development and reinforcement of technical communication skills throughout engineering undergraduate programs can be considered beneficial to students.

An alternative approach to infuse communication instruction in engineering programs is communication in the disciplines (CID). According to Dannels (2002), in many disciplines such as business, accounting, engineering, mathematics, and others, specific CID scholarship is becoming more relevant in the students' preparation for the workplace.

The CID Approach

CID is an additional model of communication across the curriculum (CXC). CXC programs provide assistance to other disciplines on the teaching and learning of communication skills with the purpose to meet an increasingly demand for students that are not only content specialists, but also coherent communicators (Dannels & Housley Gaffney, 2009).

CID is a communication pedagogy grounded in principles of situated learning, disciplinary knowledge construction, and the social construction of speaking. The CID framework recommends curricular and pedagogical implementations, and suggests specifically that communication instruction across the curriculum should focus on oral genres, standards of effectiveness, and evaluation practices of the target discipline. This approach considers that student learning that occurs in general, basic courses can be enhanced with instruction that is situated within practices that are important to the discipline. A CID model provides a different alternative for learning communication that builds upon the work done in the basic courses. Essentially, a CID model is based on a situated communication pedagogy, characterized by the following theoretical principles:

1. oral genres are sites for disciplinary learning.
2. oral argument is a situated practice.
3. communication competence is locally negotiated.
4. learning to communicate is a context driven activity (Dannels, 2001).

Through the CID educational approach, disciplines collaborate with each other to enhance the alignment of students' communication competence and the perceived needs of their discipline and professions (Sullivan & Kedrowicz, 2011). A CID model for cross-curricular work would motivate students to consider the particular context-specific audiences they will interact with as they move into their subsequent professional experiences (Dannels, 2001).

Darling and Dannels (2003) provided an example of how research based on the CID framework can bring insights to better design instruction in engineering. The goal of their study was to understand the discipline-specific oral communication genres, skills, purposes, and audiences that are typical of the engineering workplace from the perspective of practicing engineers. They described the engineering workplace as an oral culture, where engineers are not necessarily involved in formal speaking events, and highlighted the importance of interpersonal skills. The study provided empirical support for the claim that engineers are very involved in talking activities and that oral communication matters greatly in this work environment. Many implications for the CID curricular design were discussed. For example, the authors mentioned that rather than having a focus on public speaking skills, the teaching efforts should be on teamwork and other small group oral genres such as meetings. They also argued that instructional materials should focus on the kinds of teamwork expected of engineers and what types of communication skills make the teams more effective. Additionally, the communication efforts in engineering programs would benefit from moving beyond the traditional content to providing numerous opportunities to develop skills in listening, clarity, and negotiation. These considerations are consistent with what was suggested by practicing engineers in the study of Wisniewski (2018). Engineering practitioners suggested that educators should increase students' exposure to communication used in meetings, make them aware of the importance of building relationships with downstream and external audiences, offer more practice on informal communication genres, and raise their awareness of strategies for working with multi-disciplinary peers.

In another research involving the CID approach, with a special emphasis in oral presentations, Darling (2005) studied the communication practices of one disciplinary community of mechanical engineering students and concluded that this community was driven by the discourse of technology. In other words, the discourse of technology was constantly influencing the ways of talking in the community, and specifically the ways of speaking in the public presentation genre, so that preference for the concrete artifact overshadowed a focus on the individual. Darling explained that even though it does not mean engineers do not produce and negotiate their identities and relationships through talk, it means they do so through talk about the objects they are designing, and this feature should guide CID practitioners' decisions when working with technological disciplines such as engineering.

Dannels (2002) also provided a contribution for instructional scholarship and CID practice in engineering. This study supported the idea of oral genres as sites of disciplinary knowledge construction. For example, students learned that developing and performing oral presentations with numerical evidences, substantive visuals, and deductive organizational structure were real engineering skills, so that oral presentations became sites for reproducing the norms, epistemologies, and values of the engineering discipline (Dannels, 2002). Another important implication of this study for the CID scholarship was that orality was recognized as a site for disciplinary socialization, so learning to speak was not just about delivering content, but a process to learn how to become disciplinary members. Based on this study, Dannels argued that educational initiatives on engineering communication should provide useful information that supports the socializing processes such as translating technical material for non-technical audiences, design processes into results-oriented structures, design experiments into persuasive numerical evidence, and translating technical material into sophisticated visuals. Finally, the study supported the idea of orality as a site for negotiation of disciplinary tension, through which oral genres in engineering should bridge the discipline with the larger public. To do this, engineering students should be trained to be simple, clear, and persuasive.

These examples demonstrate that research and practice of the CID approach can provide an alternative strategy to develop the communication skills of engineering students so they can become better prepared for workplace communication challenges.

Summary

Engineering communication has been a topic explored in the scientific literature. However, the need to understand the communication requirements and challenges associated with the engineering workplace is still considered a relevant topic of research since there is a persistent perception that engineers must improve their communication skills.

Engineering communication challenges are mainly associated with difficulties in writing and public speaking. Engineering communication requirements include a long list of expectations. Modern engineers not only need to produce technically appropriate designs, but to communicate these designs in written, oral, and graphical form to multiple audiences ranging from their technical peers to the general public (Troy et al., 2014).

Both traditional and innovative educational initiatives on improving the communication skills of engineering students have been ongoing in universities across the country. Among these initiatives, the CID approach has become an efficient alternative to contribute to the students' evolution as communicators according to the workplace's expectations.

CHAPTER 3

METHODS

Understanding industry's expectations of engineering communication skills is still an underexplored scientific research topic, and according to Creswell (2014), when a phenomenon needs to be explored and understood more deeply because little research has been done, this topic merits a qualitative investigation. For this reason, and due to its purpose of addressing a specific human component of the engineering profession, a qualitative approach was implemented in this study. The selection of a qualitative approach was also driven by the nature of the research questions, as recommended by Borrego et al. (2009). The research questions established for this study are:

1. How are the specific communication skills expected from practicing engineers in industry described?
2. What are the communication challenges of practicing engineers?
3. In what ways are engineering communication requirements different across varying industrial segments?

Qualitative research is a situated activity through which the observer makes the world visible through a set of interpretive, material practices that turn information into a series of representations, including field notes, interviews, conversations, photographs, recordings, and memos to the self (Denzin & Lincoln, 2011). Qualitative research requires detailed attention to language and deep reflection on the emergent patterns and meanings of human experience (Saldaña, 2013).

Borrego et al. (2009) explained that while quantitative studies emphasize large samples to generate a broad and generalizable description that is representative of most situations, qualitative research focuses on smaller groups in order to examine a context in detail and provide a description of a particular situation in depth.

Qualitative researchers study things in their natural settings, in an effort to make sense or interpret the phenomena through the meanings people bring to them (Denzin & Lincoln, 2011). Given the critical role of qualitative researchers in the interpretation of data (Creswell, 2014), one of the first steps in conducting studies using this approach is to determine and clarify the philosophical assumptions brought to the research. These are ingrained views about the nature of the problems to be studied, the research questions to be asked, and the data collection strategies to be chosen (Creswell, 2013).

This study is built on an epistemological assumption. Conducting a qualitative study with the epistemological assumption implies the researcher needs to be as close as possible to the participants in an attempt to assemble subjective evidence based on individual views. Through the subjective experiences of people, the epistemological assumption refers to how knowledge is known, and for this reason, it is important to conduct the study in the field where participants live or work. As prescribed by Creswell (2013), this study was conducted in the workplace where engineers develop their professional communication skills so participants' perspectives could be better understood through the contextualization of their work environment.

In the sequence of establishing the methodological foundations of this study, it is also important to provide clarifications about the interpretive framework or worldview that would guide its development, the social constructivism. According to Creswell (2014), through a social constructivist framework, the research goal is to rely as much as possible on the participants' views of the situation in order to seek an understanding of the world in which they live and work, and then to develop subjective meanings of their experiences. Inquirers may inductively develop a theory, instead of starting with a theory as in the post-positivism framework. Additionally, researchers recognize their background shapes their interpretation, and thus position themselves in the study.

Borrego et al. (2009) addressed the role of theory in scientific research as a description or explanation of a phenomenon. They argued that in quantitative studies, theory is utilized early in the research design to identify hypotheses and to select appropriate instruments of measurement, and the use of theory in qualitative research comes much later, if at all, as the lens through which the results can be interpreted. Data are examined without preconceptions as to existing theory, and themes emerge from the data. Even when the development of a theory is not the goal of a qualitative study, one of the strengths of the method is that new phenomena can be identified, which would not have been expected if the research was driven by pre-established hypotheses.

This study considered existing communication theories, such as the hybrid model proposed by Kmiec and Longo (2017) for making writing decisions and the most important oral communication genres for practicing engineers according to Darling and Dannels (2003). These theories were used as the lens through which data were collected, analyzed, and interpreted, but without letting them generate preconceptions or limitations in the research process. A special focus on communication in the disciplines (CID) complemented the theoretical framework guiding the development of this study. CID has been defined as “a model of situated pedagogy that prepares students for the communication demands of their professional work” (Sullivan & Kedrowicz, 2011, p. 389), by intertwining educational practices on communication with the norms, values, and ideology of specific disciplines or discourse communities. Darling and Dannels (2003) explained that CID provides a theoretically grounded rationale that can bring to communication instruction a discipline-specific perspective. Research developed with the CID approach guided both the development of some questions in the interview protocol (Darling & Dannels, 2003) and the analysis of the data collected in this study (Dannels, 2002; Darling, 2005; Darling & Dannels, 2003). In the analysis and interpretation of data, the CID approach provided a guidance for the identification of the discipline-specific communication genres, skills, purposes, and audiences typical of the engineering workplace. For example, the identification of the engineering workplace as an oral culture, where engineers are not necessarily involved in formal speaking events, but are continuously involved in interpersonal interactions (Darling & Dannels, 2003), was also identified in the data collected from the four industrial segments investigated in this study.

Methodology and Methods

Having defined the epistemological approach, the constructivist worldview, and the theoretical framework for this research, case study was identified as an appropriate methodology for the development of this qualitative research. As defined by Yin (2017), through case studies a contemporary phenomenon (the case) is investigated in depth and within its real-world context.

A qualitative case study involves the search for meaning and understanding, and its primary instrument of data collection and analysis is the researcher. Additionally, it is an inductive investigative strategy with a richly descriptive end product (Merriam & Associates, 2002).

Widely found in many fields, case study is a design of inquiry in which researchers perform a deep analysis of a case, which can be a program, event, activity, or process, and includes one individual or groups of individuals (Creswell, 2014). Denzin and Lincoln (2011) argued that even though case study is a methodology sometimes held in low regard, much of what we know about the empirical world has been produced by this strategy of inquiry, and many of the most valuable classic studies in different disciplines are case studies. Huberman and Miles (2002) discussed how to judge the quality of case studies. They explained that case studies should empower, activate, and stimulate the level of responsiveness of the reader, as well as facilitate the application of the study insights.

A worthy case should be a real-world phenomenon with some concrete manifestation. The case should not be an abstraction such as a claim, an argument, or a hypothesis. Examples of more concrete case study topics are individuals, small groups, organizations, and projects, while less concrete topics include communities, relationships, decisions, and partnerships (Yin, 2017). This study investigated the concrete manifestations of engineering communication within organizations of four different segments of industry.

Cases Selection

The process of conducting a case study starts with the selection of the cases. This selection is not done randomly, but purposefully, so that a person, site, program, community, or other bounded system is selected according to the characteristics of interest to the researcher. “The case might be unique or typical, representative of a common practice, or never before encountered (Merriam & Associates, 2002, p. 179)”.

For this study, four cases from different industrial segments were selected. Creswell (2014) argued that even though there is no specific answer for the question concerning the ideal number of cases in a case study, this number may be around four or five. Creswell (2013) added that the range of cases is expected to provide enough opportunity to identify themes and conduct cross-case theme analysis. The rationale behind the selection of the four industries for this study was the identification of industrial segments with significant hiring rates of practicing engineers and the most attractive employers from the perspective of students pursuing engineering in the United States. Reliable sources of data were utilized for the identification of these industrial segments: the Bureau of Labor Statistics (BLS, 2018a), Data USA (2018), and Universum (2017).

The BLS is the main fact-finding agency for the federal government in the broad field of labor economics and statistics. The BLS collects, processes, analyzes, and disseminates essential statistical data to the American public, the U.S. Congress, other federal agencies, state and local governments, and other interested organizations (BLS, 2018b). The BLS provides recent and projected data about employment in the engineering profession. In the occupational outlook handbook of the BLS, different engineering disciplines are grouped in a category named ‘architecture and engineering’. Engineering occupations account for more than 50% of the entire architecture and engineering category. Electrical and electronics engineers, civil engineers, mechanical engineers, and industrial engineers are respectively the leading occupations among all the engineering disciplines (BLS, 2018a).

Another source that provided data to support the selection of the cases for this study was Data USA. This is a comprehensive online representation of the United States data, which combines eight publicly available government data sets (Datawheel, 2018). Using the same wide category used by the BLS – architecture and engineering – Data USA (2018) provided a ranking of the industries with higher hiring rates. The top industries hiring professionals in the category of architecture and engineering are architecture, engineering and related services, electronic components and product manufacturing, aircraft and parts manufacturing, motor vehicles and motor vehicle equipment manufacturing, and construction (Data USA 2018).

The last source of data considered in the selection of the cases for this study was the report provided by Universum (2017) addressing the most attractive employers from the perspective of students of business and engineering majors worldwide. Universum is a global research company that works with several industries, universities, alumni groups, and professional organizations to gather insights from students and professionals in order to advise employers on how to attract and retain talents. Universum provides services in several markets throughout the globe and is physically present in 20 countries (Universum, 2018). Annualy, Universum unveils the list of the World's Most Attractive Employers (WMAE). In the 2017 report, 294,663 students were surveyed, including 149,226 engineering/IT students, in the world's 12 largest economies: Brazil, Canada, China, France, Germany, India, Italy, Japan, Russia, South Korea, the United Kingdom, and the United States.

Based on the data observed in the sources aforementioned, the four industrial segments selected for this study were: High-Tech, Automotive, Aerospace, and Manufacturing. These four industries are significant representatives of the main employers of the top engineering occupations: electrical and electronics engineers, civil engineers, mechanical engineers, and industrial engineers (BLS, 2018a), and include the most attractive industries for future engineers according to Universum (2017). A similar approach in the selection of industries was used by Norback et al. (2010) by strategically targeting organizations that could represent potential employers for engineers.

For each industrial segment, one participant company and two participant engineers were invited to participate in this study. Engineers currently working in leadership positions in these companies participated in face-to-face qualitative interviews. Purposeful and convenience sampling (Creswell, 2013) were utilized in the process of selecting these engineers, since participants were identified from the alumni pool of USU. Relevant data about the companies and the engineers participating in this research are summarized in Table 4 and Table 5.

Table 4

Participant Companies Data Summary

Industry	**Company**	**Size of Organization**	**In-company Training in Communication**	**Performance Evaluations of Communication**
High-Tech	Company 1	~ 130	No	Yes
Automotive	Company 2	Locally ~ 400 Globally ~ 60,000	Yes	Yes
Aerospace	Company 3	Locally ~ 100 Globally ~ 12,000	Yes	Yes
Manufacturing	Company 4	Locally ~ 450 Nationally ~ 25,000	Yes	Yes

Table 5

Participant Engineers Data Summary

Industry	**Engineer**	**Job Title**	**Highest Degree Earned**	**Number of Years in Industry**	**Previous College Coursework on Communication**
High-Tech	Engineer 1	Product Manager	B.S. in Mechanical Engineering / BS in Business	15	Yes
High-Tech	Engineer 2	Director of Research and Development	Ph.D. in Mechanical Engineering	14	Yes
Automotive	Engineer 3	Senior Director/Plant Manager	B.S. in Mechanical Engineering	32	No
Automotive	Engineer 4	Principal Engineering Fellow	MBA and MS in Mechanical Engineering	34	Yes
Aerospace	Engineer 5	Senior Director of Engineering	M.S. in Mechanical Engineering	31	Yes
Aerospace	Engineer 6	Director of Electrical Engineering	M.S. in Systems Engineering	31	Yes
Manufacturing	Engineer 7	Chief Metallurgist	MBA	16	Yes
Manufacturing	Engineer 8	Maintenance Manager	MBA	23	No

The companies representing the four industrial segments selected for this study have their own characteristics as organizations. The specific features of the participating companies of each industrial segment are described below.

High-Tech industry

The high-tech industry is represented in this study by a company considered a world leader in vehicle automation. From the company's headquarters in northern Utah, the organization serves clients in the mining, agriculture, automotive, government, and manufacturing industries with remote control, teleoperation, and fully automated solutions.

In the mining business, the company has partnered with major players in the industry to deliver vehicle automation technologies that have revolutionized mining operations. In the agriculture field, the company has worked to bring about the technology of robotic agriculture with fully autonomous farm equipment. The automotive industry is another focus of the company. Research and development in the company related to this industry have allowed innovative solutions that rewrite the way vehicles are tested with safety, accuracy, and efficiency. Additional innovations of the company can be found in many other segments such as orchard/vineyard, security, and military.

The company has around 130 employees. The main building is very modern. Many walls and windows are made of glass, which conveys the idea of a transparent and open environment. Technology is everywhere from the conference rooms to the test centers. Employees work in an apparently comfortable and informal environment typical of high-tech companies.

Engineers in this company are not involved in formal communication skills training. They are only instructed by the human resources department about ethical ways to communicate, especially in interviews with candidates for new job positions. Similarly, performance evaluations of communication skills of engineers occur indirectly through quarterly and yearly general performance evaluations of the leadership and other employers.

Automotive industry

The company selected to represent the automotive industry in this study is a worldwide leader in automotive safety. The company's products are sold to all major car manufacturers globally. The company has global presence and operations in 27 countries. The organization is a Fortune 500 company headquartered in Stockholm, Sweden, and incorporated in the state of Delaware. The company is the result of a merger of a Swedish and a U.S. company.

The organization develops, manufactures, and markets airbags, seatbelts, and steering wheels. More than three airbags or seatbelts made by the company have been delivered to every vehicle produced globally during the past ten years. The company has been responsible for many of the major technological breakthroughs within automotive safety for more than 60 years.

The specific company's office visited during this study is a very modern plant located in Utah, where around 400 employees work. Globally, the company has more than 60,000 employees. Many employees work in an open environment with individual cubicles very close to each other where communication is clearly facilitated. Other rooms around the cubicles are more private, but their walls are made of glass, which also convey a sense of open communication between leaderships and employees.

The airbags produced by the company are exposed in a separate wall where the cubicles are placed. Colorful walls and decoration give the impression of modernity. Employees circulate freely in the office and the dress code seems to be informal. Employees are apparently comfortable in the work environment.

The company has trained engineers in some communication skills, specifically presentation skills. The communication performance of engineers is evaluated through two or three questions in the general assessment of each employee.

Aerospace industry

The aerospace industry is represented in this study by a global leader in aerospace and defense technologies. The company designs, builds, and delivers aviation, defense, and space systems for customers worldwide, both as supplier and contractor. Products developed by the company include: launch vehicles and related propulsion systems, missile products, subsystems and defense electronics, precision weapons, armament systems and ammunition, satellites and associated space components and services, and advanced aerospace structures. The company's headquarters is in Dulles, Virginia. Approximately 12,000 people in 18 states across the U.S. and in several international locations work for this organization.

The company's plant in Utah has a very traditional architecture. Around 100 employees work in this facility. In front of the main entrance, a real rocket with the NASA logo is exposed, and catches the attention of anyone passing through. Inside the company, in the main lobby, institutional videos about the company's accomplishments are presented on a big flat screen, while the decoration conveys more modernity than the external area. Some employees wearing blue uniforms circulate in the facility. Other employees dressed business casual can also be seen circulating inside the office. The overall internal environment can be easily associated with a place focused on scientific research and development.

In this company, engineers in leadership roles are trained in some communications skills, especially those related to how to effectively communicate with subordinates, and they also have their communication skills assessed in internal performance evaluations.

Manufacturing industry

In the manufacturing industry, the company participating in this study is a steel manufacturer with a wide range of products and sizes that serve a variety of markets from agricultural and automotive to construction, energy, and shipbuilding. The company is part of a bigger conglomerate which is a Fortune 500 organization with approximately 200 operating facilities.

The company is considered very profitable in its specific industry and does high investments in innovation. Quality is also an important aspect of the business. Throughout every step of the manufacturing process, the company utilizes in-process controls, and conducts mechanical and dimensional audits to continuously monitor the quality of its products. The company also implements lean manufacturing workplace systems to improve safety, to identify problems faster, and to increase quality practices.

The specific plant visited in this study is a big and complex facility with a traditional and simple architecture. Workers circulate in a casual dress code, using safety accessories. No specific style of decoration can be identified inside the buildings. The overall environment seems to be influenced by a sense of safety, practicality, and hard work.

Engineers in this company are exposed to different internal training programs, including classes related to communication skills such as dynamic presentations.

Data Collection

According to Creswell (2013), the data collection process is a series of seven interrelated activities, with the intention of gathering valuable information to answer the research questions. These seven data collection activities are summarized in Figure 2.

Creswell explained that, although the researcher may start the process with locating a site or an individual, another entry point in the circle can be used. As shown in the figure, the data collection activities consider the importance of gaining access and to establish rapport with participants. Through the purposeful sampling, rather than the probability sampling, it is necessary to intentionally sample a group of people that can best inform the researcher about the problem under examination. After selecting sites and people, the most appropriate approaches to collect data must be defined. To collect information, the researcher normally develops protocols or written forms and defines ways for recording data, such as interviews or observational protocols. Additionally, potential issues related to data collection (e.g., recording information) – field issues – should be anticipated. Finally, the researcher must decide appropriate ways to store data and protect it from damage or loss.

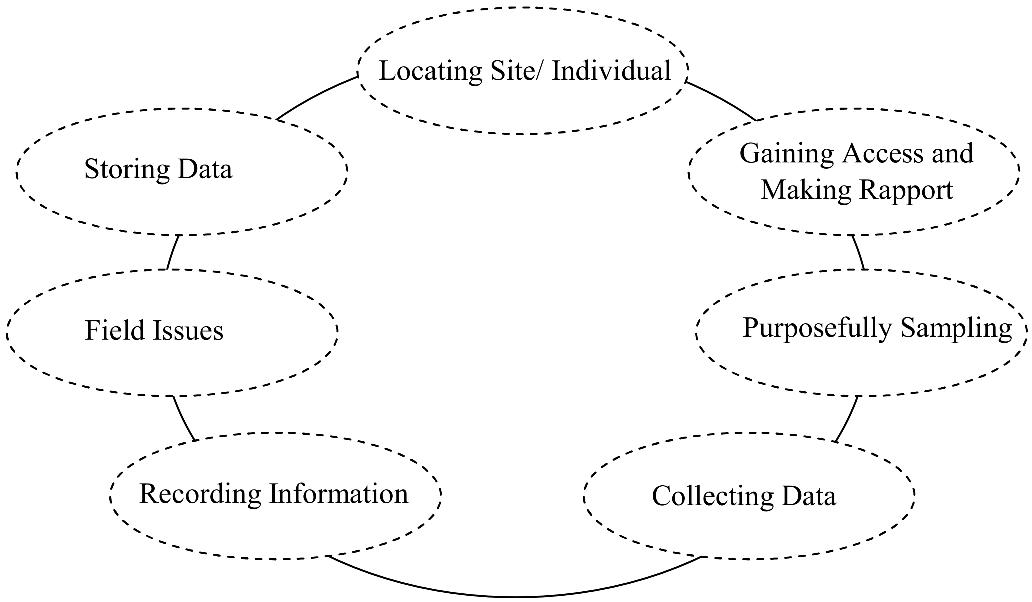

Figure 2. Data collection activities. Adapted from "Qualitative Inquiry & Research Design: Choosing among Five Approaches (3rd ed.)", by J. W. Creswell, 2013. Copyright 2013 by Sage Publications.

In this study, participants from the four industrial segments selected were initially identified from the pool of alumni at USU. This same strategy was adopted by Norback et al. (2009) in the process of recruiting executives for interviews and panels on the topic of engineering communication. Engineering professionals from the researcher's network were also contacted, either to participate in this study, or to indicate potential participants. While the sampling process considered the profile of the participants, which was determined as engineers currently working in leadership positions in industry, the case study sampling strategies adopted were purposeful and convenience (Creswell, 2013), including sites or individuals accessible to the researcher. The first contact with the potential participants was established through e-mail and phone calls. Potential participants received an electronic formal letter with a concise description of the study and its objectives and were invited to contribute with the research. A letter used to invite participants can be found in the Appendix A.

The main procedure of data collection in this study was qualitative interviews. Interview is one of the most important sources of evidences in case studies and commonly found in this research design. Interviews can provide good explanations of key events, as well as insights on the participants' perspectives. Case study interviews are normally in the form of guided conversations rather than structured questions (Yin, 2017). In this study, interviews with practicing engineers were expected to reflect their current perspectives on engineering communication skills required in the workplace, the challenges they encounter in their role, and the communication requirements in the specific industry they work.

Participant engineers were invited and engaged in face-to-face interviews. According to Creswell (2014), in qualitative interviews, the interactions with respondents can be done face-to-face or through alternative communication means, such as phone calls.

Given the nature of the research questions established for this study, in-depth interviewing was considered the most appropriate strategy to interact with participants, as recommended by Gubrium, Holstein, Marvasti, and McKinney (2012). Largely associated with inductive research, in-depth interviewing is more suitable if the research questions are descriptive or explanatory, such as how and what questions. The emphasis of in-depth interviewing is on how individuals and groups make their experiences meaningful in their everyday activities, events, or places (Gubrium et al., 2012).

While performing the in-depth interviews, the researcher was guided, but not restricted, by the questions included in the protocol available in Appendix B. This means that when unpredicted insights on engineering communication emerged spontaneously from participants' perspectives, these ideas were included among the collected evidences. The interview protocol was developed with the assistance of a qualitative research expert and a communication expert from the faculty team in the Department of Engineering Education of USU. Some of the questions were adapted from previous studies on engineering communication (Darling & Dannels, 2003; Norback & Hardin, 2005; Norback et al., 2010).

Approval from the Institutional Review Board (IRB) was sought by submitting a proposal with details of the procedures to be implemented in this study (Creswell, 2013). A consent form was developed for participants' review and signature in order to have their authorization for participation in the study appropriately documented. Appendix C contains this informed consent.

In addition to using the interview protocol and taking notes during the interviewing process, data collected was audio recorded (Creswell, 2013), and subsequently transcribed by professional transcribers from the company Speechpad contracted by the researcher. Speechpad is a company specialized in protocol transcriptions. Speechpad provides high-quality transcriptions and captions at competitive prices. The company has an international customer base that ranges from Fortune 500 companies to boutique businesses and individuals. The company began its operations in 2008, and the services provided are based on high accuracy transcripts and captions, consistency and reliability (Speechpad, 2018). The interviews were transcribed in the text format and then imported in the software MAXQDA for subsequent qualitative analysis (MAXQDA, 2018).

Data was stored by using appropriate technology such as hard drives and cloud computing storage such as Box (Box 2018), making sure backup files were created, and anonymity of participants and organizations was respected.

Field issues, such as the logistics to access the companies, the scheduling of interviews according to the participants' availability, and the expected time to be spent on each data collection session, was handled and negotiated with organizations and the engineers who agreed to contribute to this study. The expected time spent on interviews was between 45 minutes and one hour as suggested by Norback and Hardin (2005). Participants were offered an incentive of an Amazon gift card valued at $50 USD.

Data Interpretation

The general intent of data analysis in qualitative research is to make sense of text and image data, in addition to segmenting and taking apart the information, and then putting it back together. Data analysis in qualitative research normally occurs simultaneously with other parts of the process, including data collection, and the writing of the findings. For example, while one of the interviews is occurring, the researcher may be analyzing an interview collected earlier, or organizing the structure of the final report (Creswell, 2014).

Data analysis in case studies is not constrained by restrictive rules, but can be challenging for non-experienced researchers. One of the suggested starting points is to search for promising patterns, insights, or concepts while going through the data, in order to define what to analyze and why (Yin, 2017).

In this study, the following steps indicated by Creswell (2014) guided the analysis of the data collected:

Step 1: Organization and preparation of data for analysis. This included the transcription of the interviews, typing field notes, cataloguing additional qualitative materials, and separating the collected data by each of the industries investigated, so that the sources of evidence could be easily identified as part of one specific industrial segment. All the audio records and transcriptions were organized in separate digital folders for each participating company and each participating engineer.

Step 2: General reading of all data to look for main ideas expressed by participants, the tone of the ideas, and the overall impression of depth, credibility, and use of the information. Creswell (2014) explained that because data collected in qualitative research is normally dense and rich, not all the information can be used. Therefore, researchers need to focus on some data and disregard other parts of it. In this study, while all the dataset was initially considered for analysis, and all the transcriptions were completely read, participants' comments and other parts of the interviews identified as non-relevant to answer the research questions were disregarded during the coding process.

Saldaña (2013) also discussed choosing the amount and the type of data to be considered in the analytic and coding processes in a qualitative study. He explained it is necessary to develop the ability to judge what is important in the data recorded and what is not, and thus code only what is relevant. In this sense, what should be coded includes parts of social life such as participant activities, perceptions, and tangible documents or artifacts produced by them. Additionally, the researcher's reflective data in the form of analytic memos and observer's comments in field notes can be included in the amount of data to be coded. In this study, pictures, analytic memos, and observations of the industrial settings where the interviews took place were added to the data collected and considered for analysis. These additional materials were used to keep record of the visual elements of the physical environment where engineers work and to keep track of the ideas emphasized by the interviewees during their discussions about engineering communication skills.

Step 3: Coding process initiation. This process involved identifying data segments and labeling these segments with a term or code.

In qualitative studies, a code can be understood as a word or short phrase that symbolically assigns an attribute that captures the essence of a language-based or visual data. It is a researcher-generated construct that represents the primary content of data. In other words, a code symbolizes and attributes interpreted meaning to each individual datum for later purposes of pattern detection, categorization, theory building, and other analytic processes. Coding is not a precise science, but mainly an interpretive act, so that different researchers may do different coding decisions for the same piece of data. Coding can also be seen as the transitional process between data collection and more extensive data analysis (Saldaña, 2013).

As an example of the coding process performed in this study, the word or code 'audience' was assigned to the following statement: "so I communicate with a lot of different people, meaning, from engineering up to the army, or the navy representatives that are funding our research" (Engineer 2, Interview 2, Lines 10-12).

As recommended by Saldaña (2013), the coding process occurred simultaneously with the data collection phase, and not after all fieldwork was completed. A codebook was developed in order to keep a record of the codes in a separate file. The codebook should include the set of codes, descriptions of each code, and a brief data example (Saldaña, 2013). According to Creswell (2014), the purpose of the codebook is to provide definitions for codes, and improve the coherence among them. The codebook can evolve and change based on the information learned during the data analysis. The codebook developed for this study is available in the Appendix D.

Two cycles of coding occurred. In the first cycle, structural coding and descriptive coding were the methods applied. Structural coding is particularly suited for studies involving multiple participants, standardized or semi-structured data-gathering protocols, hypothesis testing, or exploratory investigations. It is also more suitable for interview transcripts than other types of data. This coding process results in the identification of large segments of text on broad topics and then coding and categorizing the data corpus so that it is possible to compare segments in terms of commonalities, differences, and relationships. These segments can form the basis for an in-depth analysis within and across topics (Saldaña, 2016). In the application of the structural coding method in this study, conceptual phrases related to some of the research questions used to frame the interview were assigned to segments of data, as suggested by Saldaña (2013). As an example of the structural coding process implemented in this study, the phrase 'communication challenges', which is directly related to the research question 'what are the communication challenges of practicing engineers?', was assigned as a code for the passage: "*I think that's probably the biggest challenge. You know understanding the* *younger generation's needs and wants in the industry*" (Engineer 3, Interview 3, Lines 273-275). Through descriptive coding, a basic topic of a passage of qualitative data was summarized in a word or short phrase. Descriptive coding is especially appropriate for beginning qualitative researchers and is suitable to virtually all types of qualitative studies. The method generates an inventory of topics for indexing and categorizing the qualitative data. Interview transcripts are among the forms of data that can be coded through descriptive coding (Saldaña, 2013). One example of the implementation of descriptive coding in this study is the assignment of the code 'global communication' to the passage: "*We're communicating with tech centers all over the world. In Detroit, in Europe, in Japan, in China, and Korea, so I think communication is very key. And especially when we're dealing with, I would say you know global projects*" (Engineer 3, Interview 3, Lines 7-10).

After the first cycle of coding, when the structural and descriptive coding methods were applied, transitional coding occurred through memos and field notes that were gathered throughout the interview visits as well as during the first cycle of coding. The research questions and the literature review, in particular the CID framework, were used as point of references by which similarities and differences among the sub-codes were further analyzed. Using a constant-comparative approach, the sub-codes were reduced from original 24 sub-codes into 12 sub-codes. These 12 sub-codes were used for the second cycle of coding, which consisted of pattern coding. This process can be understood as a meta-coding through which explanatory or inferential codes are generated so that emergent themes can be identified (Saldaña, 2009). Miles and Huberman (1994) explained that pattern coding is an appropriate strategy for the second cycle of coding, the development of major themes from data, the search for rules, causes, and explanations for the data, examining social patterns of human relationships, and the formation of theoretical constructs (as cited in Saldaña, 2009, p. 151). The software MAXQDA (2018) was used in both coding cycles. All interviews were imported to MAXQDA and coded according to the codebook developed for this study. Through the use of MAXQDA, the coding results were compared among different interviews, which facilitated the identification of patterns across cases.

Inter-coder reliability was conducted in the first cycle of coding between the researcher and another graduate Ph.D. student so that 25% of the codes were discussed. The second coder was exposed to two interviews randomly selected from the set of eight transcriptions. The transcriptions were initially segmented and coded by the researcher. The segments were sent to the second coder without codes. The second coder then assigned his codes for each utterance or segment of the interviews. Subsequently, in an arbitration session, the codes assigned by both the researcher and the second coder were compared and the disagreements were discussed until at least 80% of agreement was achieved.

Step 4: Through thematic analysis, the 12 codes generated in the transitional coding process were condensed in four major themes. These themes were compared and verified with the scientific literature. For example, the theme 'clear, concise, and precise written communication' confirmed the characteristics of good technical writing discussed by Knisely and Knisely (2005). The themes are included in the discussion session of this dissertation report and consider multiple perspectives from the participants. Themes were analyzed for each individual case and across the four different cases as recommended by Creswell (2014). As an example, the theme ‘multiple audiences, tailored messages, and appropriate mediums’ was evident in the automotive industry as well as consistent across the four industrial segments investigated in this study.

A theme is an outcome of coding, categorization, or data analysis in the form of an extended phrase or sentence that identifies what a unit of data means and what it is about. In the analytic process, the goal is to distinguish the themes to be explored in a study. Like coding, thematic analysis, or the search for themes, is a strategic process as part of the research design (Saldaña, 2013). In this study, the themes were identified by taking into consideration the emphasis and frequency in which they were approached by the participants in their discussions of engineering communication skills. No emerging theme was verified.

Step 5: Representation of descriptions and themes. Data in this study were represented in a logical sequence, organized in different written sessions and tables when appropriate. For example, the cross-case analysis summarized in tables 6 and 7 present the differences and similarities among the cases explored in this study.

Step 6: Interpretation of the findings and results. In this step, the lessons learned were reported. The interpretation was drawn on meanings derived from a comparison of the findings with information gleaned from the scientific literature.

This qualitative research included all the procedures expected to be implemented in the case study approach. Based on the objectives and research questions initially established, the data collection process was planned and performed accordingly, and the data analysis occurred with the use of appropriate instruments and methods, so the research outcomes could lead to valid conclusions.

CHAPTER 4

CASE STUDIES

Each of the four industrial segments investigated in this study has its own characteristics when it comes to engineering communication. In this Chapter the communication aspects of the four industrial segments (High-Tech, Automotive, Aerospace, and Manufacturing) are explored across cases and individually. In order to develop a cross-case analysis of these industrial segments, the differences and similarities in terms of communication aspects of the engineering profession were explored and summarized in Table 6 and in Table 7 respectively.

Table 6

Communication Differences among the Four Industrial Segments

	Industrial Segment			
Communication Aspects	**High-Tech**	**Automotive**	**Aerospace**	**Manufacturing**
General communication features	Communication is very technical	Communication is more fast paced, people expect fast answers	Communication is very formal	Non-hierarchical communication
Specific communication requirements	A good understanding of technology is required	Global communication is prevalent and requires cross-cultural interactions	Collaborative communication involving multiple organizations is required	Communication involving a great number of people requires more personal skills
Communication strategies	Open and honest communication	Communication must consider cultural differences	Communication is more planned, tied with goals and priorities	Communication must be flexible
Communication challenges	Translating technical content into clear messages	Cross-generation communication inside the industry	Dealing with and disseminating high volume of information	The (putatively assumed) introverted nature of engineers may affect their communication performance

Table 7

Communication Similarities among the Four Industrial Segments

Communication Aspects	Industrial Segment High-Tech	Automotive	Aerospace	Manufacturing
Communication is considered absolutely critical	✓	✓	✓	✓
Communication is tied to the career performance	✓	✓	✓	✓
Oral communication is the most demanded modality of communication	✓	✓	✓	✓
Face-to-face communication is prevalent and the preferred form of communication	✓	✓	✓	✓
Update meetings are very frequent	✓	✓	✓	✓
Written communication, especially e-mail, is the second most demanded modality of communication	✓	✓	✓	✓
Written communication is expected to be clear, concise, and precise	✓	✓	✓	✓
Multiple types of audiences: coworkers, customers, suppliers, contractors, vendors, government entities, stakeholders	✓	✓	✓	✓
Communication is tailored according to the audience and the situation	✓	✓	✓	✓
Multiple types of mediums: e-mails, instant messages, text messages, phone calls, conference calls, presentations, meetings	✓	✓	✓	✓
Video conference tools are frequently used	✓	✓		
Miscommunication in writing is a challenge	✓	✓		
Public speaking is a challenge			✓	✓
Technology has affected communication by increasing the speed of interactions, the volume of information, and the number of e-mails	✓	✓	✓	✓

Cross-Case Analysis: Communication Differences among the Four Industrial Segments

In the High-Tech industry, communication is characterized by being very technical and engineers need to have a good understanding of technology in order to communicate effectively. This technical language become a challenge for engineers when it is necessary to translate technical content in more understandable messages especially when the audience is formed by non-technical people. Another specific aspect of this industrial segment is the open communication that is typical of the informal environment of companies in the High-Tech industry. In addition to the open communication, engineers are encouraged to communicate in an honest way.

In the Automotive industry, the fast-paced communication is one of the main characteristics. In an industry where interactions and activities occur in a high-speed, people expect fast answers. This industry is also global by nature and communication is affected by this specific feature. Engineers need to learn how to communicate globally, by having the capability to understand and be sensitive to cultural differences when interacting with people from other countries. Additionally, the cross-generation communication is a challenge. More experienced and younger engineers need to overcome the communication barriers related to the use of technology and other behaviors based on generation differences.

Communication occurs in a very formal way in the Aerospace industry and it is frequently linked to different types of documents. Communication is also more planned and tied with goals and priorities. One of the requirements to communicate effectively in this industry is the ability to collaborate with multiple organizations. The flow of information is very dense in this industry, and this is considered a challenge for engineering communication.

Communication in the Manufacturing industry is affected by the high number of people normally involved in manufacturing activities and requires a great deal of flexibility from engineers as communicators. Communication in this industry is more egalitarian and less hierarchical. The (putatively assumed) introverted nature of most engineers may affect their communication performance in this industry.

Cross-Case Analysis: Communication Similarities among the Four Industrial Segments

Communication is considered absolutely important in all industrial segments investigated in this study. Engineers in the four industries also recognize their communication performance is intrinsically associated with their career advancement and success.

Oral communication, especially face-to-face communication, is the most frequent and preferred form of communication among engineers in all the industrial segments. This specific form of communication occurs in constant update meetings, dyadic interactions, teamwork, and public speaking. Written communication, especially e-mails, is very important as well and requires engineers express themselves in a clear, concise, and precise manner.

In both oral and written communication, engineers are exposed to various audiences and need to communicate accordingly. This includes tailoring their messages and selecting the appropriate mediums since a wide range of communication channels is available to engineering professionals. Video conference tools, such as Skype, are considered very useful mediums, especially in the interactions with customers.

Engineering communication has been directly affected by technology in the four industrial segments. The main perceived effects of technology are the acceleration of the communication interactions, the high volume of information available, and the number of e-mails exchanged among engineers.

All of the industries investigated in this study indicated that miscommunication in writing and public speaking are aspects that need to be improved by engineers.

Single-Case Analysis: Communication Aspects of the High-Tech Industry

Communication is recognized as a very important and ubiquitous element of the engineering profession in the high-tech industry. It is used in multiple forms and contexts, and innovation seems to be frequently involved in this process.

In daily meetings, also called stand-up meetings, for example, the team of engineers utilizes a software solution that tracks the tasks they are currently responsible for, so the participants can communicate and coordinate the teamwork. As explained by one of the engineers, these meetings are a common way of communication with the purpose of providing updated information to the team of engineers:

> *So my team, which would be a team of engineers, I mostly communicate with them. And the medium we use are our stand-up meetings. We have one every day for about 15 minutes where we talk about what we did the previous days and what we plan on doing today and any problem that we might have or help we need* (Engineer 2, Interview 2, Lines 84-88).

In another context, communication is used in the interaction with different government entities in order to submit research proposals and to report the status and results of current research projects funded by these entities, as mentioned by the engineer:

> *I interact with engineers on my team and also with different government entities that we submit research proposals to and also to do the communication of where we're at in the research process, to talk about our results, and to present to them* (Engineer 2, Interview 2, Lines 7-10).

In addition to considering communication very critical to the engineering profession, engineers in the high-tech industry acknowledge that good communication skills are tied to success in their career. The belief is that the better the communication skills of an engineer, the faster will be his or her career advancement, as argued by one of the engineers:

> *I've seen some engineers do it really, really well, they're good at it, and some are not. And those that are good at that communication are the ones that tend to advance more rapidly in their career progression. So I feel it's a very important principle that if done well can enhance an individual's career* (Engineer 1, Interview 1, Lines 108-112).

When compared to the communication used in everyday life, the communication skills necessary for the workplace include more formality and professionalism. In this work environment, it is common for engineers to communicate very technically.

The most demanded forms of communication in the high-tech industry are oral and written communication respectively. More verbal communication is considered necessary as engineers move towards a leadership position. Personal communication between leaders and their teams and among members of the engineering teams is more frequent than e-mails and text messages. It is also considered more effective than any other form of communication. The open environment contributes to the prevalence of oral communication as well. Both engineers confirmed the importance of oral communication in this workplace:

> *I just think personal communication is so much more effective than anything else* (Engineer1, Interview 1, Lines 423-424).
>
> *I guess in the different modes, the verbal, I would say is the most important* (Engineer 2, Interview 2, Lines 55-56).

The critical factors of oral communication are the ability to explain ideas or answer questions if something is not understood and being respectful with the audience's time in such a way the communication is simple and direct.

When it comes to written communication, e-mails are the most common form of interactions with customers, suppliers, and other external audiences. E-mails are also the main alternative used to communicate globally, as emphasized by an engineer:

> *A lot of e-mails, I work with companies all over the globe and so e-mail is nice because it's fairly immediate and then they get to see it when they want* (Engineer 1, Interview 1, Lines 53-55).

One of the critical factors of written communication is being able to simplify the message when needed considering that the target audiences, especially customers, have many other messages to read on a daily basis. It is necessary to be concise enough and to show specific points that can get the reader's attention. Additionally, it is important to be precise as engineers are frequently dealing with data. Both engineers mentioned the importance of these factors:

Being able to express yourself clearly and concisely is very, very important (Engineer 1, Interview 1, Lines 457-458).

I think you need to be more precise in written data. Because typically we're presenting results and at least in our field, you try and have quantitative results so you can show the improvement or where it didn't work as well (Engineer 2, Interview 2, Lines 189-192).

The most frequent types of documents written in this industry are engineering requirements, specifications, software protocols, design documents, testing documents, interface control documents, safety documents, FMEAs, quarterly reports, bimonthly reports, and all types of e-mails.

Engineers in this industry interact with different kinds of audiences. The main types of audiences include fellow engineers and other coworkers, leaders, customers, suppliers, and different government entities, as described by the engineers:

So, I work with a lot of different audiences. When I was beginning engineer, my audience was primarily fellow engineers and my manager, that's who I worked with. That's who I had to deal with. Sometimes I would have audiences of customers and suppliers. Today, my most frequent audience is my team. And then beyond that, I have the opportunity to communicate with my customers (Engineer 1, Interview 1, Lines 269-273).

So I communicate with a lot of different people, meaning, from engineering up to the army, or the navy representatives that are funding our research (Engineer 2, Interview 2, Lines 10-12).

A wide range of mediums is used to communicate in this industry, including e-mails, instant messages, text messages, videos, Power Point presentations, Skype calls, phone calls, and stand-up meetings. The use of Skype is very common, especially in the interactions with customers, during which the functionality of screen sharing is considered very useful. The development of videos with the purpose to communicate pictorially about designs and other solutions was also mentioned as an effective way to communicate.

Among the communication strategies used in this industry is the willingness to communicate openly. Honesty is another word used to describe the communication expected from engineers, as emphasized in the following statement:

> *Just be honest. I mean if they want to know what's going on, I just tell them what's going on. Whether that's a phone call or e-mail, I don't think that changes the information that needs to be communicated* (Engineer 2, Interview 2, Lines 170-173).

While the practice of open communication is considered important, the amount of information delivered should be managed accordingly. If too much information is provided at once to engineers, they can become distracted from what they really need to do.

Communication strategies in the sense of rewarding people for their good performance are also used in order to contribute to the development of a positive work environment. At the same time, when the message to be communicated is not good news, different communication strategies are required to deliver this information carefully in order to motivate people to collaborate with their work towards the solution of the problem. In other words, communication needs to be flexible enough to convey both positive and negative messages in strategic ways.

Many challenges concerning communication skills have been noticed in this industry. Particularly in the high-tech industry, miscommunication is very common in the interactions with customers because it is not always possible to clearly understand their expectations in technical terms. Additionally, being able to express technical information, and make it understandable to the audience is considered challenging, as indicated by the engineer:

> *I think as an engineer, trying to portray or trying to explain something that could be difficult, in terms of mathematical equations or concepts. So I think it's trying to communicate ideas that may not be fully understood by someone, in a way that they can at least understand as much as possible* (Engineer 2, Interview 2, Lines 68-72).

Miscommunication in engineering writing is another perceived challenge common in the high-tech environment. Occasionally, because of this specific challenge, engineering written messages need to be clarified verbally so that the audience can really understand the content. One of the engineers explains these difficulties:

> *Even engineers on my team struggle to express themselves and that's primarily... Well, sometimes in writing and luckily, we're a fairly small company and I can go and talk to somebody and get clarification on what they might have meant. I see miscommunication in writing* (Engineer 1, Interview 1, Lines 103-107).

Challenges related to the communication between engineers and computer scientists are also mentioned as something that potentially makes more difficult the development of a project. These two groups of professionals are frequently expected to work together and complement each other's tasks, but their different approaches are not always able to reach an agreement, as shared by an engineer:

> *I see similar bantering, you know, between computer science guys and engineers but they can become a pretty serious hindrance to a project when people just won't communicate. They won't accept somebody for their coding practices. I need them to effectively work together and I've seen this happen* (Engineer 1, Interview 1, Lines 565-568).

When the leadership is not physically present in the office, the communication in the engineering team can be negatively affected as well. This is considered another communication challenge in this industry. Additionally, being able to communicate with different people with potential different reactions to the same message is considered a challenging situation, as mentioned by an engineer:

> *So like I said, I manage a team of different engineers and everyone reacts differently to certain situations. So I think the challenge is to be able to communicate in a way that isn't, offensive isn't the word, but isn't causing them to feel like they're under pressure. I want everyone to feel valued and that the things that they're working on or that they're doing well. And so being able to convey that message I think is difficult* (Engineer 2, Interview 2, Lines 240-246).

Engineers in this industry do not have a positive perception about themselves as communicators. They believe that the learning process of communicating better occurs constantly, but there are still improvement opportunities.

Technology has affected communication in this industry. One of the perceived changes brought by technology is the use of different options to communicate quick messages in a practical way, such as texting. Additionally, technology has influenced the amount of e-mails people send back and forth, as emphasized by the engineer:

> *Lots of e-mail: e-mail, e-mail, e-mail, and I could do e-mail all day long* (Engineer 1, Interview 1, Lines 300-301).

Another observation concerning how technology has affected communication in this industry is the feeling that instant communication is required. This is not considered a positive feeling since people may develop expectations of fast answers that are not always possible to occur.

When it comes to the specific communication requirements of this industry, two main ideas emerge: the need to have a good understanding of technology and being able to communicate technically. These specific abilities should also be constantly updated because as new technologies are available, new communication terms start to be used, as explained by the engineer:

> *Where it is a new technology, sometimes as this emerges, the new terms come about and it's very easy in the early days to miscommunicate, and that's why having a good solid technical understanding can help resolve some of these challenges in communication* (Engineer 1, Interview 1, Lines 633-636).

Single-Case Analysis: Communication Aspects of the Automotive Industry

In the automotive industry, not only is communication considered essential but also intrinsically connected with global communication, due to the multinational nature of most of the projects developed and the connections established in this industrial sector. The use of communication is also associated with teamwork, which is prevalent in this industry. Engineers with different backgrounds work together in multiple projects, so communication is everywhere and every time. A significant portion of engineers' time is spent in different forms of communication, as emphasized by the engineer:

> *So like a quality engineer, a manufacturing engineer, a design engineer, a program manager, all of these different functions form a team to make it to do a project, right? So that engineer doesn't go even 10 minutes or 15 minutes alone. They're always talking and working with others so absolutely incredibly important. Everything we do provides or let's say necessitates communication with others* (Engineer 4, Interview 4, Lines 36-42).

The main purpose of communication in the automotive industry is following up with coworkers about projects status, tasks expectations and results, problem solving, as well as interacting with customers in order to make presentations, answer questions, and meet their requirements. Different types of meetings happen frequently so these communication goals can be achieved.

Communication is considered tied to the success of engineers' careers, especially when it comes to personal communication because teamwork is constantly required in their daily routines in this industry. Face-to-face communication is seen as the best way to communicate when comparing to other options such as phone calls or e-mails, especially due to the body language associated with this kind of communication, as explained by one of the engineers:

> *So I think by far face-to-face communication is the best. I think you understand more because it's not just you're reading the words. You're understanding you know body language, you're understanding or you're seeing if the individual understands what you're saying or not you know by their body language. So I*

> *always tell you know people I work with you know, please, if you can communicate face-to-face that's by far the best* (Engineer 3, Interview 3, Lines 20-26).

One of the communication strategies used in this industry is tailoring the message according to the audience. When the engineer is communicating with the top management and taking into consideration their time restrictions, communication is more condensed and summarized. When the communication purpose is to solve problems, especially with the participation of people from other countries, then including as much detail as possible in the message will be considered the ideal approach. When dealing with customers, engineers should answer their questions but without adding too much information in order to avoid more questions emerging. It is important to be direct in these interactions. The use of these different strategies is described by the engineer:

> *Another way is when I'm presenting to top management. I know that only their attention span is small because they have many other problems. And so I will try to condense and summarize maybe one-page, right? Where if I'm working with somebody on the problem, maybe somebody in India or France, then I might have many, many pages and working details, right? So I tailor the presentation to the audience. As well, when we're working with customers, we try to answer their question directly with a little you know, with enough information but not too much. Because they would tend to ask a lot more question, right? So it's important to be direct, answer the questions* (Engineer 4, Interview 4, Lines 171-180).

Another communication strategy used at work is being very careful especially in written communication since everything will remain documented. In this sense, messages need to be proofread, and it is important to make sure everything is being communicated correctly. Considering communication with people from other countries and cultures, it is also necessary to use appropriate language in order to not be offensive or misunderstood.

There is a wide range of people that are considered part of the audience in this industry. Inside the company, this audience includes people in different hierarchical levels from technicians to the top leadership, as well as people from other countries, due to the global nature of the operations. Customers are the main representatives of the external audience. Several types of mediums are used in the communication routines in this industry. Phone calls, e-mails, Skype, Power Point presentations, text messages, instant messages, and meetings, which happen in a high frequency, are the most common mediums utilized by engineers. However, the preferable communication mode is verbal communication, especially when it is face-to-face, as confirmed by the engineer:

> *So I mean I think the whole trend kind of have been you know I'll receive a text or somebody will send me an e-mail or an IM but I'd still rather, hey, don't send me text. Don't send me an IM. Let's sit down and talk* (Engineer 3, Interview 3, Lines 106-109).

Among the most demanded forms of communication in this industry are meetings, e-mails, and phone calls. Therefore, oral communication is more frequent than written communication, even though both are important.

The critical factors of written communication are being plain, clear, and concise, especially in e-mails. Independently of the audience, e-mails, memos, and other written documents must be reviewed before being sent. Grammar errors and misspellings must be avoided. When it comes to audiences from other countries, it is necessary to be more careful and take into consideration the culture differences. Finally, being polite and using salutations are also expected. Concerning oral communication, it is important to know the audience and give them appropriate information and details when needed. It is also necessary to ask if people understand the information.

E-mails, technical specifications, test reports, analysis reports, status reports, manufacturing documents, work instructions, and failure modes are among the most common types of documents written in the automotive industry.

The self-perceptions of the engineers as communicators are positive, even though one may believe he is not 'politically correct' and just states the facts, while another may think he is too focused on details.

One of the biggest communication challenges perceived in this industry is the miscommunication found especially in e-mails, frequently requiring verbal follow-ups to make the message understandable.

Another perceived communication challenge is related to cross-generation interactions, considering the differences between older and younger generations' way of communicating, as emphasized by the engineers:

> *The biggest challenge I would probably say here is, you know, we have individuals who are over 50-years-old and then you have individuals who are early 20s who have just graduated from college and so I think there's a big difference between the way you know they want to communicate and the way we want to communicate* (Engineer 3, Interview 3, Lines 259-264).

> *But we've talked a little bit about a text message, in some cases, is not the most effective tool. But it's a very convenient, easy tool. And I think the generation, the*

younger you get, is more comfortable with that tool. Some of the older generations certainly aren't (Engineer 7, Interview 7, Lines 457-460).

Communication with people from other countries and cultures is also considered very challenging, especially in an industry that is very global by nature, as explained by one of the engineers:

A lot of people will also tell you if they don't understand. They'll say, please, repeat. Or, please, say this over again. I'm not sure I understand what you're saying here. But the Japanese, in particular, won't say that and so you must ask. And, heavens, they know English much, much, much better than I know Japanese, but sometimes maybe not good enough to have effective communication (Engineer 4, Interview 4, Lines 263-268).

The way technology has affected communication in this industry is by significantly improving the speed and facilitating the conciseness of communication. Communication also has become more practical and effective, as emphasized by the engineer:

Well, Skype is really good, where we can share documents real-time. That is a huge improvement. And e-mail, it's much better, right? And then also texting is better, because we can then just write a few words. You know, can you do this? Yes. Instead of having to call up. How are you doing? How's your day going and that kind of thing so we can be more concise and quicker (Engineer 4, Interview 4, Lines 301-306).

One of the specific communication requirements of this industry is being able to communicate globally by using different types of mediums. The automotive industry is essentially global, thus it is important to be able to communicate cross-culturally, as mentioned by both engineers:

> *If we're dealing with let's say our associates in Japan or China, you kind of have to understand their culture. So you know there's culture differences. There's I think different approaches on how you communicate if that makes sense* (Engineer 3, Interview 3, Lines 67-71).
>
> *And so, since I am solving international problems every single day, I'm on the phone with people from other countries. Maybe from Japan, Sweden, France, Germany, and sometimes China, and India, and so forth. So it's very important for communication because we are from different cultures and have different accents* (Engineer 4, Interview 4, Lines 11-16).

Another specific aspect of the automotive industry is communication is more fast-paced. Communication happens fast and people expect quick answers or reactions in the communication interactions. Finally, there is a specific body of knowledge and industry requirements that affect communication in the automotive industry. Many terms and acronyms need to be learned by engineers working in this industry in order to communicate effectively with their peers.

Single-Case Analysis: Communication Aspects of the Aerospace Industry

Communication is considered absolutely critical in everything done in the aerospace industry. Upstream and downstream communication, inward and outward communication are seen as essential to successful engineering activities. While different avenues of communication are used on a daily basis, verbal communication becomes more demanded as the engineer progresses to a leadership position, as emphasized by the engineer:

> *Communication? Gosh, every form you can possibly imagine, so at a director level, what I'm finding is that verbal communication is probably one of the most important methods for me communicating. Certainly, as I worked through and progressed on my career, different levels and types of communication were always very important* (Engineer 6, Interview 6, Lines 9-14).

Among the types of verbal communication, face-to-face interactions are considered the preferred way to communicate and is openly encouraged by the leadership, as mentioned by the engineer:

> *So to me, probably the most important is face-to-face communication. Because I haven't ever found anything that would replace that so I encourage my people if at all possible, you know please communicate face-to-face. So I think face-to-face communication is the best* (Engineer 5, Interview 5, Lines 90-94).

The ability to translate complex and technical content into words that is not only understandable to other engineers but also to non-technical and decision making professionals is considered one of the keys to success in the engineering career.

Communication in this industry is frequently used with the purpose of understanding and meeting cost, schedule, technical, quality, and other requirements of different stakeholders inside and outside the company. The professional communication that occurs in this industry is considered more formal and attached to a plan. There is always a reason to communicate or a set of goals and priorities to achieve.

Different communication strategies are used depending on the audience and purpose. When the communication is being established with people from other countries, for example, written communication is considered more appropriate in order to document the message, to promote more clarity, and to avoid misinterpretations. When the intention is to communicate with the team of engineers in order to engage them in projects, a mixed mode of communication involving presentations and meetings would be considered the best approach, so people have the opportunity to interact and react to the message. Another communication strategy used by engineers in this industry is to analyze the situation and identify the best way to communicate in each context, as explained by the engineer:

> *If I get to a point where we have to make a hard decision or we have to make/communicate very complex concepts, if I need to show progress on a complicated project, if you and I have to involve stakeholders or customers, and stakeholders could be internal customers or my management as well, you know, then you might say, well, gosh I need to take the time to build a pretty formal set of PowerPoint slides to that* (Engineer 6, Interview 6, Lines 200-206).

The most common audiences identified in this industry include coworkers, such as engineers, subordinates and leaders, customers, and other stakeholders. Multiple mediums are also used to communicate with different audiences. Stand-up meetings occur very frequently with the purpose to provide updates about project status and other engineering tasks. Other types of meetings, especially technical interchange meetings (TIMs), e-mails, texting, instant messages, phone calls, Power Point presentations, screen sharing applications, and teleconferences are among the main mediums utilized by engineers.

After verbal communication, written communication is the second mode in terms of frequency in this industry. It takes mainly the form of e-mails back and forth as an asynchronous way to communicate. The most demanded modes of communication will also depend on the specific engineering role. The nature of the work of some engineers will require them to communicate more via written documents. Engineers working in leadership positions tend to use much more oral than written communication, as emphasized by the engineer:

> *Right now I would say that very little of my communication's written. In a leader role, I communicate by speaking* (Engineer 5, Interview 5, Lines 252-253).

The critical factors of oral communication are making sure the message is completely understood and to eliminate ambiguities. Additionally, it is necessary to specify what is important about the message and to avoid long conversations that may lead to miscommunication. Regarding written communication, one of the critical factors is to be brief and summarize the main points of the message. It is also important to think carefully about what has been written, try to anticipate potential misunderstandings, and avoid them. Reviewing the message before sending it by proofreading the content is very important. One of the engineers clarifies this idea:

> *So you've got to really read your own communications with a, how can people misinterpret this? And make sure that I've really clearly conveyed my intent. Because your message goes out to a lot of people. You may not have that opportunity to clarify what you really intend to all these people so you have to be really careful and make sure that you're really communicating in a way that your intent is true and that people will not misinterpret what you truly intended* (Engineer 6, Interview 6, Lines 339-346).

The most common types of written documents in this industry are test reports, analysis reports, design documents, specifications, models, and presentations.

Engineers in this industry have a positive self-perception of themselves as communicators. They believe good communication skills are some of the elements that led them to a leadership career. However, there are many challenges associated with communication in their view. Public speaking, for example, is considered one of the big challenges faced by engineers. They also believe that because engineers are generally introverted people, they do not communicate very well. Another perceived challenge is the need to deal with a high volume of information and being able to sort through it. When working with complex projects with the participation of several people, having all the engineers reach the same body of knowledge and disseminate ideas to large groups are also considered big challenges, as explained by the engineer:

> *Because when you get on complex projects, you have to do it with multiple people. It's really hard. Because you know some people are going to spend more time reading stuff. You know some people absorb stuff by reading, some people absorb stuff by listening. Yeah, trying to get that common base of knowledge, it's hard. It's just time-consuming and hard* (Engineer 6, Interview 6, Lines 357-367).

Technology has affected communication practices in this industry in many ways. A perceived negative effect of technology in the engineering communication routines is that some people engage and rely too heavily on electronic communications such as instant messages and e-mails. Another aspect brought by technology is the high speed through which it is possible to convey a high volume of information. When it comes to the ability to have access to the needed information at any time or just retrieving it from its source when necessary, the technology impact is considered to be positive as argued by the engineer:

> *But I think the other thing that technology has brought to us that's been significant for an engineer in the communication world is access to the information that you need to do your job. You know there is no way your brain can absorb every single piece of data out there and there are so many volumes of data. I mean just, everybody can bring it up on their computer/everybody could search for it. It's just, the transference of information and the availability of information, and how quickly you can get to the information you need has just made it such a different world than it was when I first started, which is amazing* (Engineer 6, Interview 6, Lines 384-396).

The specific communication requirements of the aerospace industry include being able to communicate collaboratively across multiple organizations. The communication with customers, especially, is characterized as being very formal since it involves a set of formal documentation such as reports, analysis, and financial information. All the exchange of information is done through formal means. The engineer provides details about this characteristic:

> *We're communicating with big institutions or organizations and that kind of thing, so it's much more formal and that sort of thing. I mean I think it's vastly different. In my experience, anybody that's involved in government contracting, the way that we do this is very similar to other government contractors* (Engineer 6, Interview 6, Lines 446-450).

Finally, an additional communication requirement in this industry is to be able to deal with conflicts. Conflict management is considered an aspect to be improved among engineers.

Single-Case Analysis: Communication Aspects of the Manufacturing Industry

The importance of communication in the manufacturing industry is directly associated with the impact it has on the effectiveness of engineers. It is considered absolutely crucial to be able to communicate well verbally, as well as from a written standpoint. Communication is also considered the most critical part of leadership.

Face-to-face communication is considered the best way to interact among engineers. Many face-to-face meetings occur sometimes on a daily basis. The main purpose of engineering communication in this industry is to promote engagement and alignment of the team of engineers. It is expected and important the teams understand the long-term vision of the organization and the strategies necessary to reach that vision, as mentioned by the engineer:

> *We want our team to know what we're doing, why we're doing it, what we plan to achieve, how we benchmark success through that, because that creates an engaged team. And an engaged and empowered team is going to go a lot farther than the sum-of-the-parts mentality, right?* (Engineer 8, Interview 8, Lines 121-124)

Not only is the ability to communicate well considered tied to engineers' career success, but also is recognized as a feature that separates the types of engineers that are able to convince others about their ideas from those who are not capable of doing so, as explained be the engineer:

> *As you progress further and further, the ability to think in shades of gray, the*

ability to lead people, the ability to communicate what you want and the ideas, convincing people that this is a better way, this is a better process, those are all soft skills. They're not math, it's not calculus, it's not physics. Those are soft skills that really separate a lot of engineers that have great ideas but can't convince people that they're right, compared to engineers that have, I mean, hell, in some cases, it could be mediocre ideas that still make us incrementally better, but they're able to effectively convince a group of people this is a better path (Engineer 8, Interview 8, Lines 72-80).

In this industry, the messages are strategically shaped according to the audience, and the communications modes are selected according to the situation. When it comes to quality meetings, for example, communication tends to be very formal, including Power Point presentations, and quality charts. When the purpose is to answer customers' complex and technical questions, direct phone calls may be considered more appropriate. This idea is confirmed by the engineer:

So you have to be very self-aware of who your audience is, what message you're trying to convey and then, how you convey it. You can have two completely different groups of people and you can present the exact same message in a completely different way. At the end of the day, what's important is whether or not that message has been effectively received (Engineer 8, Interview 8, Lines 105-109).

Some strategic customers are given more attention, and different modes of communication are used to communicate with them depending on the context, as one of the engineers exemplifies:

We've got a customer that we sell a considerable amount of material to in Kansas City. They're very strategic for us because of the volumes. It's a challenging product for this type of mill to make, but we found a way that works. So we will have conference calls with them the moment something comes up. If there's a question, it's easier to shoot them off a text or an e-mail because we have that relationship. If it's something a little more complex, we'll get on a call. We typically travel out there one to two times a year (Engineer 7, Interview 7, Lines 263-268).

Generally, e-mail is considered an effective tool when the message is very factual and not open to interpretation because it is considered quick, easy, and convenient. However, face-to-face communication is considered the best way to communicate, especially when the message content is very important because it includes body language, which facilitates the clarity of the interactions.

Engineers in this industry communicate with a vast range of audiences, such as customers, suppliers, vendors, contractors, and coworkers at different levels. The communication style in this environment is less hierarchical, as explained by the engineer:

We're a very egalitarian, non-hierarchical structure. We don't have 18 levels of management, we're a very flat organizational structure. But I communicate with scrap loaders, with pulpit operators, with maintenance guys, with day-rolling supervisors, with my peers, the management team, my general manager (Engineer 8, Interview 8, Lines 196-199).

Multiple mediums are used in the communication interactions in this industry, including phone and conference calls, e-mails, text messaging, and meetings with formal Power Point presentations. The most demanded form of communication, however, is verbal communication, especially face-to-face meetings. E-mails are the second more frequently used communication tool and is mainly utilized to answer technical questions and to disseminate information.

The critical factors of written communication include being careful about what is communicated, trying to avoid misinterpretations from the reader's side, and being able to select and inform the important points of the message. Written documents need to be clear, concise, grammatically correct, comprehensible, and tailored according to the audience. Similarly, the critical factors of oral communication include knowing the audience and the message expected to come across. It is also important to know how to use different tones depending on the situation, as observed by the engineer:

> *There are times where you have to take a soft approach because you think it's going to be effective. You can lower your voice, you can be positive, you can try to motivate and inspire somebody not through fear of retribution or retaliation, but because you think a more effective way to get them further ahead in their performance or career or whatever else is going to be the soft approach. There are also other times where you're going to raise your voice. There are also other times where you're going to be much more direct, sometimes bolder. It depends how you decide to package that message* (Engineer 8, Interview 8, Lines 374-379).

Among the types of documents written in this industry are e-mails, reporting tools, data analytics, presentations, and safety reports.

Engineers in this industry have a positive self-perception about their communication skills, but they believe there is still room for improvement, since the impact of communication in their careers is recognized as important.

One of the challenges related to the engineering communication skills is associated with the (putatively assumed) introverted nature of most engineers. Frequently, engineers have difficulties engaging themselves in collaborative interactions. For those not capable to develop their communication skills, the consequences can be as serious as losing a job, as argued by the engineer:

> *Yeah, so, again, you know, most engineers and certainly metallurgists, you know, again, they're typically not your most social, outgoing folks. We had a metallurgist here who didn't work out. We let him go. And part of his critical challenge was he was not a strong communicator. He found it very difficult to form relations with people, have conversions with people. People felt awkward having a conversation with that individual* (Engineer 7, Interview 7, Lines 414-419).

Another perceived challenge mentioned by engineers is the ability to communicate unpopular messages in an appropriate way. Additionally, young engineers are perceived to have difficulties with public speaking through which they were expected to explicitly and concisely present their ideas, their rationale.

Technology has affected communication in this industry by bringing more convenience to the interactions. Text messages, for example, are considered an easy way to communicate quick reminders or to get immediate answers. Younger generations of engineers are perceived to feel more comfortable with the use of new technologies.

One of the specific communication requirements of this industry is the unique terminologies and processes used by engineers that make the language very technical. Another specific characteristic of the manufacturing industry is that communication becomes more challenging due to the number of people involved in the processes occurring in this environment. It is different, for example, from a design office or other engineering professional settings where the number of people is not so significant. The engineer clarifies this idea:

> *I can tell you in an industrial manufacturing process, it's more critical to be able to communicate, because again, there's 450 people that work at this site plus another 70, 80 contractors, we'll have hundreds of people on shutdown. I mean, we're in the people business. We make steel, but we're in the people business* (Engineer 8, Interview 8, Lines 620-624).

CHAPTER 5

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

The critical role of communication in the engineering professional environment is widely discussed in the literature (Bjekic et al., 2015; Knisely & Knisely, 2015; Nathans-Kelly & Evans, 2017; Werner et al., 2017), and was unanimously supported in the case studies developed in this research. All participating engineers acknowledged the importance of communication for the effectiveness of engineering activities.

In all industrial segments, oral communication, especially face-to-face update meetings, is very frequent and demands that engineers have the appropriate abilities to communicate in teams and in dyadic interactions. This was echoed by Keane and Gibson (1999). In the four industrial segments, engineers communicate with a wide range of audiences and need to tailor their messages accordingly, as well as to select the most appropriate medium to get the message across, as recommended in many previous studies (Darling & Dannels, 2003; Knisely & Knisely, 2015; Norback et al., 2009; Troy et al., 2014; Wisniewski, 2018). Engineers are also involved with frequent writing activities, and challenges related to miscommunication in this mode are persistent in at least two industrial segments: High-Tech and Automotive. These challenges were previously indicated by Gunn (2013). Writing is expected to be clear, concise, and precise, as suggested by Knisely and Knisely (2015) and Norback et al. (2009).

Cross-generational communication challenges or difficulties related to communication between older and younger generations of engineers were revealed in this study. Cross-generational issues, as discussed by Tomek (2011), have played and will continue to play a significant role in teamwork, because many individuals are working longer while others are retiring and then returning to the workforce. Tomek (2011) explained that currently there are four generations co-existing in the workplace: traditionalists, baby boomers, generation X, and millennials. These groups are present not only in the United States, but throughout the world. As a consequence of this diversity, different generations have different views on many dimensions such as work-life balance, career versus organizational loyalty, and technological literacy. These different views are often perceived as a hindrance to team development, but when used creatively they can actually benefit professional teams. Lester, Standifer, Schultz, and Windsor (2012) investigated the disparities in generational preferences in the workplace, including technology, face-to-face communication, e-mail communication, social media, formal authority, and fun-at-work. They verified that individuals who would be considered baby boomers and generation Xers valued technology-driven modes of communication less than their younger counterparts. In this study, evidences indicated the preference for face-to-face communication by older generations in contrast with technology-mediated communication as the preferred way of communicating by younger generations.

Different communication requirements can be identified among the four industrial segments investigated in this study. In the High-Tech industry, having a good understanding of technology is important because in this specific setting the discourse of technology is prevalent. This was previously discussed in the study of Darling (2005). In the Automotive industry, global communication and the ability to appropriately interact cross-culturally is a common requirement. The research of Kedrowicz and Taylor (2013) indicated the importance of global communication. In the Aerospace industry, communication is very formal, tied with goals and priorities, and involves much documentation. Flexibility is the main communication requirement in the Manufacturing industry due to the high number of people involved in this industrial setting.

Through the comprehensive analysis of the four cases developed in this study, four major themes emerged. In this chapter, these themes are discussed and compared with the scientific literature.

Theme 1: Prevalence of Oral Communication

Engineering communication in industry is widely dominated by oral or verbal communication used in meetings, interpersonal communication, negotiation, conflict management, and public speaking. Oral communication is also preferred by engineers, and it becomes more important as they advance to leadership positions.

The prevalence of oral communication in the industry setting was previously discussed by Darling and Dannels (2003). They argued that the engineering workplace can be considered an oral culture where the interactions are not necessarily constrained by formal public speaking events and that the development of interpersonal skills is very important. Oral communication matters greatly in the engineering work environment independently of the specific genre or the kind of audiences with which engineers interact.

Particularly, face-to-face communication among engineers occur very frequently, and it is directly associated with teamwork interactions. Meetings are the primary setting for face-to-face communication, as previously indicated by Norback et al. (2009). Different types of meetings are constantly taking place in industry, especially update meetings, which have the purpose to engage and align engineers' activities with the organization's goals. In order to participate and succeed in these interactions, engineers need certain skills to communicate effectively. The oral communication skills necessary for effective participation in meetings, which include skills in group communication, negotiation, interviewing, and dyadic communication, are a high priority in the engineering profession (Keane & Gibson, 1999). This notion of oral communication is confirmed in this study. According to Wisniewski (2018), exposure of engineering students to the types of communication used in meetings and to the practice of informal communication genres is recommended. Conflict management is another skill necessary for engineers to succeed in their participation in meetings and in other oral communication genres.

The critical aspects of oral communication include explaining ideas and answering questions, using simple and direct communication, eliminating ambiguities, making sure the message is completely understood, using different tones depending on the situation, and focusing on the important points of the message.

Even though public speaking is not necessarily the most frequently used genre of oral communication in the industry setting (Darling & Dannels, 2003), it is considered one of the challenges for many practicing engineers, because their (putatively assumed) introverted nature may affect their oral communication abilities. According to Gunn (2013) and Tenopir and King (2004), engineers are frequently not perceived as skilled communicators. Overcoming potential communication limitations is necessary to succeed both in public speaking and in daily interpersonal interactions.

Successful engineers are able to use oral communication persuasively, by convincing other people about their ideas and by clearly translating their messages into appropriate and understandable content. This is confirmed by Dannels (2002) and Darling and Dannels (2003). Ultimately, oral genres in engineering communication should bridge the discipline with the larger public (Dannels, 2002).

Theme 2: Multiple Audiences, Tailored Messages, and Appropriate Mediums

Practicing engineers in the industry setting communicate through different modes and are exposed to multiple types of audiences, both internal and external to the organizations where they work. These audiences may include, but are not restricted to, coworkers, subordinates, leaders, customers, suppliers, contractors, vendors, governmental entities, and stakeholders. The wide range of audiences targeted in the engineering communication is confirmed by several studies (Darling & Dannels, 2003; Hynes & Swenson, 2013; Nicometo et al., 2010; Troy et al., 2014; Wisniewski, 2018).

Audience awareness and the ability to tailor the message accordingly are important requirements for engineers to communicate successfully. This idea was also discussed in previous studies (Darling & Dannels, 2003; Knisely & Knisely, 2015; Norback et al., 2009; Wisniewski, 2018), and it is the reason why Mottart and Casteleyn (2008) argued that engineering students should be exposed to the idea of various audience perceptions during their college engineering preparation.

Tailoring the message according to the audience is a strategy that should be applied by engineers in industry both in oral and written communication. When the intention is to communicate with people with time restrictions, such as the top management, the message needs to be more condensed and direct. When dealing with customers, the most important attitude is to directly answer their questions without adding too much information to the message. Audiences from other countries are better approached by very detailed written messages normally sent by e-mails. One of the biggest challenges of communicating in any modality is to translate technical information into messages that are understandable to non-technical audiences. Sometimes, the same message can be communicated in different ways with different groups of people, as long as the message is understood by the target audiences.

Since many different mediums are utilized by engineers in industry, the selection of the appropriate communication channels to get the message across is considered equally important as observed in previous studies (Tenopir & King, 2004, Norback et al., 2010; Wang, 2008). Younger generations of engineers, for example, feel very comfortable by communicating through texting and other new technologies. Face-to-face meetings are preferable when engineers are working in teams. Conference calls are frequently used with customers. Depending on the medium of choice, the message transmission can be negatively affected. Therefore, it is important to consciously select the best medium depending on the situation.

Theme 3: Clear, Concise, and Precise Written Communication

In addition to having good oral communication skills, engineers need to be proficient in writing. This is the second most important mode of communication in industry.

Many types of documents are written in the engineering profession, including engineering requirements, technical specifications, design documents, manufacturing documents, work instructions, test reports, analysis reports, status reports, presentations, and all types of e-mails. E-mails are the most frequently used form of written material.

The variety of documents written and read by engineers was discussed in other studies (Norback & Hardin, 2005; Kmiec & Longo, 2017) as well as the characteristics of excellent writing (Knisely & Knisely, 2015; Norback et al., 2009). The need for standards of excellence in written communication was also revealed in this study. This included being clear, concise, and precise. A clear message can be defined as free from being misinterpreted. Conciseness is the ability to simplify the message and to focus on specific and important points. In order to ensure the message is precise, it is necessary to write with the most appropriate words and exact numbers, especially if the message includes quantitative data. A precise message is also one that is grammatically correct, and does not contain misspellings.

Since miscommunication in writing is frequently observed among engineers in the industry setting, it is necessary to proofread the message before sending it through e-mails, memos, or other documents. Considering that everything written remains documented, it is important to be very careful with written materials. According to Keane and Gibson (1999), the cost of ineffective writing can become extremely high in the industrial sector.

Theme 4: The Increasingly Importance of Global Communication

The impact of globalization in several industrial segments has been a reality for many years. Engineers need to adapt themselves to be able to communicate in an increasingly global workplace and interact effectively with different international audiences. Tomek (2011) argued that as the world continues to globalize, teams are becoming increasingly multicultural, where one or more individual from different countries or regions bring with them their unique culture, which can both enhance the team or impact the team's functioning. Areas that need to be considered include religion, work culture (or work ethic), leadership–followership culture, and communication style.

By being part of virtual teams formed by different experts located around the globe (Kedrowicz & Taylor, 2013) or by making connections with international suppliers and customers, engineers need to develop the skills that allow them to successfully communicate cross-culturally. This specific ability requires sensitivity and respect for the cultural differences. As observed by Norback et al. (2009), an example of how to practice a correct cross-cultural communication is by avoiding idioms, slang words or phrases, and acronyms.

Many other cultural distinctions may affect how to communicate with foreign colleagues as well as the selection of mediums to better interact with them. E-mail is the primary tool to communicate internationally, but, unlike the concise style that is suggested for general written documents, sometimes it is necessary to provide as much detail as possible in order to avoid misinterpretations from the reader. According to Wren (2018), writing is a culturally conditioned activity.

Appropriate communication with individuals with different cultural backgrounds (Norback et al., 2010) is no longer just a desirable engineering skill, but is currently a necessary competence for engineers to succeed in the workplace because interactions with international peers and other stakeholders is becoming more and more common in different industrial segments. Kedrowicz and Taylor (2013) suggested that the development of this ability should start in engineering programs by preparing engineering students to communicate in the global workplace and across disciplines and cultures.

In addition to the themes discussed above, relevant information related to engineering communication was identified during the cross-case analysis. Communication is directly associated with engineers' career advancement and success, confirming the arguments presented in Darling and Dannels (2003), Knisely and Knisely (2015), and Norback et al. (2009).

Engineers spend considerable amounts of time in communication interactions while working, as previously found in other studies (Knisely & Knisely, 2015, Passow & Passow, 2017, Sageev & Romanowski, 2001), and they frequently communicate with peers and other audiences due to the collaborative nature of engineering tasks, as stated by Trevelyan (2014).

Technology has affected contemporary engineering communication by accelerating the speed of information exchanges, by requiring conciseness in the messages produced, and by providing more convenience to the interactions. The high volume of information available and the ability to take advantage of it is also perceived as a benefit of technology in the communication routines of engineers.

Research Questions

Based on the analysis of the themes aforementioned, the research questions established for this study were answered and discussed.

Research Question 1: How are the specific communication skills expected from practicing engineers in industry described?

Engineers are expected to be proficient in oral communication, since this is the most common form of communication in the industry setting. The oral communication skills required from engineers include the types of speaking used in meetings, interpersonal communication, negotiation, conflict management, and public speaking. Face-to-face interactions tend to be more frequent than oral communications involving phone and conference calls.

Oral communication should be focused on the main points of the message, simple, and direct enough to express ideas and answer questions, avoiding possible misunderstandings, and using different tones according to the situation.

Even though the time spent in oral communication tends to be greater than the time spent in written communication, engineers also need excellent writing skills, since they are normally involved with the production of multiple types of documents. The most common genre of written document produced by engineers is e-mails. Written communication needs to be clear, concise, precise, and free from grammar errors and misspellings.

For both oral and written communication, tailoring the message according to the audience, and choosing the right channel or medium to get the message across are paramount for effective communication. Since engineers interact with multiple individuals or groups of people, they need different communication strategies depending on the nature of the audience.

In addition to becoming proficient in oral and written communication, engineers need to develop the ability to communicate cross-culturally, because the industry environment is increasingly characterized as a global workplace. Multiple types of stakeholders located in different parts of the world are part of the audience with which engineers interact.

Research Question 2: What are the communication challenges of practicing engineers?

Even though oral communication is very important in the industry setting, engineers still have difficulties with public speaking. This challenge may be associated with the (putatively assumed) introverted nature of many engineers as suggested by the respondents of this case study. Additionally, miscommunication in writing is prevalent in the industry setting. Frequently, engineers need to verbally clarify their written messages because they did not communicate as clearly as expected. Another communication challenge is expressing technical information clearly and effectively to different audiences. Dealing with high volumes of information and being able to sort through it is perceived as a challenge as well. Cross-generation and cross-cultural communications are problems for engineers in industry. Finally, some engineers have difficulty in engaging in collaborative interactions.

Research Question 3: In what ways are engineering communication requirements different across varying industrial segments?

While there are more similarities than differences among the industrial segments investigated in this study, some specific and distinct characteristics of the High-Tech, Automotive, Aerospace, and Manufacturing industries were identified. The High-Tech industry is a setting where the discourse of technology is prevalent and requires engineers have a good understanding of technology and are able to communicate technically. Additionally, open communication is a remarkable feature of this industrial segment. The Automotive industry is characterized by the prevalence of global communication and the need for engineers to communicate cross-culturally. Communication in this industry is also fast-paced, which requires a great deal of agility in the interactions with the multiple kinds of audiences. Communication in the Aerospace industry is very formal and frequently requires formal documentation in most of the interactions with stakeholders. The Manufacturing industry is characterized by a complex communication due to the high number of people that normally work in this setting. However, communication tends to be more egalitarian than hierarchical.

Conclusions

Communication is an essential part of engineers' professional life and intrinsically associated with their career advancement and success. Engineers in the industry setting spend a significant amount of time communicating in different forms and need to be proficient in oral and written communication, while keeping constant audience awareness. They are especially required to communicate orally in multiple contexts such as meetings, one-to-one interactions, negotiation, and public speaking. The prevalence of oral communication requires that engineers are able to communicate effectively and persuasively but does not change the importance of written communication as the second most demanded mode of communication. Engineers produce a wide range of documents, and are expected to write clearly, concisely, and precisely.

The messages produced in both oral and written communications need to be tailored according to the audience. Since engineers in industry interact with multiple audiences, they are required to be flexible enough to shape the message accordingly, and select the best medium option to communicate with the target audience.

Contemporary engineers are also required to communicate globally, since interactions with peers and other audiences located in different parts of the world are very common in most industrial segments. In order to communicate cross-culturally, engineers need to develop sensitivity to cultural differences, and avoid idioms, slang, and acronyms.

The communication challenges of engineers in industry include difficulties with public speaking and miscommunication in writing. Expertise in these two communication aspects need to be more appropriately developed among engineering students in order to prepare them to meet the industry demands. Cross-generational communication challenges or difficulties related to communication between older and younger generations of engineers were also one of the communication challenges revealed in this study. Evidences found in this research indicated the preference for face-to-face communication by older generations and technology-mediated interactions as the preferred way of communication when it comes to younger generations of engineers.

This study also indicated that technology has affected engineering communication in industry. Interactions have been accelerated by the several new options of communication mediums, such as texting and instant messages, the volume of information exchanged among engineers is increasingly higher, and the number of e-mails sent and received is significantly time consuming.

Engineering communication requirements may vary across industries, but there are more similarities than differences when multiple industrial segments are compared. In the High-Tech industry, engineers need to have a good understanding of technology, and being able to communicate technically. In the Automotive industry, global communication is prevalent, and communication as whole is more fast-paced. In the Aerospace industry, communication is very formal, tied to goals and priorities, and frequently includes the production of documents. In the Manufacturing industry, communication needs to be flexible due to the high number of people involved in this industrial setting. Additionally, communication is more egalitarian and less hierarchical.

By comparing the communication aspects of four different industrial segments, this study confirms many insights previously discussed in the pre-existing knowledge-base, while revisiting them in a different and current context. The identified differences among the High-Tech, Automotive, Aerospace, and Manufacturing industries suggest that the standardized communication instruction implemented in engineering programs can be insufficient to effective engineering communication at workplace, while demanding that engineers adapt part of their communication skills according to the specific industry to which they become part.

Recommendations

Educational programs

Communication instruction in engineering programs could increase the emphasis in oral communication, including the skills required for successful interpersonal and teamwork interactions and not necessarily focused only on public speaking. As recommended by practicing engineers (Wisniewski, 2018), educators should increase students' exposure to communication used in meetings, make them aware of the importance of building relationships with different audiences, offer more practice on informal communication genres, and raise their awareness of strategies for working with multi-disciplinary peers.

The relative emphasis currently given to written communication in many programs could be better balanced with an emphasis in oral communication. In this sense, the application of the CID approach can be very useful as a guide for the development of instructional materials with focus on the kinds of teamwork that are expected from engineers and on the types of communication skills that make the teams more effective (Darling & Dannels, 2003). Additionally, the communication efforts in engineering programs should provide opportunities to develop skills in listening, clarity, and negotiation. The CID approach can also help in making communication instruction more situated within practices that are important for the engineering discipline. In other words, communication instruction should become a context-driven activity, as recommended by Dannels (2001).

Engineering students could be exposed to or at least be trained to think about a more heterogeneous group of potential industry-specific audiences, such as industrial partners, international customers, governmental entities, and other stakeholders. They could learn how to anticipate these audiences' expectations and to tailor their messages accordingly. Additionally, the use of different communication strategies depending on the choice of communication medium could also be one of the targets of communication instruction for engineering students. They also could learn how to develop active listening skills, such as the ability to repeat, clarify, and summarize information, as recommended by Norback et al. (2009). All these skills would be better incorporated by engineering communication instruction through modern instructional approaches, such as active and cooperative learning.

Communication faculty may build on the similarities and differences among the industrial segments explored in this study to tailor their instruction. For example, since in all industrial segments, oral communication matters greatly, engineering students could be exposed to multiple types of oral genres, such as interpersonal interactions, small group decision making, teamwork, and interviewing skills, as recommended by Dannels (2001). Presentation skills could also keep being developed and improved, by adopting some criteria indicated by Dannels (2002): simplicity, persuasiveness, results-oriented, numerically rich, and visually sophisticated.

Educators should be rigorous when evaluating grammar, spelling, logical structure, and other important elements of effective written communication. Deficiencies could be reflected in grading to motivate students to improve their writing skills. The combination of the rhetorical and pragmatic approaches, including the concepts of purpose, audience, identity, context, community, and genre (Kmiec & Longo, 2017) should be considered when teaching students writing skills. Students could also be exposed and trained on how to effectively develop multiple genres of engineering documents.

In order to reduce the gap between the different activity systems represented by the classroom and the workplace environments (Paretti, 2008), engineering communication instruction must promote more situated learning, including different assessment strategies able to stimulate students to think about their audience not only as professors, and consequently graders, but as representatives of their future managers, co-workers, customers, and other stakeholders.

With the purpose of developing cross-cultural communication skills of engineers, educators could introduce international topics in regular learning experiences and assessments, such as case studies, and writing assignments. Additionally, student groups formed with ethnical diversity could be encouraged.

Future research

The differences in the engineering communication requirements across multiple industrial segments could be further explored through a quantitative or mixed method approach. The engineering communication aspects discussed in this study could become the framework for the development of a survey to quantitatively verify these differences across a more significant number of industries. Additionally, the selection of the industrial segments could be based on different criteria.

Further analysis of the engineering communication aspects across different engineering disciplines instead of different industrial segments could bring new insights for communication instruction. Additionally, the sampling process of participant engineers could be done differently, including a more heterogeneous and bigger number of interviewees.

Considering that many educational initiatives to improve communication skills of engineering students have been taking place in engineering programs since the establishment of the ABET 2000 criteria, it would be useful to investigate the communication performance of younger generations of engineers who were exposed to communication instruction compared to older generations with no previous communication training. This type of research could potentially answer the question if the current educational initiatives are resulting in tangible improvements in the engineering communication performance at workplace.

Since regular courses of English normally attended by engineering students don't target the specific skills and applications for engineers (Yalvac et al., 2007), but were indicated by most of the engineering participants in this study as the main type of previous college communication instruction, it would be helpful to develop a research comparing the efficiency of these English courses provided to engineering students in the freshman years and other communication instruction initiatives offered to students later in their engineering programs.

Research focused on exploring cross-generational communication issues among engineers could benefit all types of industrial segments, since the presence of multiple generations in the workplace has been recognized as challenge to effective communication. Additional research on how engineering programs could incorporate the specific global communication skills expected from engineers is also recommended.

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APPENDICES

APPENDIX A: ELECTRONIC LETTER FOR POTENTIAL PARTICIPANT ENGINEERS

Dear Engineer,

My name is Lilian Almeida, a Ph.D. student and researcher in engineering education at Utah State University (http://www.eed.usu.edu/people/graduate-students/lilian-almeida) and I am developing my Ph.D. dissertation on the topic of engineering communication.

You are receiving this e-mail because you were identified as a practicing engineer in a leadership role with relevant engineering communication experience in the industry setting. As a Ph.D. research assistant at Utah State University, I would like to invite you to participate in a study that will investigate the communication skills engineers need while working in industry.

If you choose to participate, I will schedule a time for an interview that is convenient for you. The interview is expected to occur in person in about 45 minutes to 1 hour within the organization you currently work or in an alternative place according to your convenience. As part of the research you will fill out an anonymous demographic questionnaire and answer questions related to your communication experience in your role as an engineer. The entire interview will be audio recorded. You will receive a $50 Amazon gift card for your participation.

The research has obtained Internal Review Board (IRB) approval from Utah State University. IRB ensures that participants' rights and privacy are protected in the process of participating in this study. All the data will be destroyed 6 months after it is collected and analyzed.

The direct significance of the study includes: providing a detailed description of the specific communication skills necessary for engineers to succeed in contemporary industry settings; identifying the most common communication challenges of engineers in industry settings; and verifying if there are differences in the specific engineering communication requirements across multiple segments of industry.

Thank you very much for considering to support this research. If you would like to participate in the study or have questions regarding it, please contact me through this e-mail address lilian.almeida@usu.edu or call me at (435) 557-6297. If you have additional questions or concerns about this research, please contact Dr. Kurt Becker, principal investigator in this research and a faculty member at Utah State University, at kurt.becker@usu.edu or (435) 797-2076.

I appreciate your attention in advance.

Sincerely,

Lilian Almeida

Ph.D. Research Assistant

APPENDIX B: INTERVIEW PROTOCOL

Participant General Information

Name: ____

Job Title: ____

Size of organization: _____________________________________

Highest Degree Earned

☐ BS Major: ______________________________

☐ MBA

☐ MS Major: ______________________________

☐ PhD Major: ______________________________

Number of years in industry: ____

Research Question 1

How can the specific communication skills expected from practicing engineers in industry be described?

Interview Questions

- Tell me about your role as an engineer and how communication is used in your position.
- How do you define communication in your role and is it tied to your success as an engineer?
- Out of the primary communication strategies that you use in your position regularly, which ones do you consider be the most important? Please explain.
- In your specific role as an engineer in industry, how are your communication skills used differently compared to communication your everyday life?

• What are the main kinds of audiences you normally communicate with and which are the most frequent mediums utilized to communicate with them?

• Which forms of communication are more frequently demanded in your work? Can you describe what some of these communication activities entail?

• In your experience as an engineer, provide some examples where you have applied different communication strategies in different situations or groups of people.

• Based on your experience in industry, what critical factors of written communication do you apply routinely? What about oral communication?

• In your role as an engineer, what types of documents do you frequently write?

Research Question 2

What are the engineering communication challenges of practicing engineers?

Interview Questions

• Did you have any previous coursework in technical communication before working as an engineer in industry?

• Does your organization offer training in communication?

• What is your perception about yourself as a communicator in your role?

• What challenges do you experience (if any) in terms of communication in your role?

• What challenges in terms of communication have you noticed your engineering team experiences. Please explain.

• As an engineer in your position, how has technology changed your communication practices or requirements?

Research Question 3

In what ways are engineering communication requirements different across varying types of industries?

Interview Questions

- Tell me about the specific communication requirements in your role in this industry.
- In your experience, how different are the communication requirements of your current role compared to other industries?
- Are your communication skills assessed in performance evaluations? If yes, please explain.

APPENDIX C: INFORMED CONSENT

OFFICE of RESEARCH and GRADUATE STUDIES
UtahStateUniversity
INSTITUTIONAL REVIEW BOARD

Full Accreditation

Page 1 of 22
Protocol #9428
IRB Approval Date: June 11, 201
Consent Document Expires: June
IRB Password Protected per IRB

Understanding Industry's Expectations of Engineering Communicati

Introduction/Purpose

You are invited to participate in a research study conducted by Dr. Kurt Becker, Profess Engineering Education at Utah State University, and Lilian Almeida, Graduate Re Department of Engineering Education at Utah State University. The purpose of this resea understanding of the specific communication skills necessary for practicing engineers to s industry settings, identify the most common communication challenges of practicing er verify if there are differences in the specific engineering communication requirements a segments.

This form includes detailed information on the research to help you decide whether to pa Please read it carefully and ask any questions you have before you agree to participate.

Procedures

Your participation will involve a face-to-face interview with the researcher in order to ope your communication experiences in your role as an engineer. Your total participation in th be between 45 minutes and 1 hour, and the interview will be entirely audio recorded people will participate in this research study at this site, and that a total of 8 people w sites.

Risks

This is a minimal risk research study. That means that the risks of participating are no m those you encounter in everyday activities. There is a risk of loss of confidentiality, which

Benefits

There is no direct benefit to you for participating in this research study. More broadly, researchers learn more about communication skills engineers need to have to work in in to help future educational initiatives in engineering education. The direct significance providing a detailed description of the specific communication skills necessary for e contemporary industry settings.

Confidentiality

The researchers will make every effort to ensure that the information you provide as p confidential. Your identity will not be revealed in any publications, presentations, or re research study.

We will collect your information through interviews and audio recordings. Notes and securely stored in a restricted-access folder on Box.com, an encrypted, cloud-based s recognize your responses. This form will be kept for three years after the study is comp destroyed.

Voluntary Participation/Withdrawal/Costs

Your participation in this research is completely voluntary. If you agree to participate now later, you may withdraw at any time by informing the researcher about your request to s choose to withdraw after we have already collected information about you, your i considered for data analysis in this research and will be destroyed.

Compensation

For your participation in this research study, you will receive an Amazon gift car Compensation will occur if participation is complete, which means that all the questions should be answered to the best of your abilities. The entire interview will be recorded. H to skip any questions that you do not want to answer.

Future Participation

The researchers would like to keep your contact information in order to invite you research studies. If you would like them to keep your contact information, please in information will be entered into a confidential data base only accessible to the researc completely separated from anything to do with this research study, and maintained contact the Principal Investigator at any time to be removed from this list.

IRB Review

The Institutional Review Board (IRB) for the protection of human research participants has reviewed and approved this study. If you have questions about the research study i Principal Investigator at 435-797-2076 or kurt.becker@usu.edu. If you have questions abo simply like to speak with someone other than the research team about questions or conc IRB Director at (435) 797-0567 or irb@usu.edu.

Kurt Becker
Principal Investigator
435-797-2076; kurt.becker@usu.edu

Lilian Maria de Souza Almeid
Student Investigator
435-557-6297; lilian.almeida

Informed Consent

By signing below, you agree to participate in this study. You indicate that you understand participation, and that you know what you will be asked to do. You also agree that you h

APPENDIX D: CODEBOOK

Code	Code Description	Example
Communication importance	How participants evaluate the relative importance of communication in the engineering profession.	Communicating information is very, very critical whether it'd be a deadline, a milestone that we're working towards, or a requirement, or a specification that the engineers are required to do their job (Engineer 1, Interview 1, Lines 139-141).
Communication purpose	Contexts and reasons why communication is used in the participant's professional routines.	Explaining what work you've done and not really selling but at least explaining it in a way that makes sense to someone that is helping fund the research (Engineer 2, Interview 2, Lines 28-30).
Communication tied to success	How communication skills are associated with success in the career of the engineer.	And those that are good at that communication are the ones that tend to advance more rapidly in their career progression. So I feel it's a very important principle that if done well can enhance an individual's career (Engineer 1, Interview 1, Lines 98-100).
Communication strategies	Special ways to communicate specific messages depending on the situation or considering different types of audiences.	I don't like to manipulate people. I see it done. I see it coming down on me from time to time, and people call it business strategies and things. I prefer to be upfront and fairly open with people (Engineer 1, Interview 1, Lines 113-116).

Code	Code Description	Example
Professional communication	Communication done specifically in the professional environment mostly in a formal and technical way.	I believe that there is a degree of professionalism that you need to treat fellow employees with but also customer base as well or potential customers (Engineer 1, Interview 1, Lines 181-183).
Audience	People to whom the communication is directed to.	When I was beginning engineer, my audience was primarily fellow engineers and my manager, that's who I worked with. That's who I had to deal with, sometimes I would have audiences of customers and suppliers. Today, my most frequent audience is my team (Engineer 1, Interview 1, Lines 258-262).
Mediums	Channels used to communicate the message, such as e-mails, phone calls, Skype.	Skype for business is huge in terms of communicating as a manager to my customer. So we could do screen sharing of our documentation, being able to communicate clearly, you know, ideas and concepts without having to meet in person (Engineer 1, Interview 1, Lines 55-59).

Code	Code Description	Example
Most demanded forms of communication	Types of communication more frequently demanded in the engineering workplace.	So, more and more verbal communication skills are necessary as you move into more of a manager role (Engineer 1, Interview 1, Lines 33-34).
Critical factors of written communication	Important aspects of written communication to be considered when writing.	And often times, I have to rewrite e-mails a few times in order to get it simple enough because I know my customers got a lot to read and do on his plate (Engineer 1, Interview 1, Lines 471-473).
Critical factors of oral communication	Important aspects of oral communication to be considered in this kind of interaction.	Yeah, orally? As well, being able to be respectful of somebody's time (Engineer 1, Interview 1, Lines 420-421).
Types of documents	Most common types of documents written in the engineering workplace.	Engineering requirements, documentation, specifications is another way I've seen us formulate design, and software protocols, and things back and forth between customers and ourselves (Engineer 1, Interview 1, Lines 71-73).
Previous coursework on communication	Describes if the participant had previous training on communication during his/her undergraduate engineering program.	I think, later on, there wasn't as much emphasis but taking English courses and things early on. I feel that helped me, I still use that information from way back in those courses in my written communication (Engineer 1, Interview 1, Lines 465-468).

Code	Code Description	Example
In company communication training	Describes if the company offers some kind of training on communication skills	We do have our HR department who will help with some communication techniques, particularly, for me as a manager helping to train me on proper ways ethical ways that I can communicate with people in an interview (Engineer 1, Interview 1, Lines 404-407).
Self-perception as communicator	Participant's self evaluation of his/her own communication skills.	I don't feel like I'm a great communicator but I feel like I've learned some things. I learned from my mentors, in terms of things I watched them do and you could experiment with that a little bit yourself (Engineer 1, Interview 1, Lines 515-517).
Communication challenges	Perceived difficulties on communication skills.	Even engineers on my team struggle to express themselves and that's primarily... Well, sometimes in writing and luckily, we're a fairly small company and I can go and talk to somebody and get clarification on what they might have meant. I see miscommunication in writing (Engineer 1, Interview 1, Lines 91-95).
Communication affected by technology	How new technologies have affected communication.	Lots of e-mail: e-mail, e-mail, e-mail, and I could do e-mail all day long (Engineer 1, Interview 1, Lines 289-290).

Code	Code Description	Example
Specific industry communication requirements	Describes if the participant can notice communication requirements that are specifically demanded in the industry he/she works for.	I feel it's very, very important that people have a good understanding of the technology, and be able to communicate technically with one another (Engineer 1, Interview 1, Lines 616-618).
Performance evaluation of communication	Describes if the company does any kind of performance assessment of communications skills of engineers.	They send out an evaluation to my team members and they'll talk about my communication, not directly (Engineer 2, Interview 2, Lines 310-311).
Face-to-face communication	Communication done verbally and in person.	I just think personal communication is so much more effective than anything else (Engineer 1, Interview 1, Lines 412-413).
Global communication	Communication with audiences located in other countries.	I work with companies all over the globe (Engineer 1, Interview 1, Line 51).
Team communication	Specific communication done among team members and from leaders to his/her team through meetings and other means.	If people are just willing to work together for the good of a project and they're working on, you know, be a good team player, that makes all the difference (Engineer 1, Interview 1, Lines 584-586).

Code	Code Description	Example
Visual communication	The use of visual resources to communicate ideas and provide clarifications.	I come back to the visual learning aspect and that if I've got a picture that I can show somebody to tell them, "Hey, we've got this design," whether it'd be an architecture diagram that we use to lay out in our minds, how we see a system coming together to communicate to a customer that we are also integrating in to their vehicle (Engineer 1, Interview 1, Lines 387-392).
Informal communication	Interpersonal communication without professional purposes.	And that way, you know, during a quick break, during the day, "Hey, how was your fishing trip?" Or, you know, "How was your trip to the amusement park with your family?" I found as I travel with employees and things, I have the opportunity to be a little less formal as were driving in a car, traveling hours to a customer site, and I appreciate that (Engineer 1, Interview 1, Lines 190-194).
Conflict management	The ability to manage well situations of disagreement.	So, conflict management, again, it would be something very, very important. I would see if it can be addressed at the university level toward people… New engineers are coming into the workplace, knowing that, "I might not get along with everybody but I can disagree with somebody and not be a disagreeable person to work with" (Engineer 1, Interview 1, Lines 223-227).