Experimental Design and Technical Writing for

ENGINEERS

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TABLE OF CONTENTS

Introduction

About Technical Writing in the Engineering Field

Welcome.

This course was created to support engineers in developing robust methodologies for conducting studies and documenting their results. While engineering students may not typically be excited about a writing course, in the professional realm, engineers frequently communicate to a wide variety of constituents as part of their daily activities. From the very highest levels of a corporation to external customers and suppliers, to hourly line operators, engineers may find themselves having to produce different types of oral and written communications to any number of audiences.

Not everyone enjoys writing. Writing is a skill that has it's own process for mastery, with individuals pursuing Bachelor and Master degrees of Fine Arts in various forms of writing such as poetry, playwriting, fiction and non-fiction works. Professions like journalism also focus primarily on writing, even though those majors are more often part of a Communications program. What is true of other fine arts like painting, music or dance is also true of writing. There is a creative nature to writing and some people are especially gifted and talented in those arts. But arts also have foundational technical skills that can be taught.

To help facilitate this training, this course combines both the experimental design elements and technical communication in oral and written formats. As such, students are able to learn the appropriate crafting of technical studies,

This includes key elements for selecting materials, establishing methods that promote internal and external validity, selecting appropriate data collection and analysis tools and communicating the relevant information to a specified audience. This also involves the students physically conducting their experiments to tangibly experience the outcomes of well-designed exercises, as well as noting opportunities of improvement for future efforts.

This course also acknowledges that writing has changed as technological advances occur. While jotting notes on paper or sketching quick designs may be helpful in a given moment, technical communication utilizes a wide range of software to support every aspect of technical writing and presenting. At the most basic level, word processing software such as Microsoft Word, Google Docs and Apple Pages assist in technical writing providing formatting resources, limited grammatical support, and easy integration of images, figures, tables and graphs. To generate such content, Microsoft Excel, Google Sheets, Apple Numbers and other statistical software such as MiniTab, JMP, SPSS, MatLab, SAS/STAT can be utilized. Extensions and web-based support including generative and non-generative artificial intelligence can assist with ideation, outlining and provide extensive proofreading addressing issues of readability and tone. For oral presentations, Microsoft PowerPoint, GoogleSlides, Apple Keynote, Prezi, Canva, and others can all be helpful for both online and in-person presentation of content.

As remote work continues to be prevalent, synchronous and asynchronous communications and presentations to groups across geographic regions make tools such as Microsoft Teams, GoogleMeet, Zoom, Slack, Skype, GoToMeeting and CiscoWebex hallmarks of an engineer's communication profile. This requires engineers to navigate professional communication in multiple platforms, making both the development and delivery of various media across appropriate modes more nuanced than in days past. Not all delivery modes will be suitable for selected content and not all content can be conveyed across all communication platforms.

With these factors in mind, engineering students must be prepared in technical communication skills far exceeding the requirements of decades passed. Engineering students must craft materials with the audience and delivery method in mind, using available technologies to facilitate both content generation and delivery, to optimize successful conveyance of ideas, results, conclusions, proposals, methodologies and more.

It is because of this professional skill set that this course supports the development of engineering students in fundamentals of experimental design, technical communications and effective articulation of such materials.

0.1 Uses of writing in engineering fields

Engineers exercise writing practices throughout their academic and profession careers at various levels, dependent on their specific discipline, industry and management level. As each of these factors can vary greatly, this text reviews different types of technical communications which are used broadly in most academic and industry settings, regardless of specialty area. What follows are just some of the types of writing experienced by engineering students and professionals.

The Engineering Classroom

Lab-based coursework often requires technical reports to document the methodology and outcomes of an experiment. As such, engineers typically write technical documents and create presentations for much of their engineering academic career. The principles taught in this course will assist not only with professional writing but also the writing required of discipline coursework and potentially supporting coursework such as advanced math, chemistry and physics. Even if the reports are not “graded for writing”, these opportunities provide excellent practice to reinforce lessons learned from this course prior to entering the engineering workforce full time.

Internships and Co-ops

Many students have shared the large number of assignments that involve technical writing at their internship or co-op experience. Generating required training documents, standard operating procedures or initial proposals for contracts and customers are often part of the job responsibilities for engineers-in-training. For organized part-time work experiences in which specific projects are assigned, students must also document their accomplishments and present them to their superiors. These technical communications also provide a mechanism for students to demonstrate their ability to produce high-quality technical communications, which may put them in higher standing with the employer for a full-time job offer or increase of responsibility.

Entry-level Positions

Like the interns, entry-level engineering positions often involve being a part of a project team or assisting more experienced engineers in their projects and work. This provides an avenue of on-the-job-training as well as mentoring possibilities. Newly graduated engineers can demonstrate their work ethic and quality of work by generating communications that are clear, concise and correct.

Ongoing Work

Engineers in every field interact with parties both within their organization and outside stakeholders. At every level of their careers, engineers will be crafting oral and written communications to other entities. This can include supplier communications, process documents, client proposals, grant applications, patent filings, quality or regulatory specifications and more. Engineers create materials oriented at hourly-employees who may not have finished high school, materials for non-native speakers and presentations for the highest levels of executives or clientele. As such, engineers must be prepared to effectively communicate with a wide variety of audiences on multiple platforms. The skills taught in this course will continue to be useful at every stage of your career.

In the next chapter, we will discuss some of the basic techniques to support writing for technical and non-technical audiences alike. While your previous writing experience can aid these efforts, technical writing, and engineering writing in particular, have to take into account considerations that would not have previously been addressed in your studies. The text continues with more detailed approaches to common engineering documents and other technical communications.

Chapter 01

Basic Mechanics of Technical Writing

1.1 Differences between narrative voice and academic voice

Most of what you read in written in a narrative voice. Whether it is the latest John Grisham novel, a blog post, an article online or posts to social media, narrative voice often sounds the way people think and speak. In some ways, that makes it easier to write in a narrative voice. Narrative does not mean literary or fiction – many pieces written in a narrative voice are non-fiction. Narrative voice refers to a style that engages personally with the subject forming a story of some kind. It could be completely fictionalized work; it could be journalism reporting factual accounts; it could be personalized accounts conveyed in a written form. In this style, the author often uses names, first person accounts and personal pronouns, adjectives and adverbs that help to paint mental pictures, as well as literary tools like similes and metaphors, hyperbole, and other story telling methods that help to put the reader into that setting. Whether you are reading a journalism piece on an upcoming election or a biography on the Wright Brothers, narrative writing connects a reader to a story. As an avid reader, I can appreciate all this form of writing has to offer.

Technical or academic voice has a different purpose. In technical writing, the goal is to present information without bias, subjective viewpoints or embellishment of any kind. It is most often used for technical reporting and academic writing, such as research papers and journals, industry reports, government documents and other academically inclined audience. It is also the style used when writing professionally as an engineer in the workplace. Both forms of writing have a specific style to match their intended audience and purpose.

Imagine the crowds of a town celebrating a win of the Super Bowl or World Series or some other major sporting event. A journalist might write, "The streets were teeming with people from all over the state. The area was buzzing with celebration and the jubilant cheers drowned out the police directives. Children were riding on their parent's shoulders to be high enough to see the crowned victors and not even the barricades could keep the fans from their heroes."
Imagine instead you work for the city planner's office and a report is going to the mayor to discuss the events of the parade. It might read more like "It is estimated that 250,000 people lined the streets for the parade. The police sound systems were insufficient in communicating directives to the crowd. Additionally, the temporary barricade proved to be ineffective for keeping civilians from the parade route."

Both write about the same event but not in the same way. Both share a focus on the volume of people and the impact the people had on police systems. However, if I worked for the mayor's office, it would be important to communicate clearly and specifically what limitations were experienced so that the city would be better prepared for future parades, while a journalist wants readers to have a "feel" for the event. It's also important to note that the public relations office for the city would be concerned with the level of celebration and the attitude of the crowds. Public Relations would want to ensure that everyone was having a good time. The engineers of the city planner's office want to ensure that they prepare for crowd control in a way that keeps citizens safe and ensures that the police can do their jobs effectively. Neither writing style is bad. They simply have different objectives.

As mentioned in the Introduction, to help provide examples of technical (or academic) voice, this text will include both. To introduce chapters, describe high level concepts and discuss general content, a more narrative voice will be used.

When discussing specific examples and techniques, an academic voice will be used to provide samples of the appropriate writing style for that given document or context.

1.2 Differences in technical writing from other forms of communication

The three C's of technical writing "Clear, Concise, Correct" have long been cited as a way of differentiating technical writing from other forms of non-fiction composition. After several basic composition courses, standard in a Bachelor of Science curriculum, students may be tempted to approach this course with the same narrative voice they used in English classes. However, technical writing has several key elements that may seem counterintuitive when compared to other writing styles.

Clear

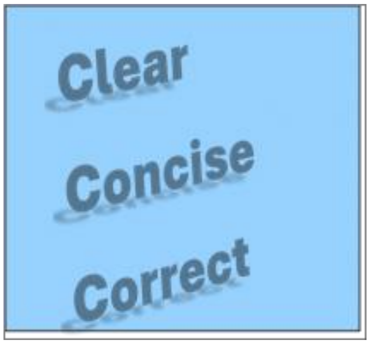
Clarity is the most important element of technical writing, as the premier goal of technical communication is to ensure that the recipient understands your document. Clarity in technical writing can be impacted by overly complicated sentences, unnecessarily long descriptions and verbal descriptions of data that can be communicated graphically instead. Awkward phrasing can also lead to confusion.

Active Voice

Using the active voice is helpful for technical writing in making it clear as to who performed the action. In the active voice, the subject performs the action (e.g. "The dog bit the man".) In passive voice, the subject receives the action (e.g. "The man was bitten by the dog.") Using active voice connects the subject and the verb in a clear way, increasing the readability.

Tense Agreement

Most technical communications report what has been completed. While there may be some documents, such as memos or work instructions, that direct individuals on actions that need to be taken, most reports present the outcome of an experiment, test, or avenue of research which is already complete. Using past tense aid the audience in understanding the order of a procedure or when something occurred, making the document clearer. When providing time-specific elements, use dates, times, and durations as often as possible.



Noun Strings

Titles and descriptions can lead to multiple nouns in sequence, which can become confusing and detract from the central message of the work. Consider the following:

"NASA continues to work on the International Space Station astronaut living-quarters module development project."

"NASA is still developing the module that will provide living quarters for the astronauts aboard the International Space Station."

The first sentence creates a string of 9 nouns that make it difficult to determine the focus of the sentence. The second sentence has the reader focus on the action (developing the module) rather than being lost in the titles

Concise

Students typically assume that writing longer documents will result in higher grades. Oftentimes engineering students have been told by English teachers that they need to add details to paint pictures for their readers. Many assignments in English composition courses have minimum word counts, which reinforce the idea that more is better. In technical writing, sometimes "more" is simply too much.

Concise writing eliminates unnecessary words which can make the writing vague, unclear or distract from the main idea of the work. A technical writing sample includes enough detail to convey clearly and correctly what occurred (or is being instructed) without the use of superfluous language.

More

≠

Better

Phrases

Consider the two phrases in the text box to the right-hand side of the page [1].

Each of these phrases identifies an action which needs to occur and the desired outcome, but the first sentence is 19 words and the second sentence is only 7. The additional 12 words of the first sentence do not change the meaning but simply take up space in the document.

One must evaluate each assembly more carefully thereby reducing the total number of defects occurring on the production line.

compared to

Evaluate the assembly carefully to reduce defects.

Verb usage

Verbs themselves can assist in making documents more concise when conjugated appropriately. Consider the following [1]:

"Is indicative of" compared to *"indicates"*

*"has knowledge o*f" compared to *"knows"*

These phrases are identical in meaning, but the active form of the verb makes the sentence clearer and more concise.

Prepositions

Prepositions can add clarity of possession and make sentences concise. If something belongs to or someone is in possession of something, an apostrophe s ('s) can note that possession without additional descriptors. Consider the following [1]:

"The attitudes of the subject indicate that"

"The subject's attitude indicate that"

While only two words were eliminated, there is additional clarity of ownership in the second example.

Expletive constructions

The constructions "It is, there is, there are" all detract from the simple construction of phrasing that can add conciseness and clarity to your writing. Consider the following phrases [1]:

"It is apparent that the cost of construction materials will increase in the future."

"Construction costs will increase."

Note that the second option eliminates the redundancy in time ("will increase" conveys as future state) and the unnecessary preparatory phrase "it is apparent that".

Correct

Correctness in technical writing can refer to multiple qualities of the document, including technical correctness and grammatical correctness. A technically correct document is free from errors in the material being presented, including calculations, graphical presentations, appropriate use of analytical tools, accurate portrayal of context and methodologies and logical discussion or conclusion from the material being presented. Many of these areas will be addressed in subsequent chapters of this book.

Grammatical correctness is also essential, as incorrect word selection, improper punctuation and misuse of grammatical conventions can both cause the reader to doubt the material being presented and change its meaning. While basic grammar is addressed in introductory composition coursework, several grammatical principles are critically important to technical documents.

Abbreviations

Technical documents often require discipline specific jargon and abbreviations. It is important that all abbreviations are properly defined prior to their ongoing use within the document. It is helpful to use abbreviations for items that appear more than three times within a single document. For example, if you will be frequently using the term "parts per million", it may be abbreviated "ppm". Some abbreviations, such as $CO2$ can be assumed to be common knowledge and do not need to be written out prior to use. When in doubt, the author should provide the written form, followed by the abbreviation in parentheses (e.g. carbon dioxide ($CO2$)) at its first use within the document.

Acronyms

Like abbreviations, acronyms are frequently used in technical fields and can be written in the shortened format after first being written out completely. All acronyms should be written fully once, even if you believe the reader will understand your phrasing. For example, more people are familiar with NASA than they are with the proper name, National Aeronautics Space Administration. However, it is appropriate to write the title fully prior to the acronym being used throughout the rest of the document. As with abbreviations, the title should be written out followed by the acronym in parentheses (e.g. Occupational Safety and Health Administration (OSHA)). This is also important as some acronyms may mean multiple organizations, such as DOE is often used for both the Department of Education and the Department of Energy. Also, acronyms do not require periods after each letter. This change is partially due to the large number of embedded hyperlinks, where periods can be part of the Uniform Resource Locator (URL).

Numerals

To be clear, concise, and correct, exact data should be used whenever possible. This includes dates, measurements, statistics, and other quantifiable data. For example, if 400 of 500 people surveyed thought smoking was bad for their health, you would want to say, “A survey found 80% of individuals viewed smoking as bad for their health.” or “Out of 500 people surveyed, 400 agreed smoking is bad for your health.” Either of these options is more clear, concise, and correct than saying “Many individuals agree that smoking is bad for your health.” Additional content about presentation and discussion of data will occur in chapter 4.

When writing numbers in documents, numbers larger than ten can be typed as numerals (e.g. 37) while one through ten are most often spelled out. Numbers beginning a sentence should be spelled out even when they are greater than ten (e.g. “Twenty race cars lined up for the British Formula 1 Grand Prix.”). When spelled out, remember to use a hyphen for numbers as appropriate (e.g. fifty–five).

Acronyms Abbreviations and Numerals

Oh My

1.3 Helpful grammatical reminders

In addition to the content in this chapter, grammatical conventions taught in English classes remain critical to writing clear, concise, and correct information. As stated previously, a document poorly written is not only ineffectual at communicating important content but also reflects poorly on the author. When you present work that has errors, your audience can doubt the competency of the work being presented in addition to questioning your skill as a writer. In this section, several wording choices are presented to assist you in crafting your documents.

Helpful verbs

Verbs are action words that aid in conveying what took place. Selecting the correct action verb is critical to your audience understanding your work. Below are verbs that can aid in communicating technical activities.

Helpful Verbs	
Instigate	Frame
Argue	Enact
Suggest	Constrain
Grapple	Enable
Operate	Instill
Predict	Categorize
Discuss	Explain
Provide	Correlate
Facilitate	Revolve

Choosing appropriate adverbs and adjectives

There are words that are used in fiction and casual prose that are not used in technical writing, due to their general nature. Adverbs and adjectives that do not convey specific descriptions can be misleading (unclear or incorrect) and add bulk to your writing (not concise) making the use of adverbs and adjectives less helpful in technical writing than they would be in other writing styles. Students often try to be more descriptive in their work causing them to use adverbs and adjectives in ways that were acceptable for other English classes but are distracting in technical writing.

It's important to note that words can be misleading depending on the audience. Consider the word "old". While we all know that the word means, it is not at all specific. Puerto Rico boasts of some of the oldest structures in the US, not including the dwellings of native peoples.

In Old San Juan, there are structures dating back to the early 1500's [2]. Compared to the oldest buildings in Evansville Indiana, which date back to the 1800's [3], Old San Juan has much older architecture. However, compared to Pantheon in Rome (built in 31 B.C.) [4] the buildings in Evansville or even Old San Juan are barely broken in.

The context greatly changes the meanings of these words, which make these words vague to a varied audience. A single grain of sand can be considered "huge" compared to a virus, as some viruses are 2,000 times smaller than a grain of sand [5]. It is a "huge" difference, but neither a virus nor a single grain of sand would be described as "huge" in most settings. As engineers, it is best to include actual measurements and units, rather than the vague descriptions listed below.

Inappropriate Adjectives
Huge
Gigantic
Terrible/bad/awful
Strange
Good/nice/great
Totally
Perfect

Technical Vocabulary
Confidence
Accurate
Resolution
Measurement Error
100%
Precise
Tolerance
Acceptable
Significance

Words that can only be used with their technical (discipline specific) meaning

Additionally, there are words that have a technical use that may not be the same as how a word is used in casual conversation. For example, many people use "accurate" and "precise" interchangeably in casual conversation, but as we will discuss more in chapter 3, these words are very different in meaning. In current American society, the phrase "100%" is a common way to show agreement or emphasis. In engineering, very rarely do we account for 100% of any result. Again, using the exact number, even when it is 99.99%, is important to correctly communicate your data.

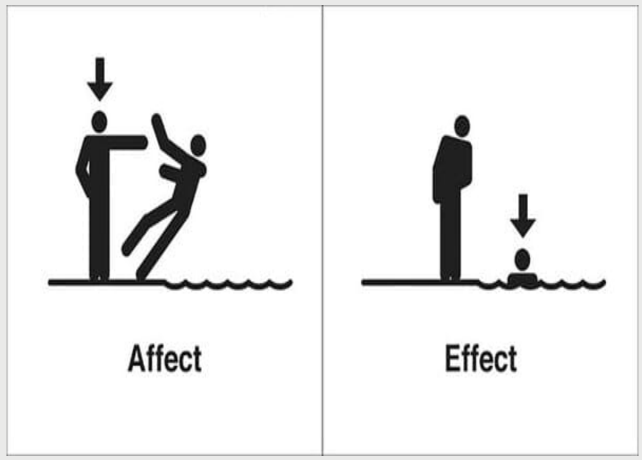
Helpful transitions between sections

Some writers have a difficult time moving between thoughts smoothly. Even though the writing should be correct, concise, and clear, you should also aim to have a document that transitions easily between thoughts. The words in the table to the right can aid in moving between thoughts, contrasts and comparisons, paragraphs, and sections.

Helpful Transitions	
Despite	Therefore
In contrast	Finally
At the start of	Accordingly
Further	Similarly
During	Additionally
With regard to	In conclusion

Common misused words or phrases in writing

More often than not, when I see a misspelling in student work, it is actually a word that was autocorrected or auto suggested by the word processing program. While spell check and grammar check can be helpful, proofreading is essential for all work to catch common errors, like those in the table below or in the cartoon along the right side of this page [6]. Many of these words are homophones (words that sound the same but are spelled differently and mean different things) which make them more difficult to catch when proofreading. When speaking, the difference between "compliment" and "complement" can be subtle to the ear. When writing, it would be easy to misspell the word and thereby change the meaning of your sentence. Several of the most common examples are included in the table.



Commonly Misused Words	
Accept – to receive	Except – to exclude
Advice – guidance	Advise – to give counsel
Affect – change or influence	Effect – the result
All ready – all people or things are ready	Already – having been completed
Complement – the whole or entire	Compliment – give praise
Eminent – distinguished	Imminent – about to happen
Everyday – ordinary	Every day – occurring daily
Farther – a great distance	Further – promote or advance
Loose – not tightly secured	Lose – fail to win
Principal – administer or sum of money	Principle – basic law or truth

Capitalization is required for the first word in a sentence, the pronoun “I”, proper names and titles with given names and for abbreviations and acronyms

- Canada
- General Motors
- The Democratic party
- President Woodrow Wilson
- NAACP

Punctuation errors

Like spelling and grammar, many word processing software will suggest punctuation and even automatically include periods or commas at times, depending on your settings. Basic rules for correct punctuation are included on the right-hand side of the page. As engineers often form lists of items, understanding the different uses for commas, semicolons and colons is a helpful skill to have.

Colons are used for lists of items

- Success depends on three things: talent, determination, and luck.

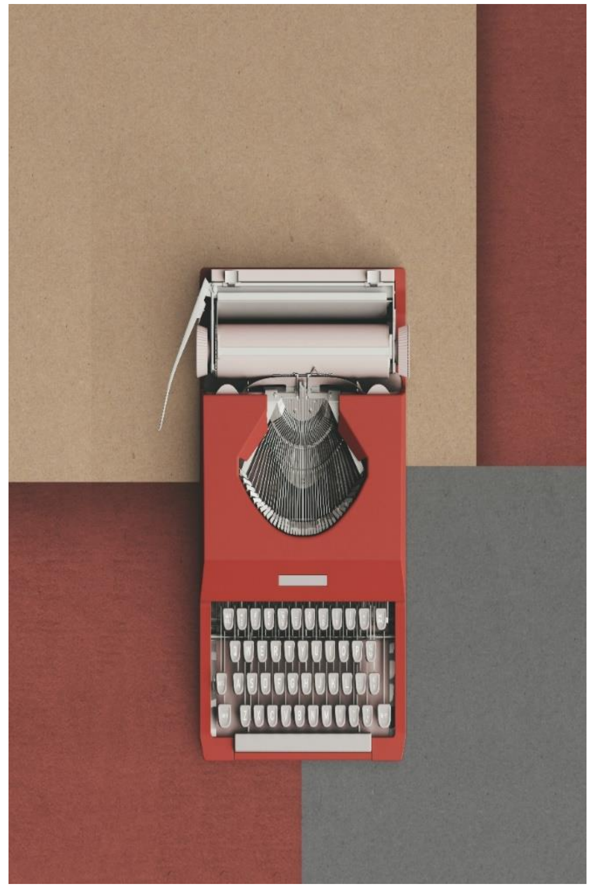
Semicolons are closely related separate clauses or series of items that include commas

- Wise men don’t need advice; fools don’t take it.
- In the crowd, I spotted Delaney, who was wearing a hat; Dylan, who had a green bandana around his head; and Curtis, wearing a fedora.

Commas are used for dates, conjunctions, or a series of items

- January 11, 2022
- At midnight, long after the final outcome of the game, the losing manager was still shaking his head in disbelief.
- A blight struck birches, maples, oaks and sycamores.

1.4 The writing process



The previous sections have reviewed wording choices, grammatical considerations and aspects of academic voice that can help you craft a clear, concise and correct document. But the idea of writing can still intimidate many. A blank page can cause people to stare and feel that sense of dread, their mind emptying of any thoughts they had prior to sitting down. I had one friend that would write gibberish, typing random words on a blank page until words started to form and the page filled with real content. Even for experienced writers, a blank page can be frightening. So how do you begin the process? The below questions can help to guide your thoughts before you begin to craft specific content.

Prior to content creation – At the onset of writing, it is helpful to ask a few questions:

- What is the goal of this document?
- What information is being communicated?
- Who is the audience receiving the communication?
- How will the information be transmitted?

What is the goal of the document?

All communication is aimed at conveying information in a way that others understand your expressed content. In face–to–face communication, over 80% of information is received through non–verbal means, such as facial expression, gestures, intonation, posture, rhythm and volume. For written communication, the words may also convey a tone, attitude or posture based on phrasing, context and format. This requires authors to be cognizant of how the information will be received by the specific audience to match the goal of the communication. The majority of written expressions are also one–direction and typically asynchronous. While we no longer require the delivery of a physical document from one place to another, even instant messages maintain a communication at someone with a delay in knowing how that information is received. This is also true for formal oral presentations, when participants are expected to listen silently until the end. When writing a standard operating procedure or work instruction, writers are intending for the recipient to execute a series of steps in the right method to produce a desired result.

When writing a Six Sigma report, authors document a process improvement and provide an explanation typically grounded in quantitative analysis to relay project results to stakeholders. When writing a bid for contract, the engineer is looking to supply evidence of capability of performing a given project within a set length of time for a competitive price. Each of these examples demonstrates how the goal of the document can impact how the document is formed.

What information is being communicated?

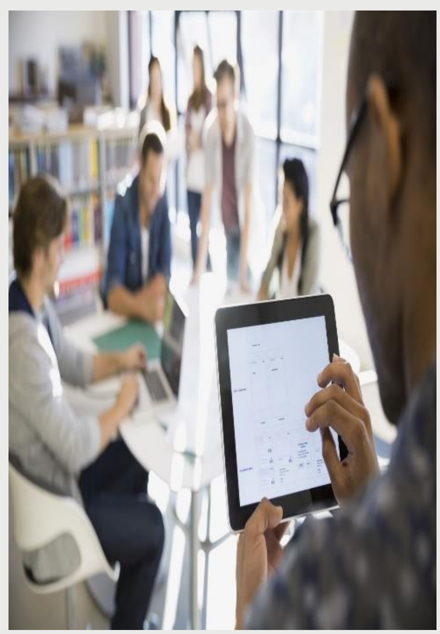
Technical documents may be focused on procedures, specifications, data analysis, design elements, scheduling information, and cost considerations, among other topics. Some information may require additional background or context for the reader. Some information may be confidential to only select audiences. Some information may be broadly transmitted or public–facing. It is important to consider from the start the nature of the information to best select a method for clearly conveying the central message to the intended recipient.

Who is the audience receiving the communication?

As seen in the previous two questions, the recipient is a critical consideration before beginning the writing exercise. The audience can impact the level of background or context required, the use of technical jargon, the selection of vocabulary and other considerations that will be discussed at length later in the chapter. In cases where a potential audience is less clearly defined, the author must write as if for a public, non-technical audience to ensure clarity to all readers.

How will the information be transmitted?

This course will discuss several common documents to engineering disciplines. A document printed for operators on an assembly line is different than a memo for all company personnel or a bid for a proposal which will be electronically transmitted to a potential client. Formatting documents specific to their audience and transmission can aid readers in better understanding the intent of the document.



Content Creation

Outlines, storyboards, flow charts or institutional rubrics can assist the writer in crafting the document for maximum effectiveness. Many large companies provide templates to follow for common technical documents. Potential clients or granting agencies typically provide a rubric with the required elements for submission as well as the weights used in the evaluation procedure.

When guidance has not been supplied by an outside source, a writer can create their own outline enumerating each specific section in a logical flow. This framework or structure can help keep the writer including the necessary content without creating unnecessary tangents that could make the document unclear.

Generative AI tools can assist in the ideation stage of content creation as well and will be written about further in chapter 2.

Writing

While it may seem self–evident, the forming of thoughts into coherent sentences, paragraphs and pages is not always as easy as it seems. Authors may have different techniques that assist them in generating content that is consistently meeting the needs of the objective. This could involve writing every day at the same time; or setting a timer and forcing oneself to write for a given length of time; or working in a specified place that frees you from distraction. A sound approach when writing is to "write big and edit small". "Writing big" gives you the freedom to document everything that comes to mind in it appropriate place with the intent of editing redundant, confusing or unnecessary content during the proofreading process.

Proofreading

Reviewing your work is a critical step in the process and should be included for all works, regardless of length or complexity. As authors, we know the intention of each word we have written, making it difficult to judge our work without bias. If our work is confusing or conveys a different tone than we intend, a neutral party can help identify opportunities for improvement. In other words, if a document has an audience, it should include an external reviewer prior to submission to the next step. For example, if you are writing a procedural document, someone should try to execute your procedure as written, prior to presenting it as the new methodology for other workers. If you are writing a report to document your results, you should have someone unfamiliar with the work read your document and summarize their main takeaways.

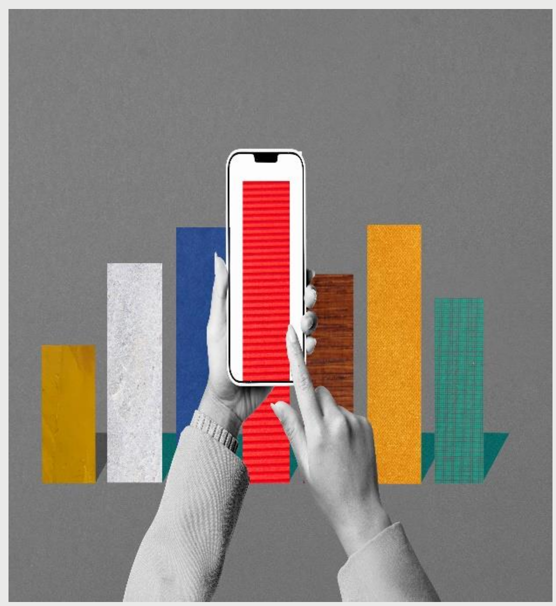
- Grammatical and spelling errors can be caught by most word processing software (like Microsoft Word or Google Docs), but those software cannot tell you if your procedure is incorrect or you analysis is illogical. Proofreading is not only for errors, but to ensure the work is clear, concise and correct. If a neutral-party reviewer is unavailable to read your work, there are a few tools to aid in self-proofing a document we authored.
- Read your work out loud. This process requires us to slowly review each word written which aids in identifying overly long or confusing concepts, as well as basic grammatical issues or a lack of flow. Even in technical documents, each sentence should have a cadence that is comfortable to speak and each section should naturally lead into the next.
- Print your work and use a ruler to review only one line at a time. This process also slows down our reading and makes each line of text our singular focus, rather than quickly skimming entire paragraphs at a time. Like reading out loud, this helps us to identify areas that are confusing or out of synch with the content surrounding it.

Formatting

After all text is present and reviewed, the formatting can be evaluated. Are the font size, face, color and spacing appropriate for the mode of transmission? Is there consistency in the justification, spacing and positioning of each paragraph? Are headings used appropriately and labelled consistency throughout the document? Are required elements, such as page numbers or tables of contents, headers and footers included as required by the specified template, rubric or convention? Are headings directly above the content or have they been shifted to a previous or subsequent page during the editing process? Are all tables, images, and figures labelled appropriately and appear without covering text or extending onto an additional page?

Formatting can take a substantial amount of time and should not be completed as an afterthought, but rather completed with the goal of assisting the recipient in having the highest quality experience when reading the document.

It is helpful to keep in mind whether or not the document will be a printed page, read on a personal computer or on a portable device, such as a tablet or cell phone. Documents posted to websites should be formatted for both landscape and portrait sizes. Accessibility checks should be used when formatting for e-readers, color-blindness and other visual impairments.



1.5 Conclusion

This chapter served as an introduction to the purpose of technical communication in the engineering discipline and a review of some basic approaches to the writing process, as well as tools to assist in writing. While not all individuals may enjoy writing as a creative expression, the technical skill of writing is one that can be learned, practiced and optimized for a given task. Whether writing lengthy reports to executives at a software development firm or brief memos to peers in an engineering design company, the basic principles for crafting a written document remain the same. Every engineer will be called to express various forms of information in a written document. The skills learned in the course will support engineers both through their academic careers and each step along their chosen career path.

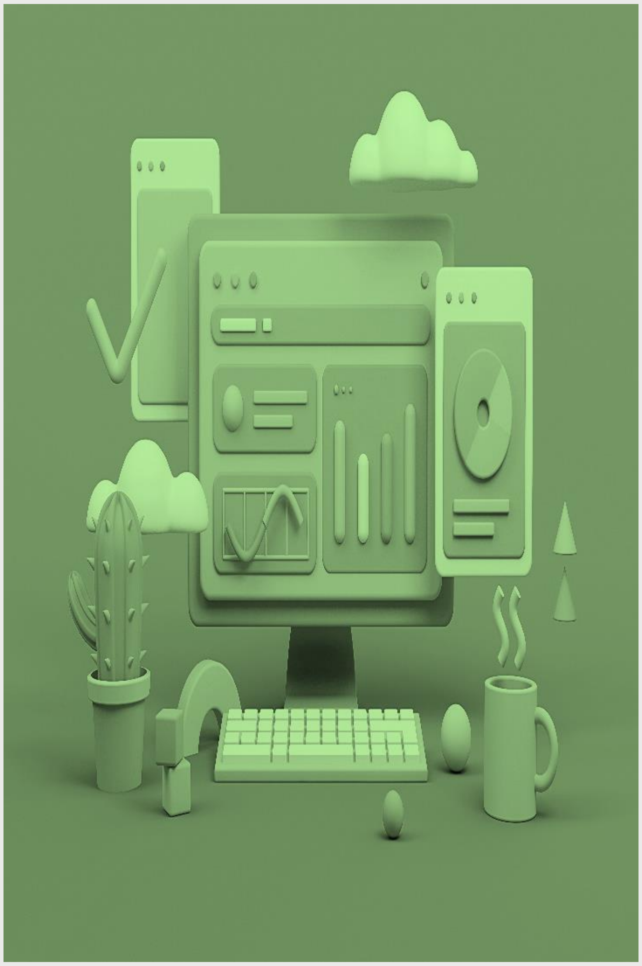
Up Next

The next chapter of this book introduces digital platforms common in engineering fields that may be used for formal and information communication. This includes software common in education and industry such as the Microsoft Office Suite, Google Tools and Mac OS applications. The chapter will also address the appropriate uses of generative and non-generative Artificial Intelligence (AI), which can be helpful in preparing documents and presentations, when their limitations for ethical use are clearly understood. The chapter will also address digital communication tools common in various industry settings. Students need to be prepared to engage over numerous applications with various stakeholders in a way that maintains technical expertise and appropriate professional etiquette. Messaging apps, shared project platforms, web-conferencing, intranet platforms and business email will be addressed in this section.

Chapter 02

Digital Media and Technical Communications

In recognition of the changes in technology over time, technical communications nearly always involve digital technologies. These can be as commonplace as email or texting, standard applications of the Google, Microsoft or Apple operating systems, team-based software like Microsoft Teams and Zoom, or productivity software like Slack. As with other written and oral communications, the use of these software must consider factors such as: the objective of the communication, the technology limitations associated with each software, the audience involved, and potential digital security concerns.



2.1 Digital tools to assist technical communications

It may be hard to imagine, but in my office, I have a copy of a dissertation my grandfather wrote when he completed his doctorate degree. Every word was typed on a typewriter by my grandmother. Years later, when my father completed his dissertation for his doctorate degree, my mother typed it on a word processor. His was the first dissertation from his research lab at Purdue University to use a word processor. Years later, when I wrote my dissertation, I typed on a laptop that had cost $2,000 and had less memory than my current iPhone. As you write for this course, I imagine many of you will write using convertible tablets with styluses, and laptops with more storage than the Space Shuttle Columbia [1]. Technology continues to evolve, becoming faster, smaller and increasing our productivity. As engineers, we should embrace the technology that aids us in becoming efficient in our tasks.

Composition tools

In academic settings, the most common word processors are Microsoft Word, Google Docs and Apple Pages. These tools all come with formatting capabilities, spelling and grammar checks, ease of adding images, figures and graphs and reference support through internal citation generators for most citation formats. These tools can also assist in creating embedded links through headers and captions within the document to automatically generate a Table of Contents. These tools also have increased the "suggested" words or phrasing while typing and autocorrecting apparently misspelled words while you type. If you choose to leave these features on (they can be turned off in the Settings menu) the author must take additional care in proofreading, especially for technical documents. These tools are intended to suggest or correct frequently used words, which may not always be your chosen word for your document. For example, the word "trial", when misspelled, might be autocorrected to "trail", which may be a more common word, but not the correct word for your context. It is important to note that citations created by these word processors may not be complete or up-to-date with the requirements of your given course or purposes. Therefore, when using these tools, double-check the format prior to submission.

Word processors are best used for technical documents and communications that are distributed via email or printed and distributed within a company. Word processors can easily integrate visuals (tables, graphs, charts, images) and can be created into templates to standardize documents within an organization.

In modern workplaces, many documents are saved to internal servers or cloud-based computing servers, allowing individuals to share documents easily, collaborate on a single document, or work from remote locations on various devices.

Word Processing Extensions

Several tools, like Zotero for citations or Grammarly for proofreading, can be added to word processing software. These extensions can add support without having to work in a separate application and can be helpful. Additional word processing assistance from generative and non-generative artificial intelligence will be discussed later in this chapter.

Basic Spreadsheets and Calculating

Engineers frequently work with data and often need to communicate the data in a visual form for others to see the outcomes of their work. The Microsoft Office Suite includes Excel, which can be used for many calculating applications and easily create graphs and charts. Excel now offers suggestions for types of charts and display options, making it quick and easy to turn raw data into meaningful displays for analysis and presentations. Other software packages similar spreadsheet applications.

Spreadsheet Extensions

Like word processors, spreadsheet software extensions can increase their functionality by adding programming content (like Visual Basic), statistical processing and predictive analysis tools, now equipped by AI software. These extensions make Excel capable of completing tasks that previously required specialty software. Apple Numbers and Google Sheets offer similar functionality for spreadsheet applications, although Google Sheets is limited in some of the advanced calculating capabilities.

Advanced Calculating

Engineers use many different types of software, depending on their discipline and industry and function within a company. However, when evaluating data, statistical analysis is often required to ensure the reliability of your data. When Excel with statistical extensions are not sufficient, software such as Minitab and SPSS are often used in industry. SPSS is one of the oldest and most powerful statistical software packages but can be difficult to learn. Minitab is more intuitive and nearly as powerful as SPSS. Web Based programs like JMP and Tableau are popular for their ease of use, but are limited in function compared to Minitab and SPSS.

Presentation Tools

One of the reasons this book uses the term "technical communications" rather than "technical writing" is because presentational speaking is a frequent occurrence for engineers. As such, familiarity with presentational tools and knowing how to craft a technical presentation for both technical and non-technical audiences is a required skill for engineers. From the Microsoft Office Suite, PowerPoint is used create presentations that can be presented in person or online. Apple offers presentational software called Keynote which has similar functionality to PowerPoint. Google Slides is the equivalent software in the Google suite of applications. Chapter 7 addresses oral presentations in great detail, which can aid you in how to design and deliver presentations using these tools.

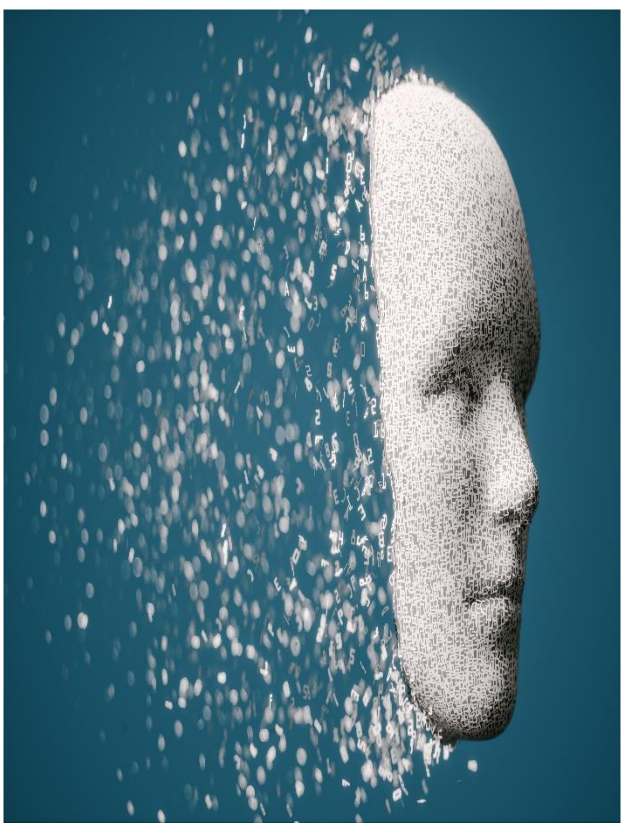
There are many free web-based software solutions that offer presentational tools very similar to the three mentioned above and some with additional functionality for web-based presentations. These include Prezi, Canva, Visme, Haiku Deck and Pow Ton, to name a few.

2.2 Use of Generative and Non-Generative AI in technical writing

Artificial Intelligence (AI) develops greater applications to writing, computing and presenting on a daily basis. Many companies have integrated AI solutions into existing software to remain competitive within their industry and take advantage of the superior analytic tools. While the use of AI in educational settings is widely debated, there are multiple software solutions that can aid in technical writing involving generative and non-generative artificial intelligence. Just as engineers adopted calculators instead of slide rules and computers instead of typewriters, artificial intelligence is a tool that should be leveraged in appropriate ways to be productive and efficient in the workplace. Below are some guidelines about uses for AI in writing to ensure you operate in an ethical fashion and make use of technologies available to you.

Non-generative AI

Non-generative artificial intelligence can be used to assist technical writing by advanced proofreading for not only spelling and grammar, but also tone, academic voice, conciseness and overall readability. These tools are never in violation of academic integrity requirements and can assist students, especially when an external peer review or proof-reader is unavailable. There are numerous programs available for free, including web-based applications such as Hemingway App and Grammarly. Students should strongly consider use of these tools as part of their proofreading process, even when a peer review or external proofreading service is available.



Potential Uses

Applications such as ChatGPT are generative artificial intelligence tools which use internet queries to generate responses to given prompts. Like a web browser search engine, the more specific the prompt, the more likely the generative AI output will meet the desired needs. Generative AI can provide an excellent overview on a topic or create outlines for written documents and oral presentations. These responses can help an individual craft their own original content, but assist in defining scope or areas of interest that the author may not be familiar with. These uses are typically acceptable within a collegiate setting, as they are not generating the final content, but rather assisting in the ideation phase. AI can also assist in aiding with research terms to expedite your own research process. While many industries have standardized templates, if you encounter a situation where you need to generate a new document without a template, such as a standard operating procedure or validation protocol, AI can help suggest formatting and outlines that align to industry standards found online. While you could perform an internet search for the same thing, AI can help streamline this process. In each of these uses, you will note that the content is still your own original content, but AI can assist in the ideation, outline and formatting processes, without any ethical concerns.

Potential Limitations

Generative AI tools assimilate information from all potential web sources, meaning that sometimes their output is incorrect. A false narrative, fictional writing, or satirical post can all be curated into a response that was meant to be factual. It is critically important that individuals using generative AI review each of the sources used to craft a response to ensure validity of the content. Generative AI is also time limited to the searchable web prior at least 24 months old. This means that when researching activities that are still taking place, for example mechanical issues with the Boeing 737Max airplane, a generative AI response will not contain information from the past two years. As members of a field where technology changes occur continuously, the lack of current information dramatically hinders the usefulness of generative AI.

Ethical Considerations

Use of generative AI to create sections of a document, or the complete document, are a form of plagiarism and are not tolerated by academic or professional institutions. Many institutions have created academic integrity requirements that prohibit the use of generative AI for student submission. At some institutions, there are both institutional–wide policies and college/department/faculty level policies specific to the discipline needs and expectations. Students are responsible for being aware of what limitations have been placed for each course that they take, as one faculty member's requirements may differ from another.

Basic Guidelines for Generative AI use

The below principles should be followed when using generative AI in your field or study and practice.

- Generative AI must be cited – you cannot claim the work is your own original work if it was not authored by you and you alone. Just as you would cite another author, you must cite generative AI when it is used.
- You must check the output for correctness – Technical writing is expected to be clear, concise and correct. As the author you take responsibility for all contributing sources, including AI results. Look at each source and verify that it is a reputable source and worthy of inclusion in your work.
- From a course perspective, check your syllabus to ensure that you are using AI within the terms of your institution and your individual course.

Productivity Tools

Depending on your company's software purchases, you may find the company you work for using various type of software solutions for productivity and workflow management. While the COVID-19 pandemic helped to advance remote working solutions, many companies continue to use web-based productivity tools even if the majority of their employees work in the office now that the pandemic is over. Some of these tools facilitate collaboration while others may be used by specific job functions or for individual assistance. Some of these tools are described below.

Meeting Tools

One only has to look at the stock prices for Zoom to know that it became a premier provider for web-based meeting after the global pandemic. Online meeting platforms allow for easy meeting and presenting across numerous locations. Recording features aid in recording meetings or presentations held using these tools, so that others can view them asynchronously. Like Zoom, Google Meet and Microsoft Teams meeting also allow for synchronous online meetings. Cisco Webex is also a provider of online meetings and fairly popular in industry settings.

Collaboration

Microsoft Teams, Google Drive and Slack are tools that allow teams of individuals to create shared spaces for file storage, online chats and video calls. Data storage and sharing is also possible with tools like Office 365 OneDrive, DropBox, and SharePoint. These tools all provide a mechanism for individuals to create shared storage spaces both inside company firewalls and outside corporate structures.

Other Common Tools

Survey applications like SurveyMonkey, Google Forms and Qualtrics can aid in the creation and distribution of surveys within your company and to outside parties. These tools also aid in the analysis of the results, by connecting to computational programs like Excel or Google Sheets. WhenToMeet, Doodle Poll, Calendly, as well as Microsoft Outlook and Google Meet, all have scheduling assistants to aid in finding common meeting times across multiple mail ap software.

2.3 Conclusion

As an engineer, you should expect to collaborate using various tools with internal and external stakeholders. Every company uses a different combination of productivity tools, requiring you to quickly learn and adapt to new software packages. However, these tools do save time and create a more efficient workflow, as well as aiding your ability to communicate technical information whether in document, spreadsheet, presentation or meeting format. You may also find that as a technical individual, people will assume that you hold expertise with these software packages and may come to you for assistance. Effective use of all that technology has to offer will not only help you communicate well but also aid you in being a productive engineer.

Up Next

The next chapter of this book introduces concepts in experimental design, which is critical for engineers to properly design, test and optimize systems in every engineering discipline and industry. The chapter includes differentiating between inductive and deductive reasoning and qualitative and quantitative research methodologies. The chapter continues with hallmarks of quantitative research, which is the more common form of study in engineering fields. The chapter also includes an explanation of the different types of variables and the sources of experimental error for each variable type. Finally, the relationship between the established methodology and the validity of data is discussed.

Chapter 03

About Experimental Design for Engineers

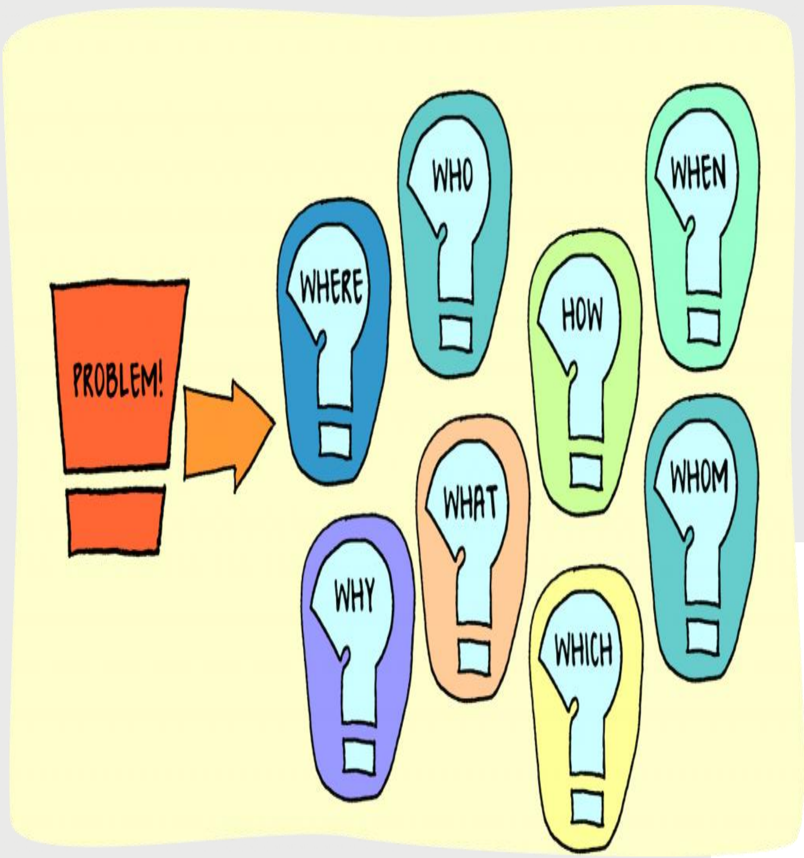
Engineers are responsible for some of the greatest advancements throughout all of history. Consider the aqueducts of Roman infrastructure that were made in 19 BCE that are still function by supplying the Trevi Fountain today [1]. Consider that the designs for a helicopter by Leonardo DaVinci were created in the 1500's, four centuries prior to an actual helicopter being made [2]. The development of civilization has depended on the minds of individuals who are willing to look at the world and see what is possible, rather than relying on simply what is. There was a time when science and engineering were more closely tied, with Galileo developing principles of math and science and kinematic motion through which theorems about the universe were developed [3]. You can also consider the physical experiments of Newton [4] and Einstein [5] as they found mathematical ways to describe the tangible world. Engineers have been called applied scientists, but we are also inventors, innovators and researchers. Engineers translate the dreams of humanity into solutions that expand our world, advance our technology and push boundaries from what is to what could be. This profession is based on math, physics and other sciences, but it is just as reliant on creativity, artistry and innovation.

Freshmen engineers rarely think about becoming an engineer because they want to calculate solutions to statics problems. While a basic circuit may be a starting point, the purpose of this education is to understand the fundamentals necessary for creating the next "new thing" or "big thing" that can change the world. Whether you are a mechanical, civil, manufacturing, electrical or engineering technology major, your future is not yet defined and I can nearly guarantee that at some point in your career you will be working on technology that does not currently exist. Engineers make new things possible. You will too.

While experimental design may seem like something more related to research scientists, engineers follow the same process for optimizing models, correlating factors impacting a system, creating new materials and alloys, programming the latest artificial intelligence and identifying solutions to global challenges. Experimental design in engineering is purposefully building robust methodologies for investigating phenomena to generate new solutions. This chapter will teach you the systematic approach to engineering design that can work in all disciplines and industries.

3.1 Engineering design and engineering problem solving methodologies

Engineering problem solving methodologies align closely with systematic engineering experimental design, but there are research conceptual models that are helpful in understanding the goals and approach to engineering design.

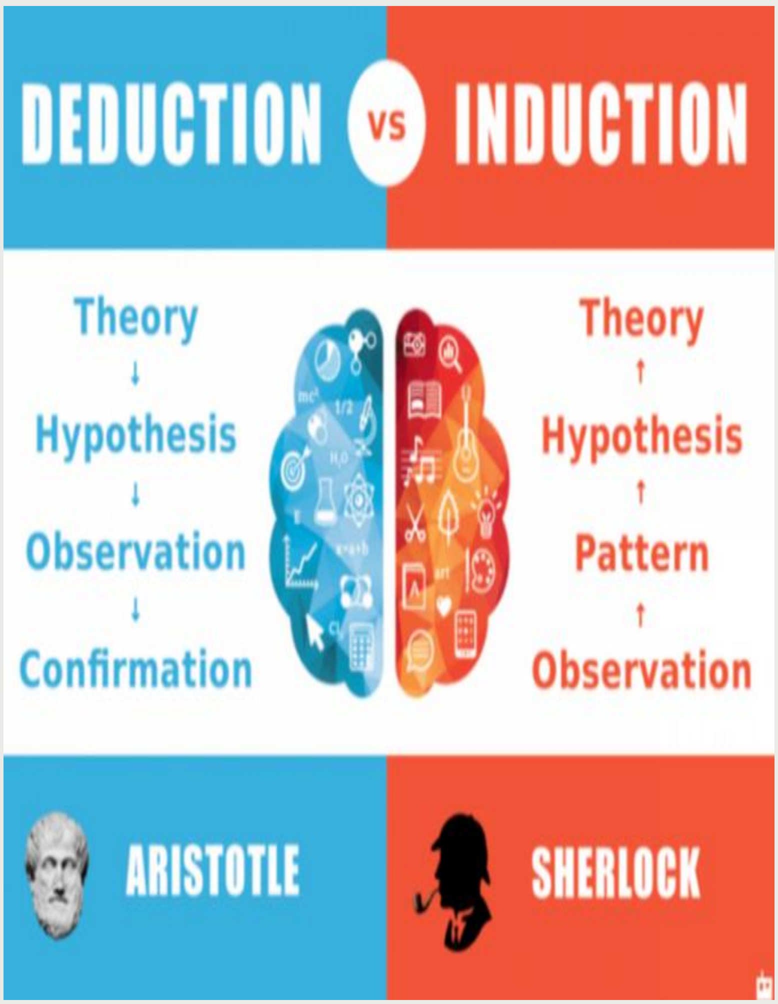


Imagine you are an engineer for a FormulaOne racing team. Ultimately, to win races, you must produce a car that can perform the best on a variety of racetracks all over the world. Tire wear, downforce, total drag, car weight, terminal acceleration and a plethora of other factors impact the overall performance, in addition to the driver's skill, the ability of the pit crew to perform their job properly and the strategy employed by the team management. Physics, dynamics, strength of materials, dynamics of machinery and other courses can explain the mechanical and electrical optimization required for maximum performance. Historical modeling and statistics can inform your strategy to choose the correct tire and set-up to have you racing towards a podium finish. Work design and ergonomics can assist in creating the best methods to minimize time spent in the pits and ensure the pit crews do not injure themselves while working on the vehicle. When a team can jack a car in the front and the back, completely lifting it from the ground, and change all 4 tires, with the car only being completely stationary for 3 seconds or less, you know the crew has practiced a very specific procedure. Mechanical, electrical, industrial and manufacturing engineers all played a part in making that happen. And the cars would not have a racetrack if it wasn't for the design and construction of the civil engineers.

Formula One racing may not be your thing, but I challenge you to think of any process, product or system, digital or physical, that didn't have an engineer involved at some step of the development, implementation or maintenance. This is why it is critical to understand the correct approach to engineering design.

3.2 Fundamental Concepts for Research Methods

Before engaging with the experimental design process, there are a few concepts that are foundational to research that we must understand.



Defining Research

Research can be described as either:

- An attempt to develop an explanation for a phenomenon
- Develop new knowledge, techniques, or processes to better human life

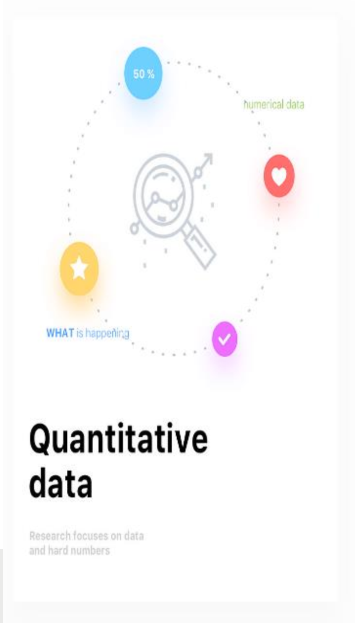
While basic scientists (those individuals who conduct research to better understand the world around us) often fall into the first category, engineers often work in the second category, building on the observations made by scientists. This isn't always true, as scientist can also develop new knowledge and engineers can also develop explanation for phenomenon, however, in general terms, scientist initiate the process of explaining "what is" while engineers use that knowledge to develop "what could be".

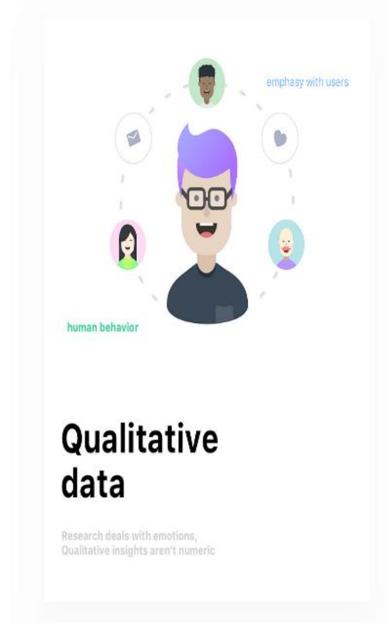
Inductive vs. Deductive

First, one must understand the difference between inductive and deductive reasoning. In inductive reasoning, one begins with an observation, witnesses patterns aligning with the observations and then develops a hypothesis which establishes a broader theory. In deductive reasoning, one begins with a theory, creates a testable hypothesis, gathers data through observation and then confirms the initial theory. Typically, engineers follow a deductive process as many engineering solutions are based on theoretical frameworks developed by math and science. Oftentimes engineers will begin with known relationships from math and physics to leverage established principles for optimization of physical systems. However, complex systems cannot be explained completely by theoretical frameworks. Actual data or historical models are required to accurately predict and control numerous factors for the optimal response.

Qualitative and Quantitative Research

While both of these methods are valid methods of rigorously understanding hypothesis, they are very different and have distinctive approaches that can even be mutually exclusive.





Qualitative Research

Like the root word "quality" implies, qualitative data explores subjective phenomena related to human subjects. This data is typically descriptive in nature and is rarely able to be captured in numerical metrics. This research can include [6]:

- Phenomenology – the description of the lived experience
- Grounded Theory – a specified approach for theory development
- Ethnography – the exploration of a cultural group
- Historical – the exploration of a historical event or era
- Narrative inquiry – the exploration of an individual or several individuals
- Action research – the empowerment of a particular group, often marginalized by society, to change existing protocols, standards or preconceived notions
- Case Studies – an investigation into a particular group over a specific issue, situation or event, often conducted as a subset of a phenomenology or ethnography
- Field research – the documentation of groups or organizations or people in their field of practice

These are not the only categories for Qualitative Research, but these are the most popular forms of qualitative research and most other categories are subsets of one of the types listed above.

It is important to note that engineers often need to conduct qualitative studies in conjunction with quantitative research. Engineers working on a new process often test that process by forming pilot studies with individuals to execute the new process and provide feedback. That is qualitative research. Engineers may require customers to test a new product and provide feedback prior to releasing the product to market. This is also done with software and video games where "Beta Testers" are provided an early release of a piece of software and give the developers feedback. The beta testers can potentially find glitches or issues that need to be resolved prior to the full release. Their feedback is also a form of qualitative research. Engineers conducting Six Sigma studies always involve end users, internal stakeholders and customers to define the "Voice of the Customer" which impacts the approach to process and product improvement. This part of the Define Stage in the Six Sigma DMAIC process is also a form of qualitative research.

Quantitative Research

Unlike Qualitative Research, Quantitative Research focuses on measured data, rather than descriptive or narrative data. This measured data can be gathered from human subjects (such as research investigating the correlation between resting heart rate and the likelihood of developing cardiovascular disease) but can also be gathered from non-human sources. An old professor of mine called this "things and stuff". Things and stuff research can be anything from the fuel efficiency of a car to the viscosity of a fluid to the orbit of a satellite to the failure rate of a bottling machine. In other words, nearly everything can be measured in some way. These data points are the foundation of quantitative studies. To provide a more formal definition, quantitative research is the systematic scientific investigation of quantitative properties and phenomena and their relationships.

Just as Qualitative Research had several categories to serve as an initial framework to a research approach, Quantitative Research also has three major categories:

- Descriptive – collecting data to determine the current state of a subject; a method of describing "what is"
- Correlational – a method for determining if a relationship between given variables exist. This method can help determine how variables impact each other in a predictable way. Note: this does not mean "Causality" – this is not concluding that one event causes another event to happen, but rather the change in one variable based on the state of another variable.
- Experimental – a method of determining a causal relationship, where you prove by manipulating one variable and measuring the impact on the other variable. Causality is difficult to prove conclusively, as it must hold true at all times and in all conditions. These relationships are often proved in scientific experiments and become the foundation of physics, kinematics, chemistry and other natural theoretical frameworks.

Each of these approaches requires the collection of data and some form of data analysis, which is typically a statistical study. To ensure the data collection and analysis are valid, there are several fundamental qualities of quantitative research.

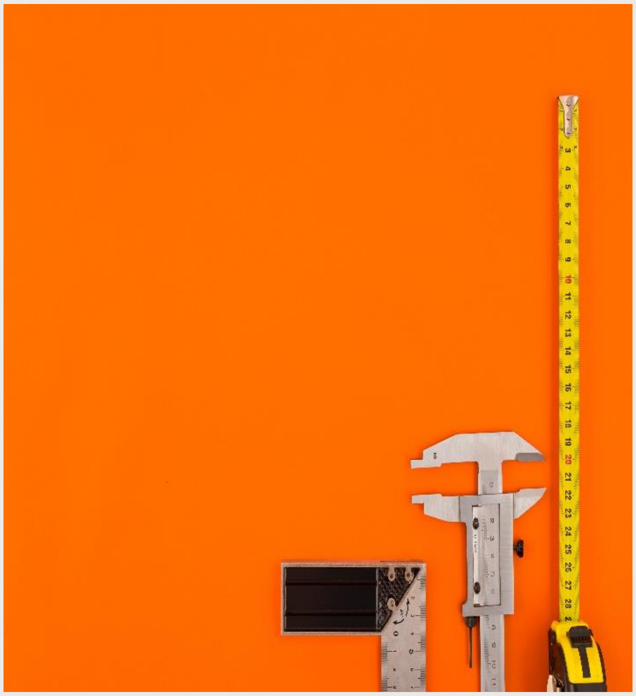
Hallmarks of Quantitative Research

For the results of research to be accepted as valid, there are conditions which must be upheld. There are:

- Purposefulness – While it may seem self-evident, having a clear purpose for your research will define every step of your experimental design. In many systems, factors interact with multiple elements in a variety of ways. To ensure that you focus on the principal goal, you must clearly define your purpose. Consider an experiment looking to measure plant growth based on the use of plant foods. To only evaluate the impact of plant food, all other factors must be equal including light, water, temperature, soil content and any other variable that could impact growth. The purposefulness of your research will help you to identify which variables you adjust, which remain constant and which you measure.
- Rigor – For an experiment to be rigorous, you must design your experiments to the appropriate standards for your audience. If I wanted to survey study habits on engineering students and only distributed the survey to a handful of students, my experiment could not be considered rigorous. My sample was not appropriate for my intentions.
- Testability – In Qualitative research, any experiment must begin with a question that can be definitively answered through the measurement of quantifiable properties. This "testable" nature is something that can vary based on your available resources. For example, if you wanted to test the shear stress of various metals, you must have equipment that can both break the materials and accurately measure the force required to do so. If you do not have the appropriate setting, equipment and materials, the question you ask may be valid, but you make lack the resources to perform the necessary tests.
- Replicability – Your experiment, when replicated by someone else, using the same materials, equipment and methods, should produce the same results. This replicability helps to validate both your methodology and your results, from which you base your conclusions. In the show, The Big Bang Theory, the character of Leonard is an Experimental Physicist, meaning he tests in his lab the theories that other physicist have put forward based on mathematical equations and he replicates the experiments of other physicists to verify that the results are consistent, even when another research conducts the work [7]. This form of peer review is critical to the research process and is practiced around the world in scientific and engineering companies. Replicability ensures that your methods support the outcome no matter where, when or who performs the work.

- Precision – Precision is the repeatable nature of your work to a specified resolution of measurement. The resolution of the measurement should be appropriate to the work's applications. For example, even though the dimensions of a single Lego piece are units of length, you would not use a six-foot tape measure to conduct an experiment on the quality of manufacturing processes of Legos. A single brick (1*1 stud brick) is 8mm * 9.6mm [8]. It would not be appropriate to try to measure this with a measurement tape or even a ruler if you were conducting a quality audit. Instead, you would measure this with precision measuring equipment such as calipers or a micrometer and you would want to ensure you were using the correct metric units. Every 1*1 stud brick should match these dimensions to ensure your Lego sets can fit together as required. This element of meeting specific dimensions over and over again includes both accuracy and precision, which we will discuss later in the chapter. For your experimental process to demonstrate precision, you must select the appropriate units to measure, the appropriate measurement device to provide the correct resolution and the appropriate way to collect the data to ensure each data point is correct.

- Confidence – Confidence refers to the statistical interval for which you feel confident about your statistical analysis. Many engineering students will follow the convention of using a 95% confidence interval when conducting statistical analysis. While this may sound excellent (a 95% is typically an A grade, for example) not all situations warrant a 95% confidence interval. For example, what if only 95% of airbags opened in a collision. That means 5 times out of 100, someone's airbag wouldn't deploy properly. Dependent on the end use, 95% may be an acceptable interval, but keep in mind that it is not always true.



- Objectivity – In one of the key differences between Qualitative and Quantitative studies, objectivity is an important attribute of methodologies for Quantitative work. In Qualitative studies, the researcher often interacts directly with the subjects of the study and connects closely to their study. If you were completing an Ethnography of military families about their experience when their loved ones are deployed to a war zone, you would expect to hear personal accounts that reported individual thoughts and feelings specific to their perspective. This is appropriate for Qualitative studies. In Quantitative studies, the information is data driven to remove subjectivity from the researcher interacting with the data they collect. Even when the data is collected from human subjects, like the difference in comprehension between students in online courses compare to face-to-face classes, the data should be objective. By collecting numerical data, rather than impressions or perceptions, the subjectivity is removed. In this example, the study could benefit from what is called "Mixed Methods" where both Qualitative and Quantitative data is collected. In this case, the researcher might look at the difference in test scores for students in each course and interview the students for their opinions and perspectives about their course format. Subjectivity in research is not wrong, but it is inappropriate in Quantitative studies. Much like the concept of replicability, anyone executing that particular experiment with the same materials, context and measurement tools should receive the same outcomes.
- Generalizability – This term refers to the ability to extend the results of the experiment to a broader context. However, the ability to generalize the results does depend on sample size. If I tested a phone for battery life and measured the average battery life to be 7.5 hours, I could not generalize that to all batteries. There are too many other potential variables such as: what is the model of the phone; how old is the phone; how many aps were running; if they were on Wi-Fi or cellular or both and countless other factors. We will discuss this more when we discuss variables later in the chapter. However, if an experiment is design and executed correctly, with a sample size representative of the population, the results should be generalizable within the same context.
- Parsimony – This concept regards simplicity. As such, this aligns with Occam's Razor, which states when you have competing concepts explaining a result, choose the simplest one [9]. In other words, choose the simplest cause for the provided evidence. For example, when someone walks into a room dripping with water, you would probably guess that it was raining outside. They might tell you that they had actually been hit by a water balloon walking into the building, but that would not be a reasonable initial assumption.

These concepts should be kept in mind when designing a Quantitative experiment.

3.3 Understanding variables

Previously in the chapter we have discussed several scenarios where variables impact the outcome of the work. In fact, for Quantitative Research, the very foundation of the research design begins with a question that can be answered by collecting and analyzing data. The data measured corresponds to the variables involved in the study. There are some variables which may be kept at a set level, while others we adjust in intentional ways to record the outcome. Based on the use of the variable within the experiment, it could be classified as a constant, a control, an independent or a dependent variable.

Constant, control, independent, and dependent variables

- Constant and Control Variables – As the name implies, constants remain, well, constant. They do not change in the context of the experiment. They can also be called control variables. Some constants involve natural forces, such as a gravitational constant, where a control variable is something that has been selected to remain unchanging as a way of isolating other variables. For example, if you were to measure free fall from a given height, the constants involved with this experiment would include the gravitational constants, the coefficient of friction on a given object or other natural considerations. However, if you repeatedly drop items from a set height, the variable "height" is being controlled throughout the experiment. Therefore, the control variable is one that remains the same but can be changed or has been selected by the researcher or engineer. I cannot choose to change the gravitational constant, but I can choose to change my initial height from which the object is flying.
- Independent Variables – An independent variable is the variable that is altered at set intervals to determine a change in the experimental results. For example, different mixes of components change the properties of concrete. Most concrete mixtures involve ratios of water, cement, sand, and crushed rock. Depending on the application, each of these could be changed. Additional structural supports like steel rebar can impact the overall strength. One could design an experiment changing the proportions of each of these ingredients and then do destructive testing to determine the strongest combination of factors.
- Dependent Variables – As the name implies, the dependent variable changes based on the adjustments made to the independent variables. Building on the example above, if I was measuring the strength of the concrete, concrete strength would be the dependent variable. It is dependent on the factors we mentioned, namely, ratios of cement, sand, crushed rock and water.

- Nuisance variables – Nuisance variables are exactly what the name conveys – they are variables that cause a nuisance to the experimenter. In every experiment, it can be nearly impossible to account for all factors in a fashion that can be quantifiably explained in its entirety. Nuisance variables are therefore variation that can be named but cannot be removed from the experiment. A student did an experiment testing the impact of a nutritional supplement on their weightlifting capacity. In this experiment, they were measuring the increase in muscle mass and maximum weight lifted on 3 specific lifts. These were the dependent variables. They kept their calorie intake, water intake and sleep and exercise consistent throughout the process. These were control variables. They added a set amount of the nutritional supplement to their daily intake, as recommended by the manufacturer. This was the independent variable. After the manufacturer recommended length of time, they measured their muscle mass and repeated the 3 specific lifts in the same manner to measure the new maximum weight they could lift. This was a well-planned, well executed experiment. But if you looked at their sleep control variable, you would note in the data that even though they went to bed and they got up at the same time every day, their sleep varied, according to their Apple Watch. Why? Well, it could have been countless reasons including ambient stress level, temperature of their body, how the foods interacted with their body, noise from outside their room and many other potential nuisances. These are nuisance variables. You can see the variation of the sleep, even though the experimenter tried to maintain constancy in every element under their control. But this wasn't in their control. The individual could go to bed and rise from bed at the same times every day but they couldn't actually control the amount or quality of their sleep. As this experiment focused on muscle building and most muscle development takes place while people are sleeping, these nuisance variables absolutely had an impact on the experiment, but there was no way to isolate the source of each variation or their total impact. This introduces a concept of error to the system, which we will discuss more in the next section.

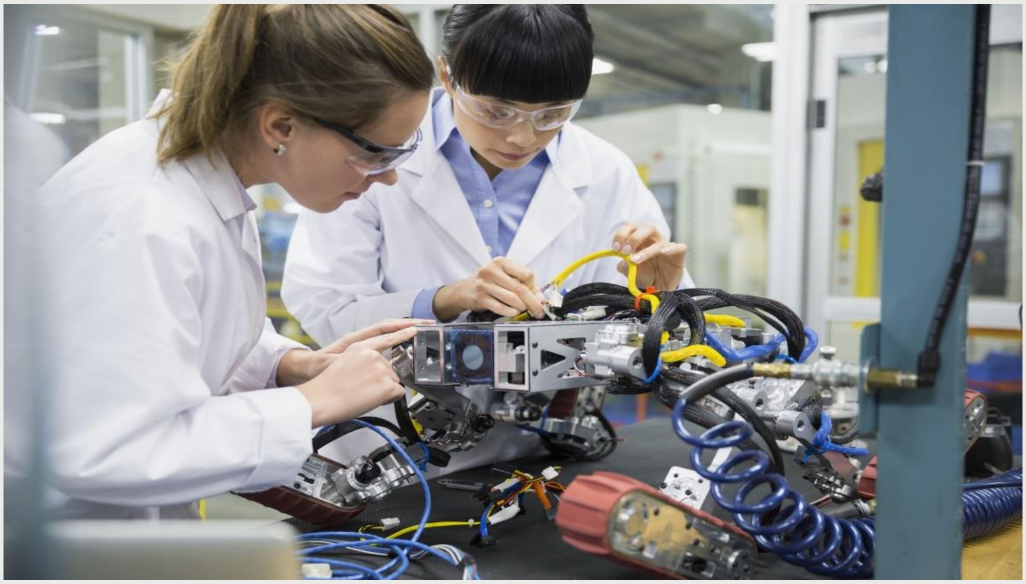
Understanding Error

Nuisance variables exist in nearly every experiment. In quality engineering terms, we talk about variation as having common causes or special causes. A common cause is one that occurs naturally within a system and cannot be completely eliminated. This means that every process has a particular goal, but tolerances are embedded account for these slight variations that are continually impacting the system in little ways. Imagine a packaging line that is filling bags of Nacho Cheese Doritos. The corn chips have been formed, fried, coated with seasoning and travel on a conveyor into the bag. Sealed bags travel over a scale checking that the weight is within the given tolerance to make it acceptable to sell to a customer [10]. While the manufacturing process runs incredibly fast and reliability, not every chip is exactly the same size or weight and not every chip has the exact same amount of seasoning on them. Not every bag has the exact same number of chips. In fact, not every bag weighs exactly the same, but they are all close the package stated weight of 1 ounce (for the snack bag) or 9.25 ounces (for the larger bag) or any other packaging configuration. The manufacture sets the automatic packaging line to separate packages that deviate too far from the goal weight, but there is a small range of acceptable weight variance that will still be sent to customers. Could you really tell if your Dorito bag only had 9.15 ounces just by looking at it? Or would you mind if your Dorito package had 10 ounces instead of 9.25? These slight variations are accepted as part of the practice of manufacturing. So while a manufacturer will aim to eliminate as much error as possible, it is understood that there will always be some amount of error. This is true in every engineering field, not just manufacturing. However, to know how to interpret the validity of our data, we do need to recognize where error comes from and how to quantify it.

Below are categories of error that can be expected in engineering systems and experiments.

- Environmental – This type of variation includes error from the context of the system or experiment. A student conducted an experiment where they were testing the accuracy of two different types of arrowheads. While the day was not terribly windy, the experiment took place outside and small wind currents could impact the outcome. Even in a laboratory setting, small variations in temperature, air current, humidity, sound, vibration or other environmental factors could impact an experimental outcome.

- Instrumentation – Anytime measurements are being taken, one must consider the instrument used to collect the data. Several keep factors involve instrumentation and impact the validity of the experiment.
    - Resolution – As mentioned previously, is the measurement device the appropriate tool for the desired level of precision for your data. If you are measuring something, the measurement device should be able to measure to at least one greater level of precision. For example, if I am measuring something in centimeters, the measurement device needs to have the ability to accurately measure millimeters, to provide validity for my centimeter measurement.
    - Calibration – Every measurement tool should have the capability to be adjusted against a known standard. Depending on the application, these known standards can be called standards or gauges. These standards are established by various agencies, depending on the industry but many standards are managed by the National Institute of Standards and Technology, which set requirements for measuring devices, standards, calibration requirements and practices for regular use, maintenance and calibration [11]. In pharmaceutical manufacturing, the calibration of the scales weighing the ingredients occurs on a monthly basis. To calibrate, the company brings weights of known values (1 gram or 10 kilograms or whatever is appropriate for the type of scale) and validates that the scale weighs with the desired accuracy and precision. The act of calibrating a measuring device provides validity of a measurement, knowing that the device is operating correctly against a known measurement.
    - Zeroing – Measurement devices must be properly operated even after calibration. One key factor in operation is that the device can be set at a true "0" location. That is, absent any materials, the measurement device begins at zero. On digital devices, this is typically a setting or button that can be pressed to return the starting value at zero. This ensures that the display reads the actual measurement for the given object.



- Operator Error – Even if your equipment is functioning correctly and the environmental conditions are controlled as possible, error can occur due to mistakes in operation.
    - Parallax – Parallax is the distortion of the reading due to distance between the point of measurement and the measurement device. If you've ever driven by a speed check device on the highway at rush hour, you will note that with multiple cars in multiple lanes traveling simultaneously at highway speed, the display of speed does not always seem to align with your car. While the device might work well aimed at one single vehicle, the general collection of data by being aimed at multiple lanes with cars passing quickly makes it difficult for the device to correctly read each vehicle.
    - Lag time – Every human has a delayed response in recording the measurement due to the processing time it takes to note the measurement and make the recording. If a person is trying to time the 100-meter dash for the world's fastest person, even though they might stand right next to the finish line, that means when the starting gun goes off, they must first hear the sound and then press the button to start the stopwatch. When the person crosses the finish line, they must view the person crossing the tape and press the button again. Each of these actions has a lag between the human senses noticing the event and pressing the button on the device. Electronic sensors, vision systems, and other digital devices (like RFID tags on the shoes of the runners) aid in increasing the accuracy of the measurement by removing human responses and lag time.
    - Personal error – Sometimes people make mistakes. When it is noted that the operator has errored, whenever possible, the trial should be repeated. If it cannot be repeated, that data point should not be included in the results, as you know it is incorrect.

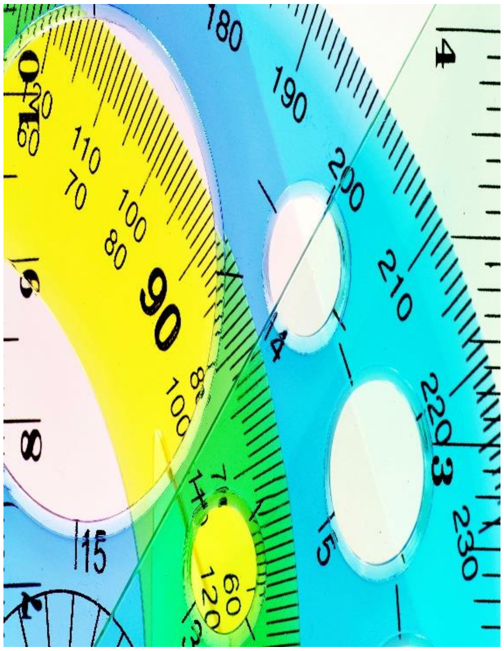
Without selecting the correct instrumentation, ensuring it is both calibrated and zeroed and operated correctly, the readings for the data collection cannot be considered accurate measurements and the experimental results are no longer valid.

Accuracy and prevision are not synonyms but are closely related and directly impact our understanding of variable and the data we collect [13].

- Measuring accuracy and precision
    - Measurement error is a measurement of inaccuracy or how far an item is from a true value.
    - Uncertainty or Standard Error is a factor of the standard deviation and sample size.
    - Relative error is a measure of the true value compared to the measurement and provides a measure of accuracy.
    - Relative uncertainty is a measure of variation in the measurements compared to the measured quantity and is a measurement of precision.

Understanding accuracy and precision of variables

- Accuracy – Accuracy is the closeness of the measurement to the true value. If you look at the target diagram, the most accurate mark is the one that is in the very center of the bullseye. Any distance from the center of the bullseye would show inaccuracy. The RediWhip production line aims to fill each can of whipped cream to 13 ounces [12]. Any time the filling machine operates above or below 13.0 ounces, the machine is considered to be inaccurate.
- Precision – Precision is the repeatability of the event at the same level of accuracy. In the diagram, this is represented by having a group of marks right next to each other. Precision is important in the results to ensure that you are consistently having the same outcome from the same parameters.



3.4 Conclusion

When crafting a methodology to ensure validity of the results, you should factor all the topics introduced in this chapter. You need to consider what your goal is and what variables must be considered to answer your given question. When you identify the variables, you must think how you will collect the data, including the experimental environment, your measuring equipment and the potential sources of error. Once your data is gathered you want to account for accuracy and precision through evaluating your error and ensuring your results are statically sound given the applications for your work. In the next chapter we will talk about graphical displays of data and how to best communicate this to your audience. The saying "garbage in, garbage out" holds true in data analysis. If you do not have sound data, it doesn't matter how visually appealing you can make the data appear using graphical tools. Above all, your data must accurately reflect your process and directly relate to the question at hand. Following the steps in this chapter can ensure the validity of your data gathering and analysis, thereby supporting the results and conclusions you make.

Up Next

In the next chapter, we will focus on how to display the data you have collected in a way that communicates clearly to your intended audience. The axiom "a picture is worth a thousand words" holds true in technical writing. Raw data or large data tables rarely convey meaning to the reader. It is the visual depictions of data that help the reader understand the significance of the work performed. To present data well, we must first understand the data collected, which often involves some sort of statistical analysis. After reviewing descriptive statistics and common probability distributions, the chapter examines various graphical methods to display data, highlighting how to choose which graph best portrays the focus of the data. Finally, the integration of graphics into the narrative work is discussed.

Chapter 04

Data Analysis and Presentation of Data

This chapter presents basic principles of data analysis using fundamental statistical concepts with the support of Microsoft Excel. While statistical analysis is a large area of study, requiring extensive quantitative analysis, the method of presenting meaningful data in technical documents is consistent regardless of the complexity of the analysis being conducted. As such, this section focuses on how to best present your data, as well as a review of several common tools for data analysis in engineering fields.

4.1 Basic Statistical Principles

In the previous chapter the hallmarks of qualitative research were discussed, with an emphasis on how an engineer could ensure validity of their results. Through rigorous experimental design and a firm understanding of how data is measured, collected and analyzed, engineers can use the results to answer critical questions in engineering design and broader contexts in their field.

Engineers use statistical software to analyze raw data and quickly assess the outcome of their work. These software packages (like Excel, Minitab, SPSS and others) were mentioned in chapter 2 of this text. While other coursework will teach statistical analysis in much greater detail, some foundational concepts will be presented here to aid in your data analysis for this course.

Descriptive statistics and their use

Descriptive statistics are a set of calculations that help one to understand a data set. Depending on your software, different calculations can be included and the desired output can be customized to display the results most relevant to your analysis. Prior to any hypothesis testing or the formation of confidence levels, these calculations can aid in a basic understanding the data set.

- Sum – This is the addition of all data points.
- Count – This is the number of data points in the set.
- Arithmetic Mean – The mean of a data set is one of the most frequently used parameters for statistical analysis. For a single data set, this can be calculated by simply dividing the sum by the count. This is the same approach for calculating an average.
- Median – The median is the middle number when all data is arranged from minimum to maximum values.
- Mode – This is the number repeated the most frequently in the data set.
- Range – The range of the data is the difference between the maximum and minimum data point in a data set. This is the most basic measurement of dispersion of the data.
- Variance – This is a calculation of how far away each data point in the set is from the mean.
- Standard Deviation – This is the square root of the variance. The standard deviation was used in chapter 3 to calculate standard error. Standard error is often included in descriptive statistics.
- Quartiles – Quartiles represent the division of the data into four parts. The 2nd quartile is equal to the mean (which is the midpoint of the data or 50% of the data). The first quartile represents 25% of the data while the 3rd quartile represents 75% of the data.

Some data packages can include other calculations such as kurtosis and skewness, as well as confidence levels based on a given percentage.

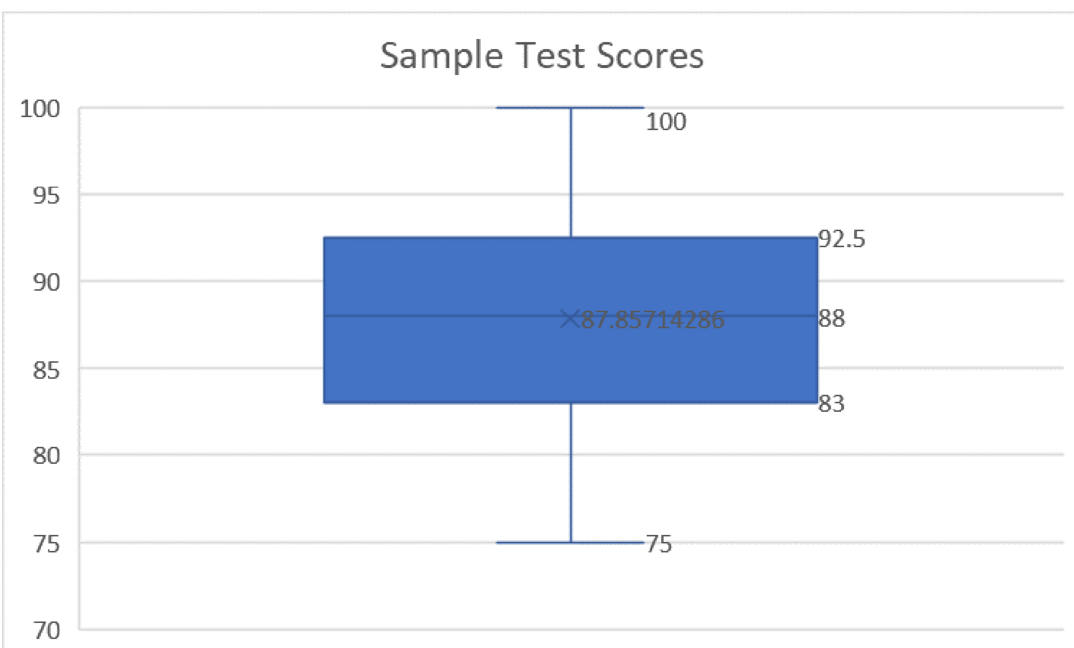
Example of Descriptive Statistics

Descriptive statistics are very helpful in basic understanding of a data set as a whole, rather than individual data points. Imagine you take a test and receive a score of 88%. This may or may not be a good score relative to the rest of the course, depending on the rest of the class. While this single score can tell you that you received 88% of the possible points, it does not give you any idea of position within the class. Now imagine that your professor posts the descriptive statistics for the entire class and they provide the following information:

Category	Result
Sum	1230
Count	14
Mean	87.85
Median	88
Mode	84
Minimum	75
Maximum	100
Range	25
Sample Variance	53.67
Standard Deviation	7.32
Standard Error	1.96

Now your individual score of 88% is contextualized within the results of the entire class. Your result is just slightly higher than the course average of 87.85. While the minimum score was 75%, there was at least one individual who received a perfect score.

Looking at a box plot of this data you can see the 1st quartile is 83 and the 3rd quartile is 92.5. The median of 88 matches your score, putting you right in the middle of the data for this exam.



How does this help us better understand a single data point or the set of data points? Your test score is in the middle of all test scores. This tells you that you performed similarly to your peers. For the instructor, the test scores averaging around a high B actually indicates that the test was probably too easy.

For most data analysis, the descriptive statistics help us to understand the characteristics of the data set. Most complex analysis begins with these measures.

4.2 Probability distributions

Probability distributions are sets of data that align to an established model of data with specific characteristics. Probability distributions show the frequency of data in a theoretical model that aligns to established relationships that assist in predicting how to model data according to its properties.

- Discrete Probability Distribution Mean and Variance
    - Mean or Expected Value – For random discrete probability distributions the mean of the distribution can be calculated by multiplying each individual sample by the function of the distribution. Arithmetically this calculates the weighed average of possible values with weights equal to the established probabilities.

      Mean or expected value

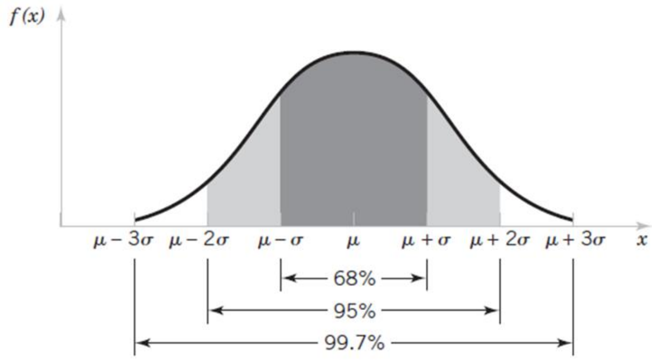
      $$\mu = E(X) = \sum_{x} x f(x)$$

    - Variance – For a discrete random probability distribution, the variance measures the variability within the distribution by calculating a weighted measure of each possible squared standard deviation with weights equal to the probabilities.

      Variance

      $$\sigma^2 = V(X) = E(X-\mu)^2 = \sum_{x} (x-\mu)^2 f(x) = \sum_{x} x^2 f(x) - \mu^2$$

- Normal Distribution – The normal distribution is the most frequently used distribution in statistical analysis. Many hypothesis tests (such as using the Z or T table for hypothesis testing, conducting an Analysis of Variance (ANOVA) or conducting a linear regression, as well as others) begin stating that data must be random, independent and normally distributed. Normal data is symmetrical with respect to the mean and follows a bell–curve shape, as illustrated below.

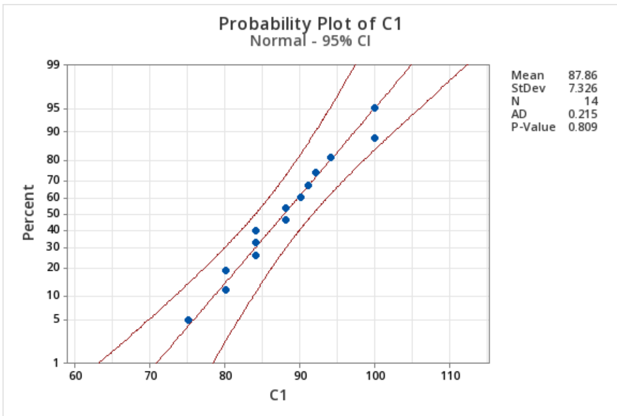


Normal data follows the Measures of Central Tendency which state that in normally distributed data, the mean of the data set will equal the median, which will equal the mode. In other words, the center of the data will also equal the central number of the data set, which will also be the most frequent number within the data set.

The Normal Distribution is helpful because processes following a normal distribution have established probabilities, as illustrated above. In normally distributed data, approximately 68% of the data will fall within one standard deviation of either side of the mean. Following this construction, 95% of the data will fall within two standard deviations and 99.7% will fall within three standard deviations of either side of the mean. This information allows us to predict the behavior of the entire population, based on a collected sample. Any normally distributed sample can be transformed to align with the Z–table or T–table for easy calculations of probabilities of receiving a specific value, or being above or below a set value.

Normal Distribution Example

From the data set used in the test score example, we can create a normal probability plot in Minitab and receive the following output.



Based on the results, this data is normally distributed. You can tell because the points all fall close the centerline and are within the bounds of the outer lines. The p−value is also greater than the established criteria for the p−value (0.05) which also indicates a normal distribution. Using this information, we could test the probability of receiving a grade higher than your 88% based on this sample being normally distributed. Using probability based on the data being normally distributed, we can calculate that there is a 47% chance that a classmate received a higher grade than you.

While as an engineering student you should have at least one course dedicated to statistics, it is helpful to understand the role of descriptive statistics to assess your sample in an appropriate way. It is also helpful to know that if your data is normally distributed, you can evaluate your data using more sophisticated analytics to predict the behavior of data of the population based on your sample.

4.3 Presenting Data

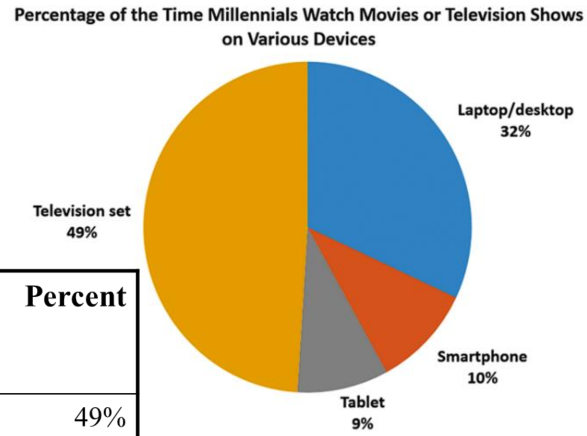
When presenting data, your goal should be to aid the reader in understanding the main point of your data analysis. Raw data is rarely presented in technical documents, which is why the summarized information provided by descriptive statistics is so helpful. The following sections hold true for tables, charts, images and figures. For simplicity, I will only use the word graphical depiction or figure. Any figure included in your document should be referred to within the body of your narration. In your narration, you can refer to it by number or name, but you want to place the figure in a way that the reader does not have to search the document for the content. Whenever possible, include your initial narration about the figure either directly above or below the referenced figure. If the figure is on a different page, it can be helpful to note the page, for example, "see Figure 3 on page 2".

When creating the figures in Excel or other software applications, ensure you include all information that will help the reader to understand what they are looking at when viewing the figure. For graphical depictions, you must include all appropriate information including:

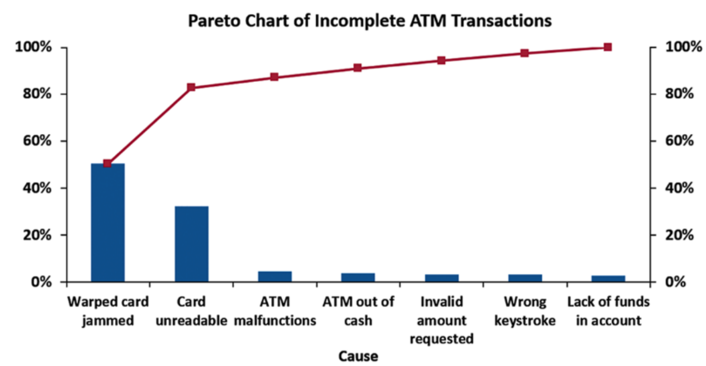
- A figure number and title – This chart number and title can be used in the Table of Tables and Table of Figures, as well as provide a reference point within the narration.
- Caption – Using the caption function of your word processing software, insert a caption that includes the figure number and title, as well as a brief description of the figure itself. For individuals using screen readers, this caption will be read to the individual. Including brief descriptions aids in making your work more accessible.
- Axis labels – Each axis should be labeled with the appropriate units provided. Most default settings use the spreadsheet column header for the axis labels. If your column header did not already include units, you can edit the axis to include this information.
- Series label – Most spreadsheet software defaults to calling your data "Series 1". You need to edit the field so that the data is labeled appropriate such as "Exam Scores" from the example earlier in the chapter.
- Data labels – Based on the type of chart, figure or graph, it could be helpful to include the data labels which provide the reader with the actual value of each data point displayed. Sometimes this can cause the figure to be cluttered and hard to read. Choose the option that best conveys the information of the figure to the reader.
- Coloring – keep in mind how the figure will be presented. While software applications automatically color your data, the colors selected can be changed. If you have multiple series displayed on the same field, make sure the colors do not clash or cause issues with individuals who may be visually impaired. Some colors are easier to see on a screen than they are on a printed document (like yellow or other lightly saturated colors).

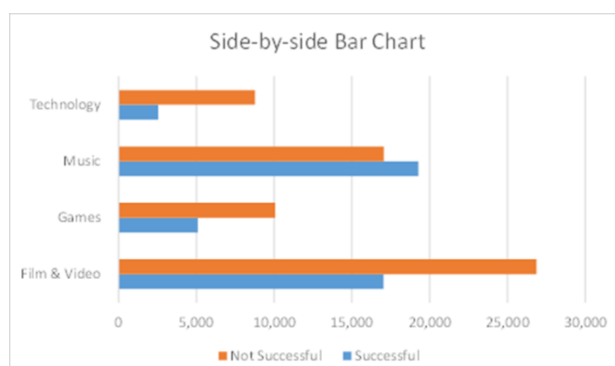
Types of Figures

- Pie Chart Example – The figure to the right shows a data table next to a pie chart. Pie charts are helpful to demonstrate sections of a whole. While this figure isn't numbered or captioned, you see the title explains the intent of the figure. Each data series is labeled with both the numerical value and the title of the section. In this case, the table is redundant and could be removed.
- Pareto Chart with Cumulative Frequency Line – This is a bar chart with a cumulative distribution line overlaid on the right-hand axis. This provides an example of a 3-axis chart. When using a 3-axis chart, the left and right y-axis do not need to be identical, although they are in this example. As a Pareto chart is a frequency plot, with each bar showing the frequency of occurrence, this chart would be more helpful if the left-hand y-axis was the actual count of occurrences and the right-hand y-axis was the percentage of occurrence. The cumulative frequency line shows the cumulative percentages of occurrence as they are summed across the chart.
- Horizontal Multi-series Bar Chart – This bar chart illustrates a horizontal orientation of the data with the categories on the y-axis and the numerical values on the x-axis. Note that neither axis is labeled, which makes it difficult to understand what is being presented. With more than one series present, your chart should also include a legend which includes the color and description for each data set.



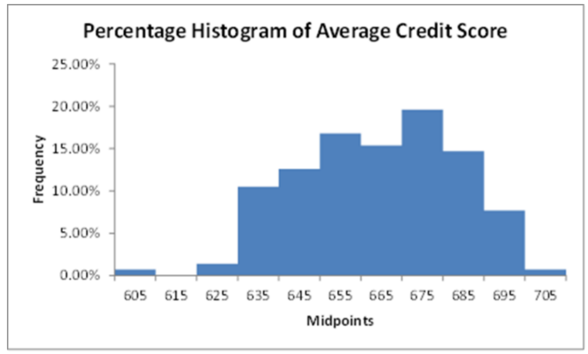
Devices Used to Watch	Percent
Television Set	49%
Tablet	9%
Smartphone	10%
Laptop / Desktop	32%

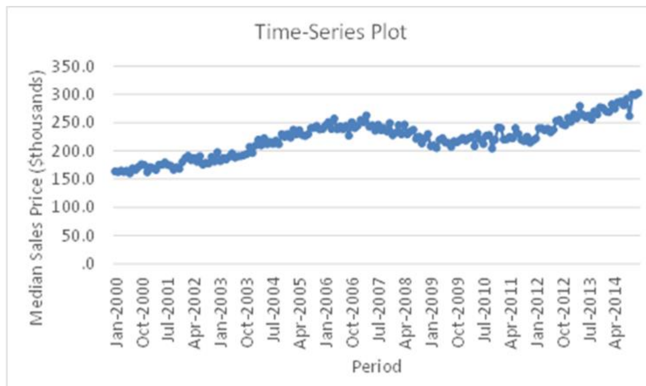




Types of Figures

- Histogram – The histogram shows frequency data in pre–established bins of equal width. These bins group frequencies into specific ranges and are helpful in presenting ranges that align with categories or specific meanings. For example, if I was to make a histogram of grades, each bin would be created to represent a letter grade.
- Time Series Plots – Dot plots or line plots showing data trends over time can be very helpful for analyzing how data changes over time. This type of graph can be constructed for other quantifiable values, if it is not time based.





While spreadsheet software applications will autosuggest chart types, focus on the main idea you are hoping to convey to the reader when creating your figure. If you are comparing data to a standard, it can be helpful to add a visual reference point. The presentation of data should help the reader better understand your analysis.

4.4 Conclusion

This chapter focused on the presentation of data in technical reports. While not all documents will include data, a large percentage of technical and engineering documents include a visualization of data in some form. When presenting data, you want to consider what visual could best aid the reader in understanding the content as a whole. You should also consider the audience, how the document will be presented (printed, online, email attachment) as well as accessibility features for those individuals who might be vision impaired. With these considerations in mind, your presentation of data can help support your narrative, allowing your reader to arrive at the same conclusion you present in your document.

Up Next

In the next chapter we will introduce common engineering documents, including memos, executive summaries and white papers. These documents are typically brief and often prepared for internal audiences. Each of the documents will be presented with the objectives, key features and examples of these in practice.

Chapter 05

Common Document Types in Engineering

Engineers are expected to write several different types of documents depending on their professional experience, discipline of study, type of industry, and role. For example, interns often speak about their summer internships including writing standard operating procedures, drafting project proposals, and reviewing work instructions for accuracy. Engineers who manage others may also write memos or other internal communication documents. Engineers working in project and consulting roles often write proposals, respond to bid requests, and various project documents. To prepare for this variety of technical composition, this chapter reviews the unique elements of documents common to engineering careers.

5.1 Memos

Memos (or Memorandums, which is the full title of the document, although rarely used) are formal documents, oriented towards internal audiences that can include broad audiences. These documents are typically brief (only a page or two) and have a very narrow focus. While brief, memos can communicate very important information, including changes to policy, operational procedures or announcements about changes within a company. Prior to the digital era, memos were often printed, distributed to individuals and/or posted in common areas for all to read. In today's industry setting, memos are often disseminated through email and posted to internal websites, although important policy changes may still be printed and posted in common areas. While brief, memos are formal documents and can be a challenge to write, as they often reflect policy or changes to broad audiences.

Similar to other company specific documents, the format is of a memo often follows a specific template, used department-wide or even company-wide. The contents are dependent on the type of memo being authored. For engineering related memos, the format is typically notifying the audience of changes to a product, process or policy. Therefore, the general format can be captured with the following sections:

- Header Information – Following the provided template, this typically includes the name and title of the author, the intended audience, the date and a subject matter.
- Introduction or Purpose – The first paragraph should provide the necessary background for the memo. While brief, you want to ensure that your audience understands the overall purpose and any supporting background that may be necessary to provide context to the subject.
- Discussion Paragraph – In the central content of the memo, you must present in a logical format the main theme and any information that supports the resulting change, action or recommendation. For engineering documents, this can include a presentation of data when necessary.
- Actions or Recommendations – As a result of the information provided, this section should document the next steps. In many cases, memos are made to inform individuals about decisions that have been made and how it will impact the audience. This could include an informational statement, like the announcement of a change in vacation time accrual, or a statement that requires a change in procedure, like the example below.
- Closing – Many memos follow a template that is similar to that of a letter or some other form of correspondence. As such, many memos include a formal closing. This will be included in the template if a closing is required.

Example Memo

Example Header

Below is the header of a sample memo. In this format, the memo includes To, From, Date, and Subject, as well as a salutation, typical of a letter or email.

> Memo
>
> To: Production Floor Operators
>
> From: Human Resources
>
> Date: 3/14/23
>
> Subject: Time Clock Changes
>
> Operators,

Example Introduction or Purpose Paragraph

Following the header, the first paragraph provides context for the memo and the background that has led to the decision being presented in the document.

> Numerous issues have been identified with the existing time clock, including inaccurate recording and the data entry errors from the paper time cards into the payroll management system.

Example Discussion Paragraph

Now that the audience understands why the memo is being written, the author can include the relevant information for how the decision was made. In this case, the author provides a case for lost productivity and the actions that must take place to correct this action.

> As the errors have created inefficiency for multiple departments, as well as incorrect paychecks for operators, a new time clock will be installed that automatically records your time of entry and departure from the production floor, as well as automatically updating the payroll system. Beginning Monday, you will need to clock in and out using the new time clock.
>
> To clock in and out:
>
> 1. Swipe your badge through the time clock, which will be placed at the main doors of the production floor.
> 2. When your name appears on the display, click the green button to confirm your entry to the production floor.
> 3. When leaving the floor, swipe the badge again. Click the green button to confirm your exit from the production floor.

Example Actions or Recommendations

The new procedure is provided with details of how the procedure should be implemented and the expected outcome.

> This process should be repeated every time you enter and exit the production floor for the start and end of your shift, for your breaks and for your lunch. There is no need to swipe your card to leave the production floor for work-related items, like team meetings or appointments with other departments.
>
> This new system will eliminate payroll errors and increase efficiency for multiple organizations.

Example Closing

After presenting the new policy, this closing emphasizes the desired outcome and includes a formal closing. For this memo, both a traditional salutation and formal closing were used. If you choose to use a salutation for a greeting at the beginning of the memo, a formal closing should be included for consistency. If no salutation is used in the header, a formal closing is not required. Even without a formal closing, every memo should have a concluding paragraph.

> This new system will eliminate payroll errors and increase efficiency for multiple organizations.
>
> We thank you in advance for your assistance in implementing this new system.
>
> Thank you.

There are some engineering documents, like Engineering Change Notifications, that follow a very similar style to memos, but are given specific titles based on their function and purpose. These titles and formats will often change based on your engineering discipline, the type of company you work for and industry standards.

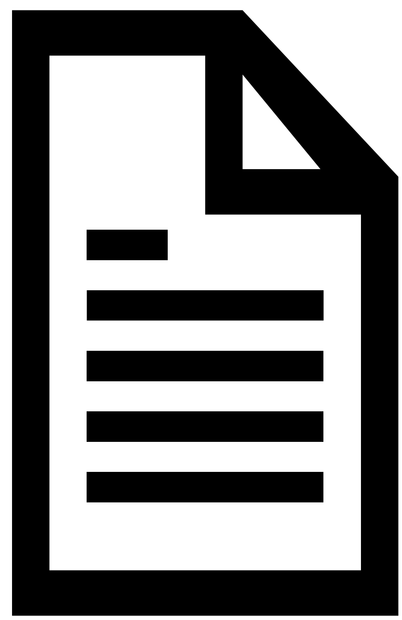
5.2 Executive Summaries

Executive Summaries are standalone documents typically based on the content of a full technical report. Executive Summaries contain identical sections to a full technical report but are abbreviated to present only the most critical information in a brief format. As a rule of thumb, Executive Summaries are often just a few pages or roughly 10% of the original document. For example, the Executive Summary to some government reports can be more than 20 pages, but are still less than ten percent of the original document.

As its name implies, an executive summary often is aimed at an executive audience, or those who are at the highest managerial levels within a company. While the topic may be technical in nature, the audience often comes from a non-technical background, like business management. Chapter 7 will present in detail the sections of a full report. As these sections are identical to an Executive Summary, this content will serve as an introduction not only to writing executive summaries but to authoring technical reports.

Front Matter

In the case of longer executive summaries, like those from government agencies, a Cover Page, Table of Contents or other form of Index may be required. The front matter should include whatever the provided format includes. If no format is provided, a Table of Contents is typically helpful for documents that exceed 5 or 6 pages.



Introduction

For an Executive Summary, the Introduction section can look nearly identical to the Introduction of the full report, depending on the desired length of the document. For an Executive Summary the Introduction includes a brief overview of each section included in the document. These sections would typically include either background or relevant context, the methodology, data analysis and results.

Like any other technical document, the Introduction should introduce the reader to the purpose of the activities described and to the purpose of the document. The reader should clearly understand why the activities were performed and the expected outcome. This includes information about the context or background that brought about the engineering activities. For example, if you completed a study for a new supplier of raw materials due to supply chain delays post-COVID 19, you would briefly described the materials being sought and the delays experienced and the impact of the delays on operations.

You also need to introduce the scope of the document so the reader knows what to pay close attention to. Even with an abbreviated format, you should highlight areas of the methodology and data analysis, as well as key results of implications to help guide the reader through your document.

WHAT AND WHY

Methodology

Your methodology will not reflect a step-by-step procedure when writing an Executive Summary. The methodology should be clear, concise and correct. To accomplish this for the methodology section, your focus should be on "what" and "why". To describe what you did, focus on specific context or setting and techniques used for execution of your experiment. To address why you selected this specific method, state how the methodology impacted the accuracy and precision of your data collection, contributing to the overall validity of the work performed. You should also include any limitations to your methods, which could be factors of nuisance variables as discussed in chapter 3, or limitations to your study.

Compared to full technical reports, the methodology is frequently the section most reduced from the original document. This is because the details provided in the methodology are rarely as important as the results and implications to the executive audience. When considering your audience, their focus is often on the result or decisions or implications or next steps required. Therefore, the methodology only needs to convey basic information that confirms that the appropriate methods were used support the outcome.

Presentation of Data

The presentation of data should be a combination of both narrative and images that aid in the reader's comprehension of your conclusions. Raw data is not necessary for this to occur. Instead, critical data should be summarized and presented in clearly labeled tables. Graphical representations help to more clearly communicate the key attributes of the data and should complement the narrative presented in the document. These methods were described in detail in the previous chapter.

Analysis of Data

For data analysis, the author should use the graphical presentations of data to support the analysis and conclusions. The reader should be able to review the graphs or charts and draw the same conclusions that the narrative provides.
It should also be clear how the data supports the overall objectives of the work and whether or not the hypothesis was confirmed, when applicable. In the earlier example about determining a new supplier for a company, the data presented should support the decision of which supplier was chosen. If the reader views the data and comes to a different conclusion, the document has not clearly connected the data to the analysis and conclusions. If there were factors that could cause confusion or negatively impact the experiment, those should be clearly stated and support should be provided on how these factors were mitigated or no longer impact the results.

Conclusion

The Conclusion of an executive summary is the last opportunity you have to persuade your audience of your conclusion. In a single section, or sometimes even a single paragraph, the conclusion should remind the reader of the overall objective of the work performed, the key data analysis that supports the recommendations or conclusions and the next steps required either by the author or the reader.

In the Conclusion, you may also want to highlight opportunities to apply this work in a broader context or make recommendations for future work. These extensions of your work may be outside the scope of the original work but could be important to the company in the future. From the previous example, this could be notifying the readers that the new supplier selected offers additional materials or supplies that the company could use for other projects or in other divisions of the company. This recommendation does not directly relate to the initial scope of your project but is valuable to note to the reader.

Case Study

Jesmond ENGINEERING

Pollution Control & Smoke Clearance in an Underground Carpark

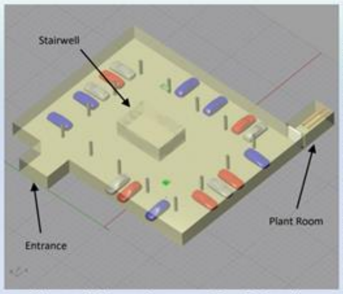


***Figure 1** The underground Car Park with entrance, stairwell and plant room marked.*

Task Objectives

Jesmond Engineering was contacted for an engineering assessment of the proposed ventilation in an underground car park. The CAD model for the car park is shown in Figure 1 with the entrance, stairwell and plant room marked. Computational Fluid Dynamics (CFD) was used to ascertain whether the proposed car park design was capable of meeting the ventilation requirements specified in building regulations for pollution and smoke control. The car park design proposal was for a mechanical ventilation system that included two impulse fans in the parking area and two extract fans located in a plant room. Two scenarios were analysed which were pollution (CO) control and smoke control. In the pollution scenario the impulse fans and only one of the extract fans operated at 50% of their maximum performance. During smoke clearance both impulse and both extract fans operated at 100% of their maximum performance Jesmond Engineering constructed a CFD Model which could solve the airflow around the car park in both scenarios with the aim of either confirming the acceptability of the design or allowing further design changes to be examined.

Pollution Control

According to regulation, the mechanical ventilation system should achieve a rate of 6 Air Changes per Hour (ACH) around all areas of the car park and 10 ACH where car engines are running and queues can form. Extract fans should be arranged to prevent stagnated areas where stale air can accumulate.

Smoke Clearance

During smoke clearance the ventilation system should achieve 10 ACH in the area where the fire is located. Also air velocities along escape routes should not exceed 5m/s to avoid impeding occupants escaping and furthermore, pressures on doors should ideally be negative and low.

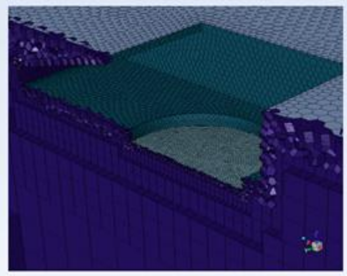


***Figure 2** Mesh around the Impulse Fan*

Computational Fluid Dynamics

A CAD model was constructed, as illustrated in Figure 1. The model contained all the major features of the carpark design including pillars and vehicles to ensure that it was representative of the actual design. The impulse fans were installed below the ceiling and the extract fans were contained in a plant room that was separated from the main car park by a louvre panel. Figure 2 shows an example of the mesh around the ceiling mounted impulse fan.

Continued overleaf

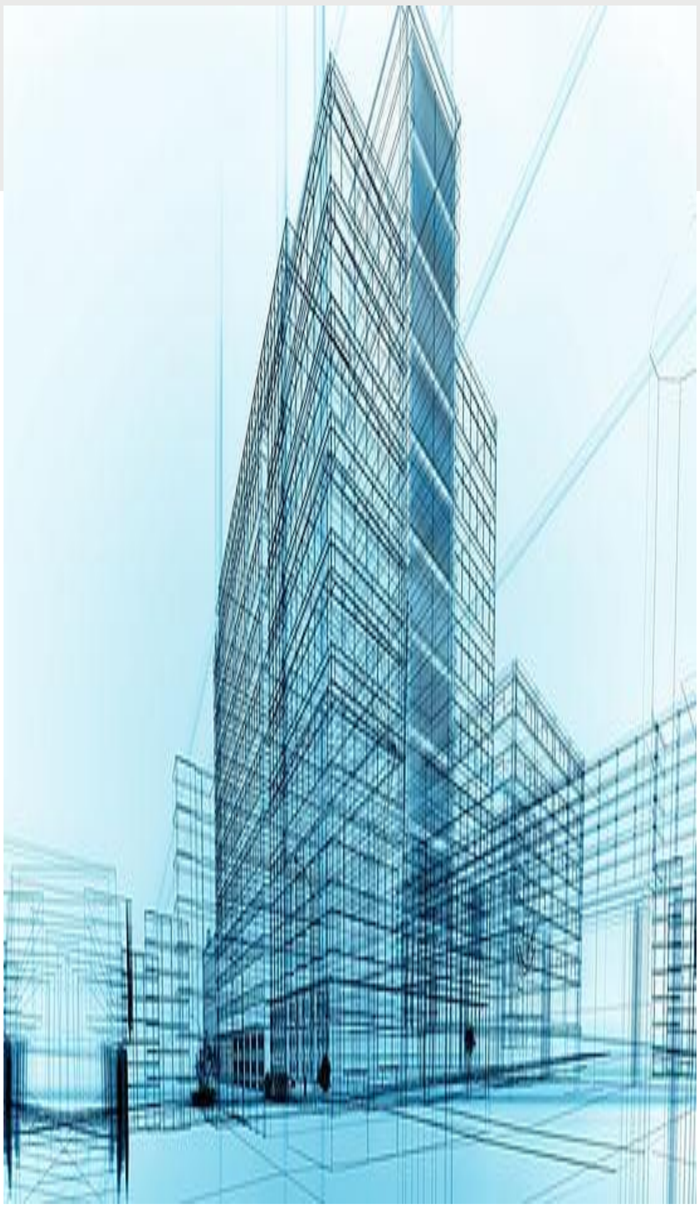
www.jesmondengineering.com Computational Fluid Dynamics

5.3 Case Studies

Case studies are the brief reporting of a singular focus, similar to executive summaries but with an audience that is typically either external customers or peers of your discipline or industry. This form of reporting allows individuals to quickly disseminate information about innovations, new products or processes or new areas of exploration. The work is often published internally, hosted on the company website and therefore does not go through a peer review process like an externally published document.

The case study audience is often most interested in the results of the work, so the format may only include a brief overview with a stated objective and short description of the methods used and context for the activities performed. The majority of the document focuses on the results and implications. Depending on what is being presented and if the intended audience is a potential customer or peers in industry, the document may conclude with recommendations for future work or broader extensions of the results.

Above is a sample case study, published on the website of an engineering firm. A link to this document is provided in the references section for further review if desired [1].



5.4 Conclusion

This chapter introduced common documents in engineering industries, including memos, executive summaries and case studies. While short in length, these documents must maintain the technical writing foundational principles of being clear, concise and correct. Using the methods for writing in a professional voice, crafting sections of technical papers and presenting data, you can successfully author engineering documents.

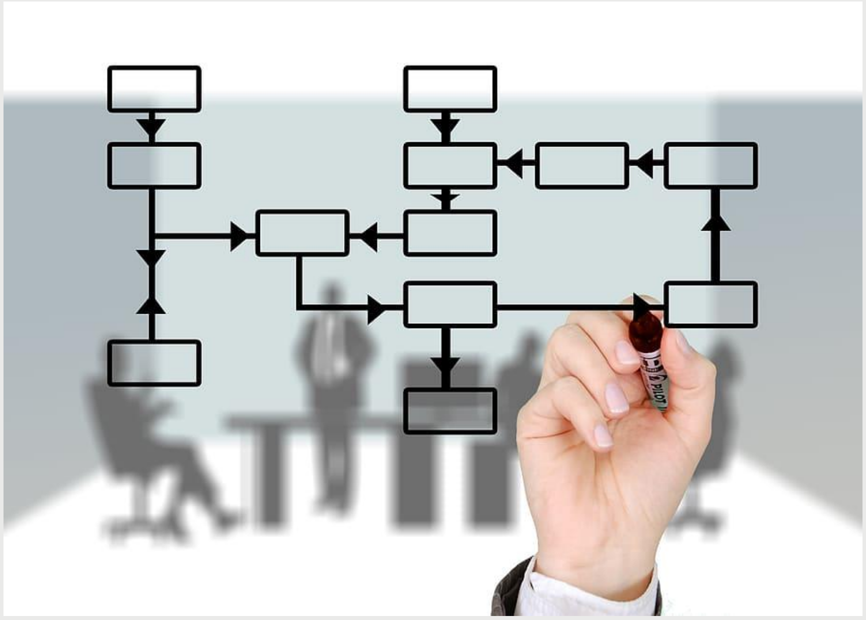
Up Next

In the next chapter, additional brief engineering documents will be presented, including Standard Operating Procedures, white papers and engineering process documents. These brief documents are also typically prepared in specified formats to internal stakeholders.

Chapter 06

Additional Brief Technical Documents

In the last chapter, several forms of documents were introduced that are common to engineering professions. This chapter continues with several additional types of documents found in engineering fields. In this chapter we will discuss standard operating procedures (also called work instructions or job instructions) which are often written by engineering interns or newly hired engineers. These are one form of process documentation. Several other forms of process documents will be reviewed. Finally, we will discuss the use of white papers in engineering and industry publications.



6.1 Standard Operating Procedures/ Work Instructions

Standard Operating Procedures (SOPs) or Work Instructions can be called by various terms in different industries or companies. Job Instructions is probably the third most common term used for this document, after SOP or Work Instruction. The rest of this section will refer only to SOPs, but the concepts hold true for any of these types of documents, even if they are called by a different name.

SOPs are designed to communicate procedures in a step-by-step way to be executed by the operators who perform the task. At many industry settings, these procedures are documented by a supervisor, engineering intern or entry-level engineer, even though the work is conducted by other employees. This means that the person writing the document has to gain familiarity with the process prior to authoring the document. It also means that the document should be validated against the work being performed prior to publishing or approving the final version of the document.

As the intended audience for this document is often an hourly-paid employee, you must make sure the steps are written at the appropriate educational level for the intended operator. There are highly technical SOPs written where the operators are highly educated individuals completing very technical processes. More often, SOPs are written for individuals who have limited higher education or may not have completed high school. Prior to beginning to author an SOP, it is important to know the language level of the audience. It is also possible that the intended audience does not speak English as their native language. In some cases, SOPs are translated into other languages to enhance comprehension of the operators. When this occurs, it is critical that the translated document is verified by someone who speaks both languages, to ensure that the translation is correct. Some technical terms do not have a word-for-word translation and require adjusting the language to communicate the appropriate concept.

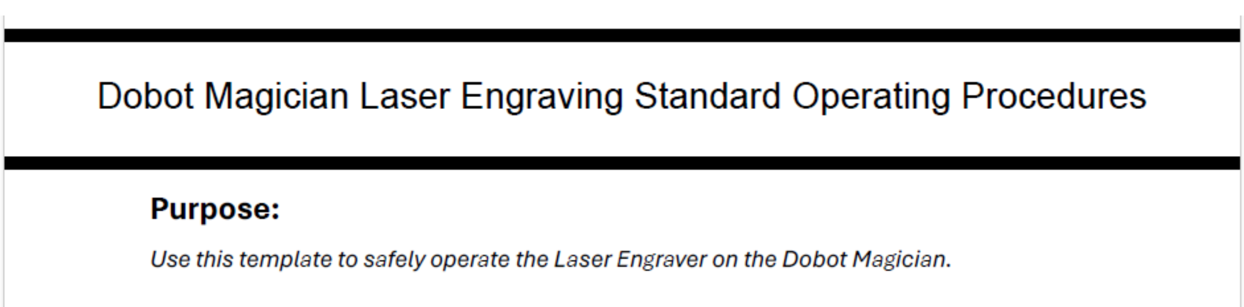
SOPs frequently have a template specific to the company and these templates are standardized so that operators have familiarity with the documents even when learning a new technique, process or piece of equipment. In highly regulated companies, the format may be specified from the regulating body, such as the Food and Drug Administration (FDA) or International Organization for Standardization (ISO).

You may ask yourself, why does everyone have to do things the same way? Prior to the Industrial Revolution in the 1800’s, all manufacturing was single piece construction with each craftsmen building each item to order. After the Industrial Revolution, concepts around standard work were presented by the individuals who would become the pioneers of the field of Industrial Engineering [1]. In the early 1900’s formal SOPs began to appear in various industries to ensure that tasks were easily repeated in the exact same way every time. During World War II, with the sudden need to increase production rates, standard operating procedures became common place in all sorts of industries, supported through the standardization of military documents following American National Standards Institute (ANSI) requirements. Additional governing agencies proliferate the use of standard documents to adhere to the requirements of the industry regulating bodies. Standards not only allowed for process control, but also led to an increase in productivity and quality. SOPs also serve as a mechanism for training individuals on the correct procedure, to ensure all operators new to a task complete it in the same way. SOPs also create a process flow that can be analyzed for improvement. With the advent of ISO, industries of all kinds adopted the use of SOPs including healthcare, finance, service industries, telecommunication, aviation and internet-based processes.

To create an SOP you want to identify the process steps, the equipment used, the safety requirements and any prerequisite training that should be completed prior to an operator conducting this process. You should also consider equipment or process set-up that should be verified prior to beginning the procedure and any personal protective equipment (PPE) that is required or recommended. Elements that must be documented in some way should also be noted with importance.

SOP Example 1 Header

Using whatever template your company provides, you will typically have a name for the SOP. It may also include a numbering convention, revision date and author. Example 2 highlights these fields.



Dobot Magician Laser Engraving Standard Operating Procedures

Purpose:

Use this template to safely operate the Laser Engraver on the Dobot Magician.

SOP Example 1 Procedure

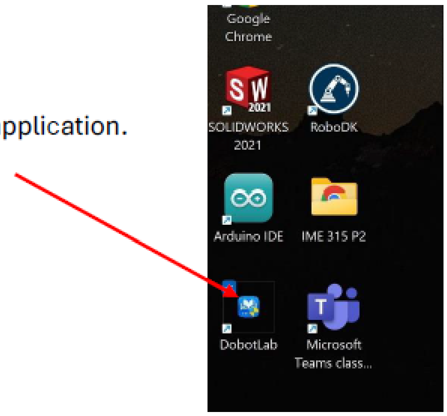
The procedure should be numbered in the order the tasks should be performed. Photos and diagrams should be used whenever possible to aid the operator in validating that they have completed the tasks correctly.

Safety:

- Always wear proper safety glasses to avoid damage to eyes.
- Fully clear environment to avoid damage to robot.
- Do not enter robot's path/laser path to avoid personal injury.

Procedure:

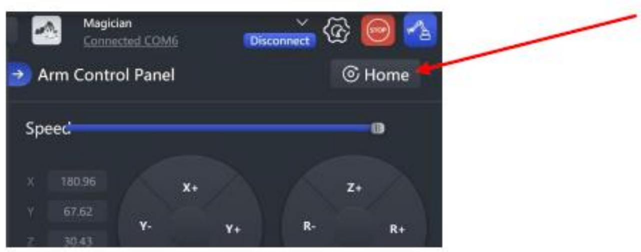
1. Open laptop/computer and start-up DobotLab application.



SOP Example 1 Embedded Safety Notes

As seen in step 11 below, the procedure should note areas when there are task specific safety concerns.

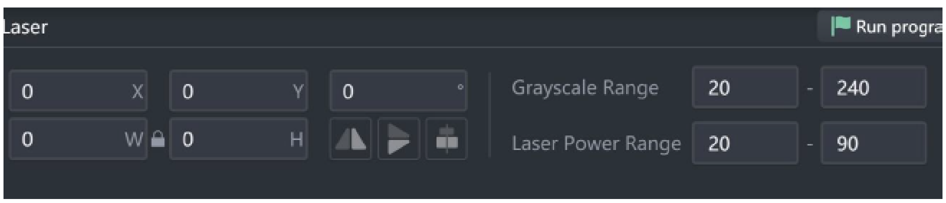
11. Home robot.
    i. BEWARE, once the home button is clicked the robot will motion in different directions to locate itself. If area not cleared damage to robot is possible.
    ii. Just below the connect button you should see a button that says home, click on home.



SOP Example 1 Procedure Verification Notes

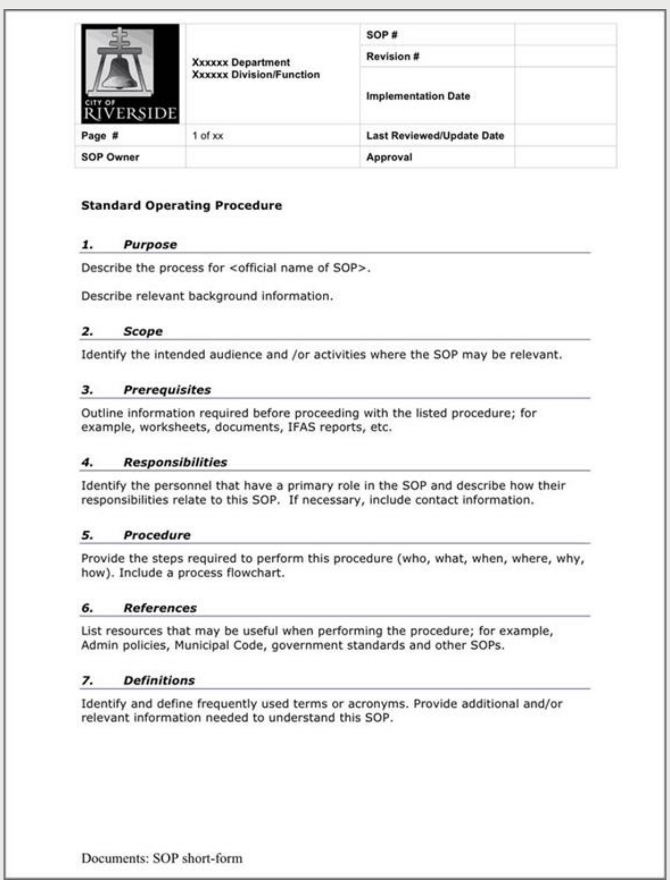
As seen in step 13 below, this procedure provides specific setting requirements and provides an opportunity for the individual to verify that their settings match the requirements of the procedure

13. Set engraving size.
    i. At the top left of the screen there are multiple inputs where you can adjust what your file will look like.
    ii. Ensure that when the image is selected that the radius is the color blue. If the radius is red, then the image cannot be made due to where the image is located. Try to fit the image somewhere between the two-arcs shown by the dotted lines.
    iii. **FOR MEDALLION SET**
        1. **X: 267 Y:35**
        2. **W: 70 H:41**



SOP Example 2

The below example shows a template that can aid the author in creating content for each of the required areas [2].



CITY OF RIVERSIDE	Xxxxxx Department Xxxxxx Division/Function	SOP #	
		Revision #	
		Implementation Date	
Page #	1 of xx	Last Reviewed/Update Date	
SOP Owner		Approval	

Standard Operating Procedure

1. Purpose

Describe the process for <official name of SOP>.

Describe relevant background information.

2. Scope

Identify the intended audience and /or activities where the SOP may be relevant.

3. Prerequisites

Outline information required before proceeding with the listed procedure; for example, worksheets, documents, IFAS reports, etc.

4. Responsibilities

Identify the personnel that have a primary role in the SOP and describe how their responsibilities relate to this SOP. If necessary, include contact information.

5. Procedure

Provide the steps required to perform this procedure (who, what, when, where, why, how). Include a process flowchart.

6. References

List resources that may be useful when performing the procedure; for example, Admin policies, Municipal Code, government standards and other SOPs.

7. Definitions

Identify and define frequently used terms or acronyms. Provide additional and/or relevant information needed to understand this SOP.

Documents: SOP short-form

6.2 White Papers

White papers are similar to journal articles in composition and format, but are typically written as corporate documents on technical topics that may be of interest to a broad technical audience. Like case studies, these documents are frequently published to company websites, although they can also be published privately on individual websites or blogs. With these publishing methods, an official peer review is rarely conducted.

The contents of a white paper can resemble journal articles or technical reports, but they do not necessarily follow a specified format, depending on the company and the intended audience. Some companies have their technical personnel author white papers on topics that may interest their customers about changes in the industry or new developments in technology, products or processes. These documents are often written with fellow engineers or business–to–business customers in mind. Therefore, the content focuses on descriptions of the systems and results to positively highlight opportunities or advances within the company's capabilities.

White papers are also used in the scientific community to self–publish research that has been conducted to solicit feedback from other researchers in their discipline. Specific websites have been created for peers to share their research internationally. This feedback helps researchers to learn who else is working in that same area of research or receive feedback prior to completing the peer review process for being published in a journal. As publishing in a journal can take anywhere from 18 – 24 months, this self–publication method advances research more quickly.

Examples of several different paper are available using the links from the images below [3, 4, 5].


HYPERLEDGER

Hyperledger Blockchain Performance Metrics

ABOUT HYPERLEDGER

Hyperledger (http://hyperledger.org/) is an open source effort created to advance cross-industry blockchain technologies. It is a global collaboration including leaders in banking, finance, Internet of Things, manufacturing, supply chains, and technology. The Linux Foundation, the nonprofit organization enabling mass innovation through open source, hosts Hyperledger. The Linux Foundation also enables a worldwide developer community to work together and share ideas, infrastructure, and code.

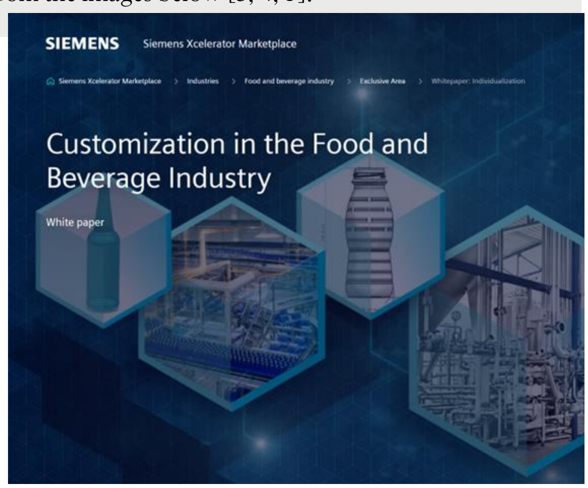
About This Paper

This is the first white paper from the Hyperledger Performance and Scale Working Group (https://wiki.hyperledger.org/groups/pswg/performance-and-scale-wg). The purpose of this document is to define the basic terms and key metrics that should be used to evaluate the performance of a blockchain and then communicate the results. This paper also serves as a platform-agnostic resource for technical blockchain developers and managers interested in using industry-standard nomenclature.

While we appreciate that there may be discrete definitions for the terms "blockchain" and "Distributed Ledger Technology (DLT)," for the purposes of this paper we will treat both terms synonymously and use the term "blockchain" throughout.

This document provides some guidance on selecting and evaluating workloads. We expect that refinements to these definitions and new blockchain-specific metrics will warrant future revisions of this document.

In future documents, the Working Group plans to discuss workloads in greater detail and to offer additional guidance on standard procedures and emerging best practices for evaluating blockchain performance. To provide your feedback and stay informed about subsequent versions of this paper, please join us in the Performance and Scale Working Group (https://wiki.hyperledger.org/groups/pswg/performance-and-scale-wg).



6.3 Process Documents and Quality Documents

In industry, companies often have additional documents for specific purposes that you will interact with as an engineering. Depending on your engineering discipline, industry and position within the company, you may find yourself generating many different types of documents. Each of these documents continue to follow the goals of all technical writing: to be clear, concise and correct. Each document may have a different target audience, objective and format, but the same techniques discussed in the previous chapters remain critical to completing a document that meets your given objective.

Technical documents of this type often communicate information about processes, standards or products. These internal documents are typically controlled within the institution to ensure that only the latest revision is the only document in use. The documents can include information about test results, validation efforts, internal quality audits, project documentation and engineering change notifications. The content will vary for each of these different documents.

Six Sigma Documents

Six Sigma or Lean Six Sigma is a common process improvement strategy used in various industries to reduce variation within a process to increase revenues, decrease cost, increase quality or better meet customer requirements. Below is a sample template for a Six Sigma Charter [6].

HEALTHCARE SIX SIGMA PROJECT CHARTER TEMPLATE EXAMPLE

GENERAL PROJECT INFORMATION

PROJECT NAME		PROJECT MANAGER	PROJECT SPONSOR
Hospital Discharge Process Improvement			
EMAIL	**PHONE**	**ORGANIZATIONAL UNIT**	
	000-000-0000		
GREEN BELTS ASSIGNED		**EXPECTED START DATE**	**EXPECTED COMPLETION DATE**
		08/01/2022	08/01/2032
BLACK BELTS ASSIGNED		**EXPECTED SAVINGS**	**ESTIMATED COSTS**
		$237,750	$184,900

PROJECT OVERVIEW

PROBLEM OR ISSUE	Hospital Patient Discharge Process
PURPOSE OF PROJECT	We currently aim for our discharge process to be under 1.5 hours per patient. Our real-time process has expanded to be over four hours per patient between the physician's discharge order and their exit ticket. Post-visit patient survey ratings for the patient check-out process have decreased from 4.8/5 to 2.9/5 over the past six months.
BUSINESS CASE	Patient discharge time in our unit is unsatisfactory for both patients and hospital staff. The patient backup physically interrupts the floor's traffic flow. Surveys indicate patient satisfaction decreases during the discharge process. With the newly implemented strategic planning goal, our floor needs to make changes that reflect our patient experience as a priority.
GOALS / METRICS	By August 1, 2032, we will reduce the current discharge time per standard patient from over four hours to under 1.5 hours for 90 percent of typical patient. Patient post-visit surveys will average a 4.5/5 or higher rating within nine months of implementation.

PROJECT SCOPE

WITHIN SCOPE	All typical patient discharge processes in Units C and D, from physician discharge order to patient exit ticket receipt
OUTSIDE OF SCOPE	Atypical discharge orders (discharge orders with pending interventions) and other unit discharge processes

Engineering Change Notification

Engineering Change Notifications (ECNs) are documents that track changes to materials, technical drawings, process specifications, supplier requirements and other process specific information. These documents typically follow a company specific template and are tracked using an alpha–numeric system to ensure all revisions are approved and implemented as required. The below sample demonstrates a template that can be used [7].

MAXIM ENGINEERING CHANGE NOTICE

ECN #	PAGE
	1 OF

TITLE: PACKAGE OUTLINE, 68L QFN, 10x10x0.90 MM

DOC ID # 21-0122	NEW REV: C	OLD REV: B	EFFECTIVE:
TYPE 883 ☐ SMD ☐ #	PERMANENT ■	TEMPORARY ☐ EXPIRES:	
ORIGINATOR N. DUONG	EXT: 6613	VP NAME: RICH HOOD	

OTHER DOC AFFECTED: NO ■ YES ☐ LIST: →

MATL. AFFECTED: NO ■ YES ☐ → USE AS IS: ☐ REWORK: ☐ SCRAP: ☐

For Maxfab Lot Traveler Changes ONLY: Affects version number? NO ☐ YES ☐ IF YES, ECN the Process Revision List.

For Data Sheet Changes ONLY: Review Data Sheet before printing? NO ☐ YES ☐ IF YES, initial

DESIGN CHANGES ONLY:

ROOT CAUSE:

CORRECTIVE ACTION:

REASON FOR CHANGE: PIN 1 ID AND TIE BAR MARK OPTION DETAILS ADDED. DIMENSIONAL CHANGE. DALLAS LOGO AND NOTES ADDED.

FROM:	TO:
	PAGE 1: - DETAIL A DIAGRAM SHOWN - PIN 1 ZONE SHOWN ON BOTTOM VIEW PAGE 2: ADDED TO NOTE 5 "DETAILS OF PIN #1........ZONE INDICATED ADD NOTE 11: MEETS JEDEC MO-220.
DIMENSION "L": MAX = 0.75	DIMENSION "L": MAX = 0.65

DISTRIBUTION: ☑ HQ ☑ Maxim North ☐ Maxfab South Manufacturing Areas N/A Offshore: N/A

Other: J.MOIST, L.JACKSON, M.RUBENZAHL, S.SUNG, S.SCHROEDER, A.ARREOLA, A.WICHMAN, D.GOLDBAUM, E.EVANS, @Q, @BA, @AC

ORIGINAL APPROVALS ARE ON FILE IN THE ______________ DOCUMENT CONTROL OFFICE.

APPROVALS	DATE	APPROVALS	DATE	APPROVALS	DATE
PKG. ENGR	/ /	T.MAK	/ /		/ /
S. SUNG	/ /		/ /		/ /
A. QUINTERO	/ /		/ /		/ /

Date ECN submitted into D.C.:	Document Control processor initials:

Quality Audits

Internal quality audits are routinely conducted to ensure companies remain in compliance with their own policies and with regulatory specifications. Quality audits are often conducted at regular intervals by a quality engineer or technician internal to the company but outside the department to ensure objective observations are made. Documentation of findings is often used for process improvement or training initiatives. Internal quality audits can aid in maintaining a state of compliance in between inspections from external regulatory bodies. The below sample provides an example of one type of quality audit [8].

FDOT ITSFM

FDOT TSM&O

ITSFM Data Collection Forms Audit Record

Report Date: 8-Apr-20
Serving Area: [illegible] Florida [illegible]
Project Name: [illegible]
Contractor: [illegible]
County: Osceola, Orange

LAST AUDIT NOTES

Audit 8 successfully passed audit initial failure due to unsorted pictures and missing code values, included updated data forms.
Audit 9 succesfully passed
Audit 10 sheet 3 doesn't match GPS file and failed audit / sent deliverable package back for updates

ITSFM1001
REV 04/20

				Number of Forms				Submittal Results	
Audit Number	GPS File Name	Submittal Date	Testing Date	Tested	Pass	Failed	Missing	Score	Pass/Fail
1	[illegible] 814_1 - 806_2	02/25/20	02/28/20	16	13	3	0	81%	FAIL
2	[illegible] 814_1 - 806_2	02/28/20	02/28/20	15	15	0	0	100%	PASS
3	ITSFM [illegible] 806_2-796_7	02/28/20	03/05/20	11	0	11	0	0%	FAIL
4	ITSFM [illegible] 806_2-796_7	03/06/20	03/10/20	11	11	0	0	100%	PASS
5	ITSFM [illegible] 796_7 - 788_4	03/06/20	03/11/20	14	14	0	0	100%	PASS
6	ITSFM [illegible] 789_4 - 780_4	03/23/20	03/27/20	12	10	2	0	83%	FAIL
7	ITSFM [illegible] 780_4 - 767_5	03/27/20	03/27/20	12	12	0	0	100%	PASS
8	ITSFM [illegible] 789_4 - 780_4_3	04/02/20	04/06/20	13	13	0	0	100%	PASS
9	ITSFM [illegible] SEED 801_3 - 761_8	04/06/20	04/08/20	6	6	0	0	100%	PASS
10	ITSFM [illegible] SEED 767_5 - 761_8	04/01/20	04/08/20	2	1	1	0	50%	FAIL

Page 1 of 13

6.4 Conclusion

This chapter reviewed additional brief engineering documents, including Standard Operating Procedures, white papers and various types of process documents. Each of these documents is highly dependent on the industry and company for their format and required content. However, there are several content areas consistent across most companies for these type of documents.

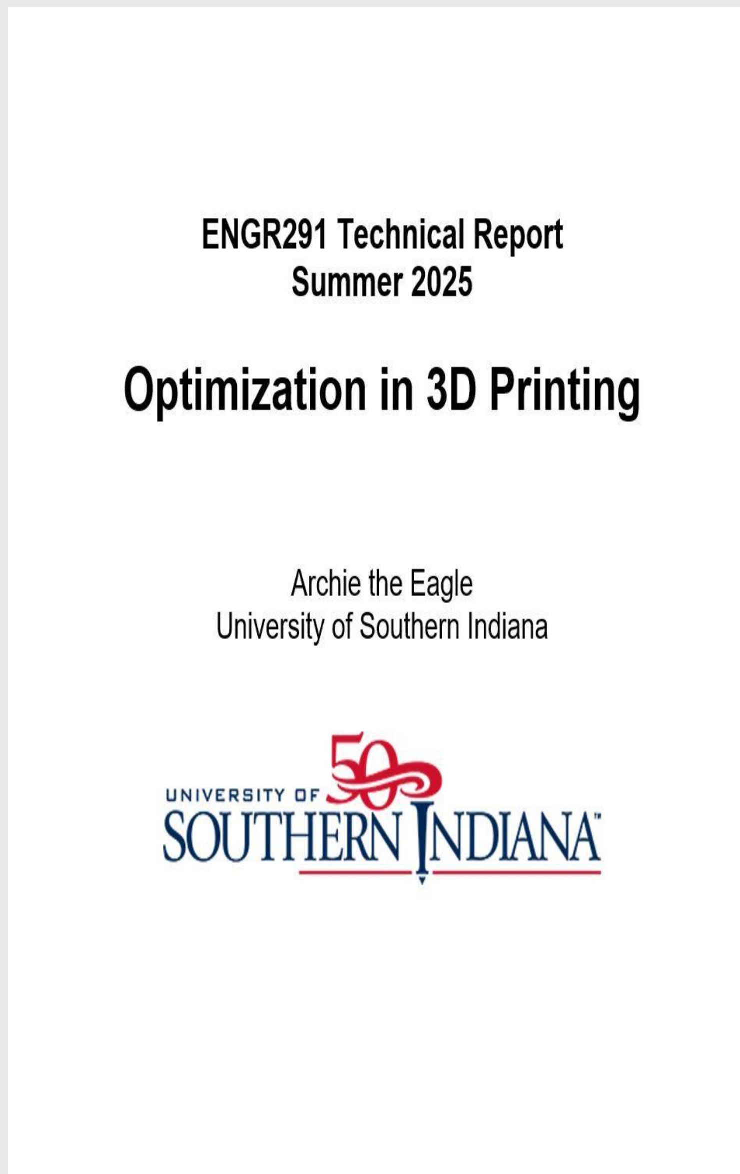
Up Next

In the next chapter, longer engineering documents, including full technical report, proposals and grants will be discussed. While these documents can feel intimidating due to their length, the content and writing process follow the same conventions discussed in the previous chapters of this text.

Chapter 07

Technical Reports and Other Large-Scale Documents

This chapter reviews technical reports, including engineering projects, customer proposals, and grant submissions. This chapter builds on previous information on technical writing, expanding on each section of a technical report with greater detail for general report writing and specific needs of industry specific documents. Examples of these documents are also provided to better understand how various engineering disciplines may require documentation with varying formats.


ENGR291 Technical Report
Summer 2025

Optimization in 3D Printing

Archie the Eagle
University of Southern Indiana

UNIVERSITY OF SOUTHERN INDIANA

7.1 Additional engineering documents

This text has covered numerous types of common engineering documents used in all different disciplines and industries. This section looks at some longer, formal technical works that you may encounter in both academic and industry settings.

Technical Reports

Technical reports can cover many different topics and use a variety of formatting conventions. In the academic setting, this may change from course to course or professor to professor. In industry, you may find differences between different companies, engineering disciplines or even different standards for departments within the same company. These formats are often provided to you and should be written in a formal, technical way using an academic voice and all appropriate notation formats. As these are formal documents, technical reports can be very similar to academic or technical journal articles and often require only slight changes to be made available to a broader audience through publication.

Proposals and Bids

Proposals and bids are documents written in a formal voice following whatever template has been provided by the soliciting body. For example, if a company wants to find a contractor to rebuild part of their office suites, they will write a description of work, as well as key requirements and then ask companies interested in bidding on the job to include specific content to be considered for the work. The minimum of these requirements typically includes information about the length of time the project would require, resource requirements, materials and total cost.

Grants

Grants are proposals to an agency or company that is soliciting proposals for funding which will be made available to accomplish specific research or tasks. Grants are often used for funding critical research or accomplishes work in an area of interest for a company. These documents must follow the guidelines provided by the granting agency.

7.2 Technical Report Sections

Technical reports aim to communicate the complete information from beginning to end of a project, process, or research activity. These documents are written in an academic voice and must accurately describe the methods, data analysis and conclusions from the activity performed. While an executive summary can accomplish this task in an abbreviated method, technical reports will provide thorough descriptions of every step of the process, rather than summarizing the content in a more concise way.

Abstracts

An abstract is a brief (250 – 500 word) summary of your entire work. Unlike an executive summary which maintains the same sections as the report itself, an abstract is typically presented in a single paragraph. Abstracts are often published in journals, poster presentations, oral presentations, conference proceedings and databases to provide readers and opportunity to have a better idea of the content of an article than simply looking at the title.

As the abstract summarizes the entire paper, you should ensure that you provide brief descriptions about the motivation for the work, the type of methodology used, the approach to the data analysis and the results. Below is an abstract from a published paper which was required to use a specified format for the journal [1].

Abstract

Purpose: The purpose of this paper is to explore how to use Six Sigma to improve the service process in higher education.

Design/Methodologies/Approach: This article summarized the previous literature to illustrate the differences between service and manufacturing process from the lens of Six Sigma, and used a practical case study from higher education to explain how to implement the framework of DMAIC in service process and the challenges occurred during implementation.

Findings: We described a case study where Lean Six Sigma (LSS) principles were adapted at the Purdue Sponsored Program Services (SPS) Pre-Award office, which is dedicated to supporting the creation of quality proposals and contracts for staff at Purdue. We described how a LSS team worked with the team to apply DMAIC in their service process, defining potential benefits such as reduced service lead-time, lower work-in-process inventory and improvement on imbalanced workflow. This case study demonstrates the numerous challenges in working with the intangible factors that hard to recognize, quantify, and analyze.

Practical Implications: It is important for practitioners to be aware of the implementation of Six Sigma in service industry, because service operations comprise 80% of the GDP in United States. The nature of service project decides the complexity to identify what to improve, and methodology. The article provides suggestions on how LSS tools and principles can be applied while running projects in a service environment.

Originality: Six Sigma has been widely used in manufacturing, but there has been limited academic research about the implementation in service industry, particular to higher education. This article contributes through demonstration the value of the DMAIC methodology in service process and identifies challenges for higher education.

Keywords: Six Sigma, DMAIC, Service, Higher Education

Paper Type: Research Paper

This next abstract provides an example of an abstract for an article where no format was specified [2].

Abstract

This paper is for ongoing work in developing unique collaborations between engineering and non-engineering students in a user-centered design course and humanitarian engineering project work. In this paper, the authors will review their integration of social and emotional competencies into engineering design and practice through a credit-based engineering course in conjunction with an Engineers in Action (EIA) Bridge Project student chapter at a midwestern public university. Previous research has shown that many universities have limited engagement with topics of multicultural engagement, working within diverse interdisciplinary teams, and approaching engineering problems from an awareness of inclusivity, cultural sensitivity and socioeconomic factors, despite the value placed on these qualities by accrediting bodies like ABET and societies like the National Society of Professional Engineers and the National Academy of Engineers. This content is often seen as a single module embedded in general engineering coursework, even though studies have shown students are often eager to connect global and societal concerns with engineering. A small number of engineering educational institutions in the United States have integrated these competencies more broadly into humanitarian or service engineering programs, but these programs are separate from traditional engineering majors such as mechanical or civil engineering. This project evaluates the professional formation of engineers by examining how engineers apply social attributes (namely those identified by the Social and Emotional Learning (SEL) framework) to user-centered design in a multidisciplinary project. This is facilitated by asking two research questions: "What key social attributes do undergraduate students identify as significant factors within service-learning engineering projects?" and "How does participating in a user-centered design curriculum impact students' identification of key social attributes associated with service-learning projects?". As part of an NSF proposal, this work is conducted through a multi-year grant that supports the development of the curriculum, as well as the assessment of the student participants. This presentation will review the theoretical framework used for the curriculum and mixed-methods research, as well as present the process of obtaining grant funding for this collaborative effort. The creation of the multidisciplinary advisory board and the program mechanisms for blending engineering and non-engineering students will also be discussed.

Front Matter

Dependent on the requirements provided, the front matter could include the Table of Contents, Table of Tables and/or Table of Figures, Acknowledgements and any other content that is required prior to the presentation of the technical work. This is highly varied content, with requirements changing by target audience, publication type, discipline, industry and company. As an author, it is your responsibility to complete the required sections as specified by the template.

Introduction

The Introduction is the first content of the technical paper and serves to orient the reader to the purpose of the work and the purpose of the technical report.

- Importance and relevance of the work – The introduction should give the reader some context into the motivation behind the work being conducted. In a purely research oriented paper, this could include your initial research question and hypothesis. For industry work, this could include the motivating situation for the project, such as looking to optimize a process or reduce costs. The reader will use this information as a foundation to their review of the content that follows. This introduction allows you to set the tone and guide the reader in what is most important about the work you conducted.
- Scope of the report – The second part of the introduction is to orient the reader to the report itself. You should inform the reader what important contents will follow and what they should pay special attention to as they read. For example, you may want to mention the methodology, highlighting an innovation practice or your method for ensuring rigor and internal validity. For the data section, you may want to briefly describe your sampling plan or context for data collection. For the data analysis you might mention your confidence level or statistical test.

The introduction will support the rest of the paper by preparing the reader to notice the most important aspects of your work and how this related to your topic for discussion. A well written introduction can help guide your writing in the following sections as well.

Methodology

In chapter 3, when discussing variables, it was stated that the methodology is critical to ensuring that your results appropriately align to your research goals and provide results that can be applied to greater contexts as applicable. When writing your methodology section, you need to present this intentionality (or purposefulness) to provide your readers with not just what you did, but why and how. It is also important to note that in some cases your methodology would be detailed enough that another person could replicate your work. As mentioned previously, there are some applied researchers who test the theoretical work of others to see if the mathematical proofs can actually be proven in a physical manner. However, not all methodologies need to be this exhaustive. Knowing your audience, the expectations of the publishing body (internal, external, or journal and the purpose of your paper should guide how detailed you are when documenting your process. Regardless of level of detail, every methodology should address the following questions in some way:

- How does your methodology increase the validity of your experiment through robust design and rigorous research methods?
- How does your methodology support your question/problem/objective?
- How does your methodology impact your data collection?
- What were limitations to your execution?

Presentation of Data

Chapter 4 of this text was focused on how to use the presentation of data effectively to communicate your results and the implications of your work to various types of audience. As introduced in chapter 1, your technical writing is highly influenced by your audience and by the goal of the document. If I am writing a technical report to other engineers to document my process improvement project, my data should focus on the impact of the work. If I am writing a report for a Lean Six Sigma project to executive management, I would follow the standard DMAIC format and the data would be spread throughout the document, as each of the five sections include some presentation of data. This is to say, your presentation of data is dependent on the experiment you conducted, the type of data collected and the type of document being written. With that in mind, there are several items that are expected in most presentations of data.

- Relevant formulas and established constants – In chapter 3, it was noted that constants are those values already established, typically from the natural world like viscosity of a fluid, or documented standards, like friction forces for known materials or established values, like the gravitational constant. While not every formula used in a process is required, if there is a formula that you have derived in a specific way for your work or a formula which was foundational to all other calculations, they should be presented.
- Sample size, composition and method – To ensure that your data adequately represents the population discussed, the size of the sample, the sampling method (like random sampling, convenience sampling, or stratified sampling) and important characteristics of your sample should be documented. If I was looking at a correlation between Hellenistic society membership (like fraternities and sororities) and cumulative GPA, I would want to document the number of individuals in each particular group and how they were selected for the study. This could include subgroupings by their academic major, their year in school or other demographic factors that could impact the study. Each of these items could influence the results of the study, therefore it is critical to provide the reader with context to the data analysis.

- Descriptive statistics – As presented in chapter 4 – the descriptive statistics are the most basic description of the data set or sets being considered. Knowing the mean, median, mode, standard deviation and standard error all provide an idea of the characteristics of the data.
- Probability distribution and hypothesis testing – Once the descriptive statistics are established, documenting additional statistical testing, such as hypothesis testing should be presented. As data needs to be tested in accordance with the appropriate probability distribution, establishing normality or documenting which distribution is being used should be clearly stated to the reader.
- Graphical summaries and displays – When presenting the data, it is rare that all raw data would be provided to the reader. Often the raw data takes up a great deal of space and isn't helpful. Summary tables of the descriptive statistics and graphical displays of the probability distribution aid the reader in seeing how your data fits with the theoretical distribution.

Analysis of Data

Depending on the format provided, the presentation of data and analysis can be combined into a single section. Sometimes the two sections are separated to have the data analysis as a singular focus for the reader. When no specification is provided, the author should consider the focus of the work. If the work is focused on documenting a methodology and the resulting data, it might be helpful to split each section. When the focus is on actions from the analysis (such as a process change to improve quality or decrease cost) the data analysis may be combined with the presentation of data to make the data section more concise. In either case, the data analysis should focus on three key areas:

- Your data analysis should draw connections between the results and your overall objective for the study. First and foremost, your data should answer the question you posed in the introduction of the work. If for some reason your experiment did not adequately answer the question, an explanation should be provided as to why this is the case or what other information is needed to answer the question.
- Your data analysis should be compared to your hypothesis or expected outcome or established benchmarks for your field. This is not necessarily the same as the previous bullet point. For example, you may have completed a project that was conducted to establish if a new motor, which was less expensive and more readily available, could substitute the existing part being used. Your initial hypothesis was that the new motor worked similarly and could make the substitution without sacrificing overall performance. However, after testing, you saw that there was a statistically significant difference between the old motor and the new motor. The new motor would not be able to be used without a significant loss of performance. Your work answered the question – could a new, cheaper moto be used. The answer did not align to your initial hypothesis, however, meaning that the overall objective of saving time and money will not be accomplished with this particular change.
- If your work has proven successful, the next step is to determine the appropriate application of the results. This extension of your results is the true impact of the work performed. It could be a small local change that only applies in a limited setting or it could be a larger impact with implications for the company or for your engineering discipline as a whole.

Conclusions

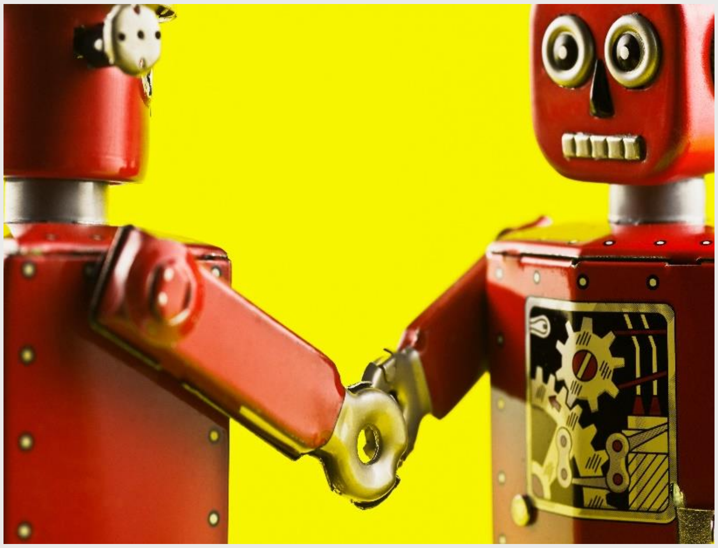
The conclusion is the bookend to the introduction of your technical report. Similar to the introduction, your conclusion should summarize the full report highlighting the accomplishments of the work. Any potential areas of expansion or replication should be restated, along with recommendations for future work. This is also an opportunity to reiterate broader applications for the work.

A conclusion is the last content your reader will remember. A well written conclusion can aid the reader in connecting the most important aspects of your work to the intended outcome. If your report is to an executive requesting funding for a follow-up project, your conclusion should leave the executive with confidence that your recommendations should be followed. If you are reporting on work completed, your conclusion should ensure that the reader appreciates the value of the work completed and impact of your efforts. If your work discovered a new process or potential for a new product, the conclusion should have the reader considering how this new process or product could be integrated with existing systems. Much like oral presentations presented in chapter 8, the conclusion of the paper should have the reader understand what is expected of them. The conclusion should clearly identify the next steps for this field of study, project or proposal.

7.3 Proposals and Bids

Proposals and bids are project specific documents prepared for external entities to either:

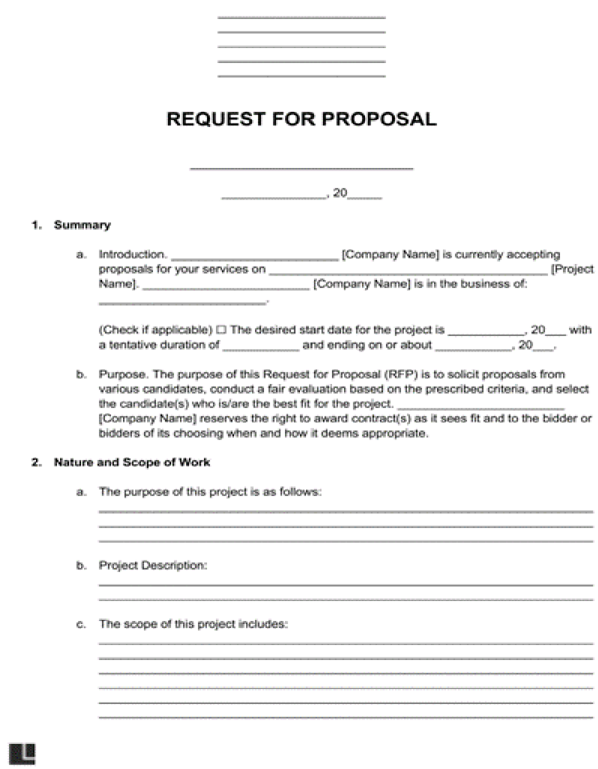
- Request others to bid on work your company needs completed
- Reply to a request for work you can complete for someone else's needs.



Content for proposals and bids

While the exact content should align to the requirements of the requisitioning entity, these documents typically include a scope of work, a timeline for completion, the anticipated budget or funding allotted and the contractual terms for completion or termination of the contract. Several examples of contracts and bids are provided to show how these documents may be formatted.

Example 1 – This request for proposal (RFP) provides for summary information about the company and the bid [3]. A purpose for the work is provided and space is allotted for the bidding company to identify their scope and description of work. Note that this is a cover page and additional content, such as the schedule and budget, could be included on subsequent pages.



REQUEST FOR PROPOSAL

____

______________, 20_____

1. **Summary**

   a. Introduction. ______________________ [Company Name] is currently accepting proposals for your services on ____________________________________ [Project Name]. ______________________ [Company Name] is in the business of: ______________________.

      (Check if applicable) ☐ The desired start date for the project is ___________, 20___ with a tentative duration of ___________ and ending on or about ___________, 20___.

   b. Purpose. The purpose of this Request for Proposal (RFP) is to solicit proposals from various candidates, conduct a fair evaluation based on the prescribed criteria, and select the candidate(s) who is/are the best fit for the project. ______________________ [Company Name] reserves the right to award contract(s) as it sees fit and to the bidder or bidders of its choosing when and how it deems appropriate.

2. **Nature and Scope of Work**

   a. The purpose of this project is as follows:

   b. Project Description:

   c. The scope of this project includes:

Example 2 – The second example shows a bid that has been completed for a request and provides the description, project objectives and expected timeline [4].

LAURA & DISPLAY

PROJECT PROPOSAL 2019

Prepared by Alex Miles
on October 13, 2019

PROJECT DESCRIPTION

A project proposal contains milestones at which certain aspects of the project are to be completed. In addition, a comprehensive project proposal includes a list of the key participants in the endeavor, together with a summary of relevant biographical data.

PROJECT OBJECTIVES

A project proposal contains milestones at which certain aspects of
the project are to be completed.

- To contact enough people to work on the project
- To implement the project successfully
- To be able to provide jobs for everyone

TIMELINE OF THE PROJECT

- October 13 - initial meeting
- October 18 - submission of ideas
- October 19 - revisions
- October 21 - execution
- December 25 - delivery of final output

7.4 Goals of Grant Proposals

Grants are a specific type of proposal in which funding is provided by the granting agency (typically a government or charitable foundation) to complete a project or research in a focus area. For example, the National Institute of Health (NIH) provides funding for scientists to research methods and medicines for treating deadly and debilitating diseases. The Department of Labor issues grants for training programs in emerging technologies or to retrain workers in fields that are facing workforce reductions.

Granting agencies create templates for submissions and often require annual reports to update the agency on the spending of the funds and the results of the work each year. These interim reports, as well as the work at the conclusion of the project, also follow specified templates. These templates often include the sections from the beginning of this chapter and potentially additional sections specific to the type of work being conducted. The requests for proposals outline the scope of work, the required timeline, the funding provided, limitations to who can apply and any other important factors the applicant should consider while creating a bid. An example of a grant solicitation is below [6].

OKLAHOMA EPSCoR

SUMMER 2023
Research Experience *for* Undergraduates

REU

Proposals Due: November 17, 2022

ABOUT THE OK NSF EPSCoR REU PROGRAM

OKLAHOMA NSF EPSCoR REU awards provide opportunities for undergraduate students from regional universities and colleges across the state to perform research in collaboration with Oklahoma's comprehensive research campuses (OU, OSU, TU, NRI) during the summer months. The goal of the program is to enhance pursuit of graduate degrees by students at regional undergraduate institutions and strengthen network collaborations across all higher education institutions in Oklahoma. Students benefit from hands-on research experiences in STEM fields and one-on-one guidance from faculty mentors. Proposals will be awarded via a competitive review process based on proposal integrity and the engagement of a diversity of students from regional institutions.

Who Can Participate

Key goals of the OK NSF EPSCoR REU program are to enhance inter-university collaboration and to increase students' pursuit of graduate degrees. To that end, the proposal must interface between a regional college/university and a research-intensive institution. This may be accomplished in one of two ways:

1. A regional university student is hosted by a research-intensive campus faculty researcher (serving as PI)
2. A regional university student is hosted by a regional university faculty member from that same institution (serving as PI), with collaboration taking place with a faculty researcher from a research-intensive institution

If both the PI and the student are from a regional university, it will be at the PI's discretion what form and level of interface with the research-intensive institution are included in the proposal; consideration of enhancing inter-university collaboration and the student's pursuit of a higher degree should be considered. In this instance, a letter of commitment and CV from the participating research-intensive institution faculty member should be included with the proposal, in addition to the PI's documents.

Applications must be submitted by a university faculty member or grant's office staff; students may not submit proposals. Current NSF grant funding is NOT required.

Types of Research Funded

Proposals in all areas of STEM research (excluding medical) may be submitted. However, award preference will be given to proposals that address S⁴OK RESEARCH topics, i.e. understanding subseasonal to seasonal weather, improving water reuse technologies, understanding terrestrial carbon and water dynamics, improving water/energy/transportation infrastructure resiliency, and understanding the social dynamics related to these focus areas.

Budget

- Maximum allowable budget is $5,000; no IDC allowed
- Budget must be used for the benefit of the student's research (i.e., student stipend, lab supplies, travel, etc.)
- No more than 5 REUs are expected to be awarded
- Medical research does not qualify for funding

How to Apply

Faculty researchers from Oklahoma colleges and universities may apply to host an REU per the instructions below. Important: Applications must be approved by the appropriate institutional grants office prior to submission (i.e., the office processing the award). The following items must be uploaded and submitted online at https://www.okepscor.org/online-submission-form-2023-ok-nsf-epscor-research-experience-undergraduates as part of your proposal package:

1. Brief description of the research project (2 pages max.)
2. Budget summary (i.e., student stipend, lab supplies, travel, etc.; no IDC allowed)
3. Faculty mentor's biographical sketch or CV (3 pages max.)
4. Student's letter of commitment (1 page max.)

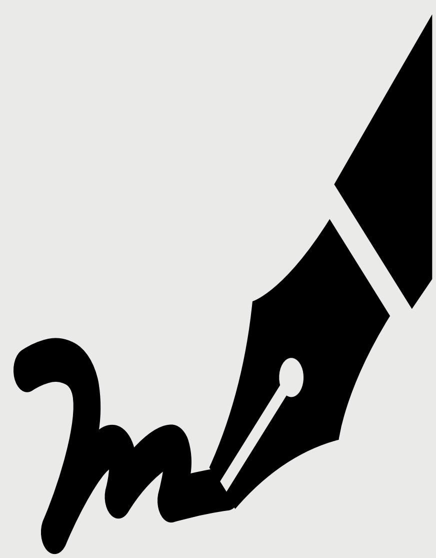
Submit online at https://www.okepscor.org/online-submission-form-2023-ok-nsf-epscor-research-experience-undergraduates
Questions? 405.744.7645 or gmiller@okepscor.org
Submission Deadline: 11/17/2022 (11:59 p.m.) * Funding Decision Announcements by: 2/1/2023

7.5 Conclusion

This chapter focused on full length technical reports including a general format for technical reports which could also be used for journal articles as well as proposals and bids for working with external entities. The chapter also discussed a specific form of proposal, namely, grant proposals. Each of these documents is a formal written document and can include both internal and external audiences. This chapter used concepts described in the previous sections for crafting a clear, concise, correct document in an engineering, professional voice.

Up Next

The next chapter will examine oral presentations of technical content for both formal and informal settings. Many of the same preparation steps for crafting a technical report are echoed when creating an oral presentation. Various types of presentations will be discussed, with the difference of audiences, settings and length considered.



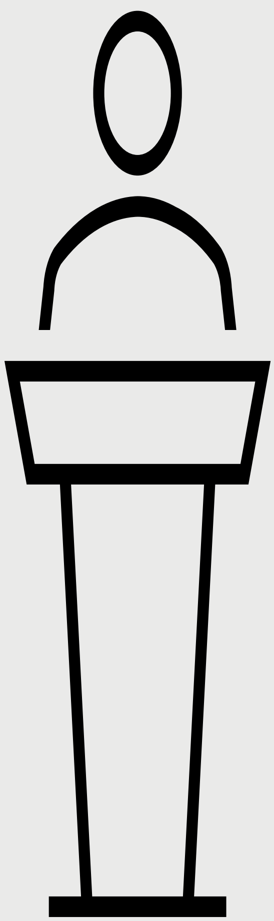
Chapter 08

Technical Presentations

This chapter reviews technical presentations for formal and informal audiences. This chapter addresses the need to consider the audience with respect to the technical content being presented as well as the nature of the presentation type. Key fundamentals for presentational speaking with technical subjects are reviewed as well as how presentations may vary based on the setting, audience and desired outcome.

8.1 Preparing for your technical presentation

As with the previous examples of technical communication involving written documents, oral presentations over technical subjects can also vary greatly based on the audience. However, there is a process which can be followed for any type of presentation , setting and audience. The steps are listed on the right and then expanded on individually.



1. Assess your audience
2. Garner their attention
3. Establish credibility
4. Provide a preview
5. Define the unfamiliar
6. Organize logically
7. Deliver in a polished and flexible manner
8. Summarize

These steps may look different or be emphasized differently for each of the following types of technical presentations, but this process will provide a solid foundation for preparing your work to be displayed and discussed.

Assess Your Audience

You must analyze your audience thoroughly before a technical presentation. Who your audience is dictates how you deliver your information. Before you begin to create presentational content, ask yourself the following questions:

1. *Who will be there?* Is this an audience that has voluntarily chosen to hear you speak about the given topic or is the presentation required? An audience that has self-selected to attend your presentation often has their own motivating interests to listen to the content and can bring a higher level of engagement that those that have been forced to attend. For example, when you are invited to present a proposal to a potential customer, the individuals are wanting to hear how your information can inform a decision they need to make – should they buy your product or hire your firm or accept your bid. If you are doing mandatory training for employees on a new procedure, sometimes employees need to focus on the information to better understand the process they need to follow. However, some trainings may be required to meet regulatory compliance or meet internal compliance standards. In those cases, employees may resent that their time is being spent listening to your presentation rather than doing other tasks. At academic conferences, often times there will be concurrent sessions to choose from, implying that your audience has chosen your presentation based on their interest in the subject matter. This often is accompanied by a higher understanding of the content being presented. As these examples illustrate, simply considering the attendees can give additional insight into how you would organize and craft your presentation. These points will be further addressed in the subsequent sections.
2. *Why will they be there?* Much like the question of "who", why someone will attend your presentation can provide insight into how much prior knowledge, experience, interest and internal motivation each audience member brings to your presentation.
3. *What will they know already?* Knowing who will be in your audience and why they are attending gives you an opportunity in advance to assess prior knowledge of the audience. Building on our previous examples, when preparing a bid for a potential client, they are already very familiar with their own needs. However, they do not know how your company can leverage their resources to meet those needs in an efficient and cost effective manner. When training employees a technique necessary to do a new task, they may not have any previous knowledge on this new process, product, equipment or technique. You may need to start with the most basic information to provide context before executing the training. For compliance related training, you may be presenting information they have previously heard, which can cause them to have lots of previous information but very low motivation to engage with your content or presence. In academic sessions, where an audience has selected to attend your session, there is an implication of personal or professional interest in your topic which often includes some knowledge of the topic as well.

4. *What will they be unfamiliar with?* In contrast to their existing knowledge, it's helpful to think of your own presentation in terms of what is unique, new or interesting. For the previous examples, a company often wants to highlight what separates them from the competition, so you would not only be presenting what you can do, but what your company offers than other competitions might not. This persuasive element adds reasons for a potential customer to select you over other alternatives. For training, it is helpful to point out functions or elements of the training that could be surprising to your audience. This is especially true in mandatory training where employees may not feel much internal motivation to pay attention. For academic sessions, highlighting your focal area can help distinguish how your work differs from others. Your audience may have some familiarity with the general content, but not the same depth in your subject matter expertise. It is helpful to consider what they will know and what they may not know to better streamline your presentation. Many presentations have to be completed in a specific amount of time, making it necessary to keep your content brief where possible.
5. *What will they find compelling (ie: data, methodology, narrative)?* As each of the previous question is answered, you are creating an outline in your mind about where your focus should be to be the most effective presentation for your given audience. By understanding what the audience will find compelling, you can help engage your audience by teasing that content from the very beginning of the presentation or recalling it at other places within the content to keep the most important information in the forefront of your audience's mind.

6. *What do I want them to do with the information they are given?* While the "ask" may seem a fairly intuitive process, it is helpful to clearly understand in your own mind the desired outcome prior to beginning the construction of your content. For example, if you are doing a proposal for a customer, consider where you are within the decision process. If the potential customer or client is seeing a series of multiple presentations over the space of several days, you may not receive confirmation of their selection at the end of your presentation. As such, your presentation should not end requesting that a decision be made. Rather, you would want to end with the potential customer confident in your abilities and clearly understanding how to contact you if they desire additional information or to proceed with your services. In a training session, you may want to end with some method of confirming that the audience has correctly understood the main ideas. This could involve a series of questions to answer using technology such as Quizlet or Kahoot, or having individuals raise their hands to answers questions out loud or even just consider the question in their own heads. For an academic presentation, it may be more critical to understand the results of your work and the next steps.

Content Clarity

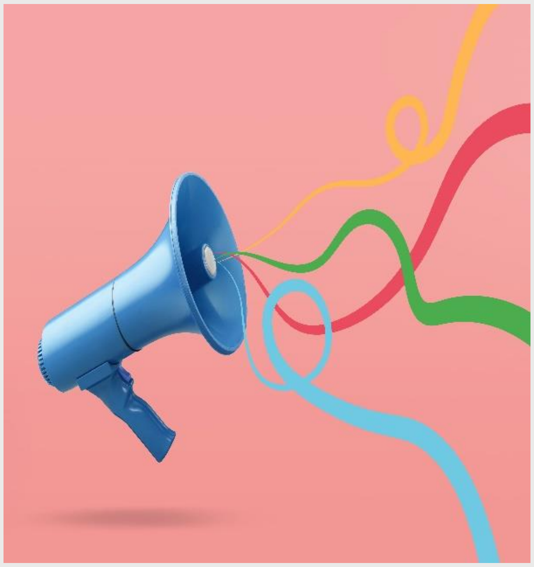
We introduced technical communication as having three critical attributes: to be clear, concise and correct. This holds true for oral presentations as well. Part of the first attribute, clarity, comes from your own knowledge of the material you are presenting to others. Know your content well enough to be able to explain it concisely. Clarity of content involves understanding what is critical content and what information can be added depending on how much time is allotted. As such, your presentation should be able to be condensed into three categories.

1. The first category is just 1-2 sentences. Imagine you are standing at the door of the room where you are presenting and a person asks, "What is this presentation about?" You have 1 -2 sentences to explain what may be a 15-minute academic presentation. You might say something like "This presentation discusses a new use for generative AI in technical writing courses for engineers." With just 1 sentence this person now knows the audience should have an interest in teaching technical writing to engineering students AND have an interest in how AI could be used.

2. Now imagine you are riding the elevator in the conference hotel down to the conference break out rooms and someone sees your name tag says "Presenter" on it. They ask you what you are presenting as the elevator begins to descend. You have maybe 1 minute or so to give the information and potentially encourage them to attend your session. This is a literal "elevator pitch" to a potential audience member. What information might you add given time to say a couple sentences instead of the first example? You might add what types of data will be presented or why people should be interested in AI in education. You might find yourself describing a bit of your subject group or the institution where your work was conducted.

3. Finally, the presentation itself will typically have a time limit from just a few minutes to a full 30-60 minutes. In each of those cases, the presentation should feel intentional and unhurried. When your presentation does not match the allotted time, you can sabotage your work by either leaving out key concepts or boring your audience with a meandering presentation that lacks purposefulness. Even with a full hour, your presentation should remain clear, concise and correct.

Garner their attention



You may have been told to open a speech with a joke to get your audience's attention. While jokes are rarely the appropriate opener in technical presentations, the idea of engaging your audience from the very beginning of your presentation is still a good practice. Your goal is to make sure your audience interested in listening even if they are required to attend. Your choice of opening words can help establish interest and provide context for your audience. If you are presenting information about a safety policy that you think your employees may not be very interested in, the opener could be "Did you know our company lost 850 hours due to workplace injuries last year? That's the equivalent of an entire month of work." That sort of attention grabber helps to support that while your audience thinks they already know the material you are going to present, workplace injuries actually did impact the company last year. Or for my example of AI and technical writing, you might consider an opener such as "Did you know that it is estimated that nearly 30 million white collar jobs in tech industries will be replaced by AI by the year 2030?" That connection could make teaching about Artificial Intelligence seem more consequential to your audience members. Narratives and personal anecdotes can also be an effective way of humanizing a technical presentation. It is important to note that these examples should be relevant to the topic at hand and should be chosen based on your knowledge of the audience, as well as the overall purpose of your presentation.

Establish credibility

It is important to let your audience know who you are: Tell your audience how you are related to your work and the content. You may consider: What/who has brought you here? What work have you completed to be here? Where does your expertise lie?

This is less about proving authority and more about continuing to provide context and orientation to your audience. For example, if you are the only person in your field that has explored a certain topic or you developed a new product or technology, it's helpful for the audience to understand you bring an expertise that cannot be found anywhere else. Or if you are bringing a proposal to a potential client, you should distinguish your role on the team. Are you an engineer who helped develop the proposal and knows all of the technical details of the proposal? Or are you a project manager who has a big-picture perspective of the proposal but may not be able to answer detailed questions of specific aspects of the proposal? Your role helps the audience to have confidence in your presentation and better understand the perspective you bring to the material.

Provide a preview

Basic psychology teaches us that people often remember the first piece of information more readily than information they receive later on. This is called the primacy effect and can be used in your presentation to help your audience recall main concepts through providing a preview at the beginning of your presentation [1]. Hearing the main ideas or the goals of the presentation helps to prime the audience to receive the presentation through a specific lens. If your goal is to have your project team choose between several options, setting the stage at the opening by saying "This presentation is going to compare and contrast multiple vendors so we can select the best solution" your audience will listen to the presentation understanding that they will be expected to select a solution at the end of the presentation. Audience members then listen to each option already making comparisons in their minds. In contrast, failing to provide that information in the beginning, you may find your project team saying "can you review the options again, I wasn't expecting to need to make a decision" and then the time presenting was wasted and must be repeated.

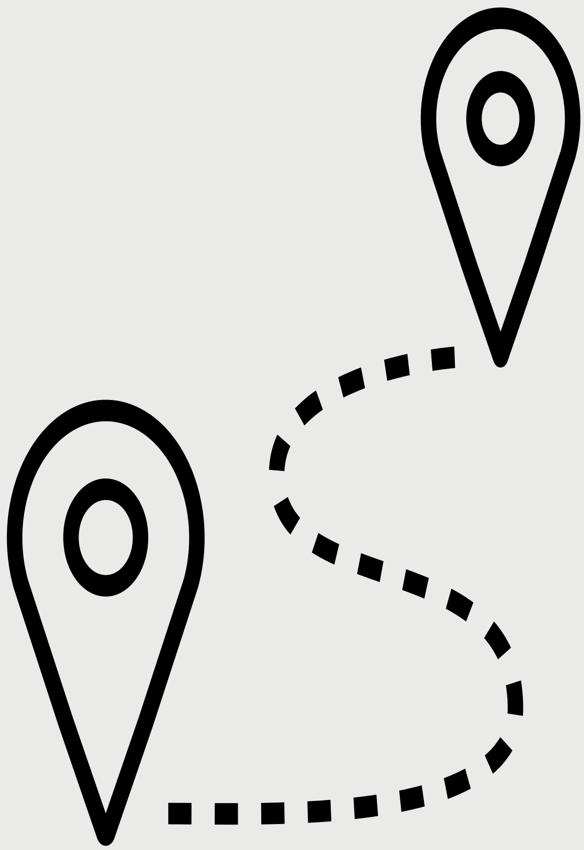
The preview can also aid you as the presenter. By offering direction to your audience about the upcoming content they maintain a sense of orientation and expectation, and you are better able to track your own progress and adhere to your pre-designed content. When crafting your preview, keep in mind: "What is my thesis?" "What am I trying to accomplish with this meeting?" "What do I want the audience to do?" With this in place, both you and your audience will keep the main idea central to the presentational experience.

Define the unfamiliar

Previously you established what the audience will know and not know, based on your audience analysis. Now that you know what they may not know or may find unfamiliar, it is helpful to define your important vocabulary, acronyms, abbreviations, industry specific terms or wording that you may use in a unique way. For example, many people use accuracy and precision as synonyms. But for engineers and scientists, accuracy refers to the relationship between measured data and an established value, while precision refers to repeatability. This distinction may not seem important to some, but in technical fields, this is critical knowledge. If you are presenting data to individuals without a technical background, you may want to define these terms so they do not hear you use them and make faulty assumptions about your meaning.

1. Logical definition: Places the concept to be defined into a category. This type of definition explains the characteristics that distinguish that concept from all other members of the category.
2. Etymological and historical definition: This definition explains how the word was derived, either as linked to some historical event or as drawn from root words in earlier languages.
3. Operational definition: Often used in engineering presentations, this explains how the object or concept referred to works or operates. This could include the steps that make up a process or how the object connects to an overall operation.
4. Defining by negation or opposition: This clarifies a term by explaining what it is not. For a well-rounded example, negation is best combined with other forms of definitions. For example, if you are defining additive manufacturing processes, such as 3-D printing, you may contrast traditional manufacturing like milling or turning which remove material, to 3D printing which layers material on top of itself to create a part through adding layers of filament until the complete part has been formed.
5. Definitions by example: This defines by relating to your presentation to material the audience will likely know. By making frequent use of examples, you provide the audience with the ability to confirm that they understand the material as intended.

While definitions may take time, these definitions add to the clarity of your presentation and can greatly impact the outcome. I was once at a presentation where the speaker kept referring to the DOE. As an engineer, this could mean Design of Experiments (which we explored earlier in this book). As an educator this could mean the Federal or State Department of Education. The speaker was actually talking about a grant from the Federal Department of Energy, but as the application was in a college setting, I spent the entire presentation thinking DOE referred to the Department of Education. It wasn't until the last slide where he included the Department of Energy logo when I realized my error. Suddenly I was trying to remember everything from earlier in the presentation to see how that mistake could change the meaning of everything else he said. My interpretation could have been completely wrong. Your audience will typically assume that they know the correct definition of the terms you use – as the presenter, it is your job to make sure critical terms are defined so that no confusion occurs with your audience.



Organize logically

Regardless of length, your presentation should have intentional design to present the material in a way that keeps the central focus clear and provides the supporting content at times that best facilitate understanding. This can change based on the type of presentation and the nature of the audience. For example, if I am presenting an update to a project team that has been meeting weekly, I might provide a brief summary of work done up to this point only briefly and then address the matter at hand. For a Six Sigma presentation to the executives of a company, reporting out all the work completed and the results, I will start from the beginning of the project initiation but my focus will be the outcomes and next steps

Earlier in the text we reviewed the use of outlines to craft of logical progression through your material. Just like our written documents, oral presentations can greatly benefit from an outline to ensure that each area discussed follows a logical sequence. As you review your notes (or outline or rough draft) ask yourself: Does the roadmap make sense? It can be helpful to receive feedback from someone less familiar with the content, as your audience typically does not have the same level of subject matter expertise as you do.

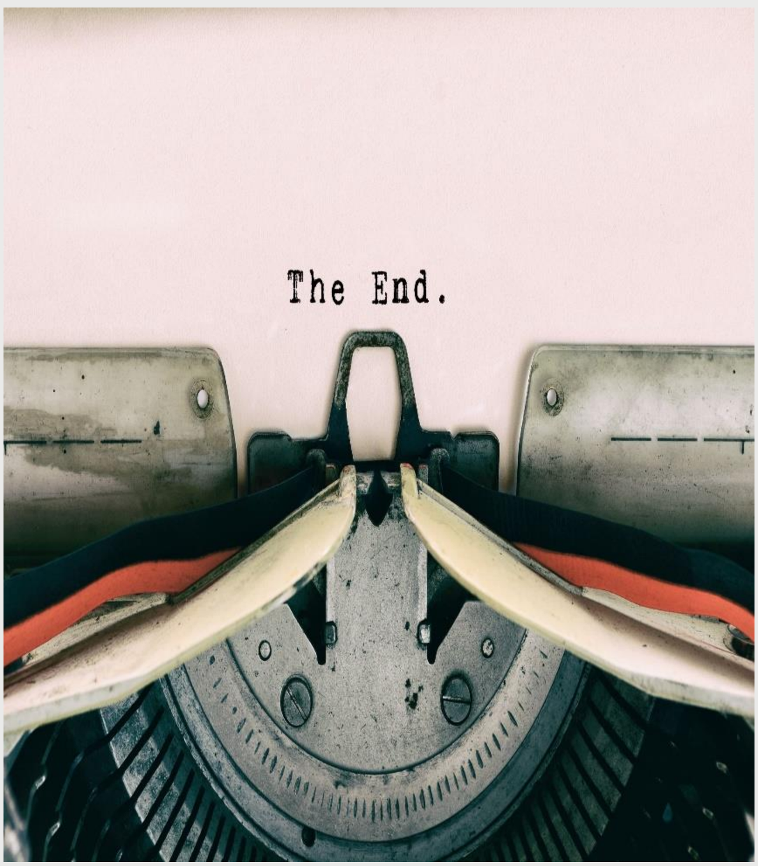
Delivery in a polished manner

While presentations can cause some to be nervous, the best way to steady your nerves is to be confident in your material. You should study your content so that you know your material well enough for your delivery to be both polished and flexible.

1. If you consider a presentation you attended that looked natural and was easy to understand, then you have a good idea of what a "polished" presentation entails. As you deliver the presentation, the audience should have confidence that you are well prepared and comfortable with the material. The more natural and comfortable you look when engaging the audience, the more confidence the audience will have in the material itself.
2. Reciting a memorized script very quickly, or too quietly to be heard, or without making eye contact with your audience can make it difficult for the audience to connect with you and can make the presentation less effective.
3. Flexibility is critical when presenting. As you deliver your presentation, you should look at your audience and use non-verbal cues to see if they are engaged with you and understanding the material. Facial expressions are helpful to identify interest, boredom, confusion and other feelings of your audience. If your audience is looking elsewhere (like their phone, laptops, reading other materials) or talking to each other, there is a strong likelihood that they are not listening to you with the level of attention you desire. If you are flexible in your delivery, you can adjust as needed to reorient their attention or explain things more fully if you see looks of confusion.
4. Presenting to a synchronous audience can be helpful in determining how well your audience is engaged in your content and how well they are understanding and retaining what you share. This can be more difficult over Zoom or other digital meeting platforms. Many individuals have a more difficult time remaining engaged in a large meeting through web-based meeting rooms. It may be helpful to include places to solicit feedback from audience members to help keep the attention of those in the meeting.
5. Most of all, remember that regardless of the size, formality or setting, you are the person most interested in your content when you begin to deliver it. If you don't appear to care about it, neither with your audience. A perceived lack of confidence in yourself or the material hurts the credibility you have with your audience.

Summarize where you've been

Earlier we discussed the "primacy effect" to aid your audience in retaining the most important concepts of your presentation. A the end of the presentation, we want to utilize the "recency effect" which is a cognitive bias that demonstrates that the most recently discussed topics will be retained more clearly than those previously discussed [2]. As such, the end of your presentation must include a summary to help your audience connect the earlier content to the most recent content of your presentation. The longer the presentation, the harder it is for your audience to retain all of the content. Reminding your audience of your central theme and purpose is helpful to ensure they leave your presentation remembering the critical content. This can be done by summarizing the main themes into just a few bullet points or a singular statement or question. If you presentation has an expectation for action (like requesting funding or being awarded a contract from a customer) summarizing the key reasons for the audience to grant your request can aid a positive outcome.



8.2 Types of technical presentations

In the previous section of this chapter, several different types of presentations were provided as examples to illustrate techniques for crafting your presentation. Now we will look at these presentations most common to engineering students, interns and those encountered early in your career.

Informal Presentations

When making informal presentations, whether in an educational or professional setting, you can expect to receive integrated, synchronous feedback and questions throughout the process. As a student, you may also receive constructive criticism on your preparation, delivery and technical content. This may happen when presenting to peers or various faculty, as educational settings are meant to provide feedback for the learning process, in addition to considering the technical matter at hand. In industry settings, you may still receive constructive criticism, especially when you are new to a company or new in your career, as supervisors can aid your professional development at informal presentations, to help you be better prepared for formal settings.

Informal presentations do not require less preparation, but refer to the setting for delivery and the structure of the interaction with the audience. For example, in a training session with line operators, you may be dressed in a production uniform and present standing while individuals stand in a group on the production floor. The material you are conveying may be critical in nature, but the setting is informal. Typically informal presentations are easy to solicit verbal feedback concurrent with your presentation. Or in a project update meeting with your team you may find yourself sitting around a table in your typical business attire, again, soliciting feedback as you present your updates. Your material should be well prepared, clear, concise, correct and follow a logical outline, regardless of formality. In some cases, this can be more difficult than in formal settings where people typically hold all of their comments until the end. In informal settings, you need to make sure you complete the presentation of your material, even when other ideas have been shared. As people are more likely to interject during informal presentations, keeping track of your place and keeping your audience focused on your discussion can be tricky at times. Tips for retaining focus in specific types of settings are included in the descriptions below. Some common examples of informal presentations include:

1. Academic or conference poster presentations: Both students and industry members may find themselves attending academic or professional conferences related to their field. Poster presentations are held in large spaces where individuals stand with a large poster (often 4 foot by 3 foot) that includes information about their work. At these sessions, those attending the conference can wander through the space and stop at those posters that most interest them. While the posters should be crafted to be a stand alone document that does not require narration, at these events, typically individuals will ask you questions rather than standing silently and reading the poster in it's entirety. Often conferences will have provided abstracts relating to each poster so attendees can easily find the posters that are most relevant to their interests. When people come to discuss your work, you need to be prepared to both provide a brief summary and answer any questions the individual may have. Before you begin talking to them, you may want to ask "What do you already know about this?" so that you can use your time effectively both targeting the content they are most interested in as well as emphasizing the main concepts of your work. It is also helpful in these settings to question your audience by asking "What else can I explain?" to fill in any gaps you may have missed.
2. Small group meetings: Depending on your industry and discipline, small group meetings can include peers, supervisors, people who report to you, internal customers, other departments and many others. The small group size often means that offices, common spaces and common use conference rooms can provide adequate space for these types of meetings. In these spaces you might use a projector or have hand-outs or even write on white boards. Whether or not a formal agenda is used, as a presenter you should use some sort of outline or guide to ensure you discuss your topic as thoroughly as required. Having a "parking lot" for other topics or questions that may have been raised during your presentation can aid in completing your discussion without losing the comments raised by the audience while you were speaking.
3. Project updates and staff meetings: These meetings are often a form of small group meetings that occur with a specific group of people on a regularly scheduled frequency. Like small group meetings, it can be a challenge to keep the group attuned to your presentation topic, as oftentimes these meetings include updates from multiple people. Even in materials are not required, handing out an outline of your topic or some other written material can assist in keeping the group on task.

Formal Presentations

Formal presentations can be a little easier to manage, as typically there is little audience interaction prior to an established question and answer period. This allows you as the presenter to move through your content in the order you prepared without worrying about the conversation being sidetracked with tangential topics. However, with less overt interaction, keeping your audience's attention and ensuring your content is correctly understood is more challenging, as you rely on non-verbal cues, discussed in the previous section. Formal presentations also typically have a setting that includes a speaker in front of an audience with formal presentational materials (such as a PowerPoint or similar presentation). This distance can make connecting with your audience more challenging, especially if it is a large group. Several types of formal presentations are described below.

1. Large Group Presentations and Conferences: Whether industry-based or academic in nature, large group presentations can be used to present technical material to a wide audience. These presentations typically use a lecture style where the speaker will discuss their topic in its entirety and then offer time for questions. Often the speaker is a technical subject matter expert presenting to others who have some interest in the field. In professional and academic sessions, attendees can choose which presentations they attend, indicating some internal motivation to learn more about your topic. For other large group settings, like corporate presentations, attendance may be mandatory, but often you will be presenting to those who have basic subject matter knowledge as being a part of that company, division, or industry. This allows you to tailor your material to their prior knowledge and focus on your central message, while academic presentations may include audience members with little prior knowledge of your field.
2. Executive-level Presentations: In these settings, you may be presenting to smaller groups in conference rooms but remain formal due to the nature of your audience. In these settings, the focus is rarely on the detailed technical information but rather focused on the results of your work and the next steps required. Often executive presentations have scheduled lengths and may be integrated into larger meetings, where your presentation is just one of the agenda items for that session. It is not uncommon to be interrupted with very direct questions from an executive level audience and it is critical to be clear about information that you know for certain and other questions that may require follow-up. A common error of new engineers is to try to seem like they know the answer to every question, to project excellence in their field. Unfortunately, this good intention can lead to poor outcomes if you miscommunicate information and must come back to your audience at a later date to clarify your error. These settings can feel intimidating to engineers early in their career. However, extensive preparation and practicing your presentation with your supervisor or a mentor can be very helpful in making sure that the presentation is effective and leaves you in a positive light.
3. External Customer Presentations: These presentations are similar to executive level presentations in many ways but also involve individuals outside your company. In these presentations, it is important to remember to define corporate specific terminology and recognize that the customer may not necessarily share subject matter expertise. For example, if you write code for companies to manage their human resource processes, your audience will likely include those in senior level administration of Human Resources, not other programmers. Or if a company is looking for your company to design a component, it is probably doing so because it does not have this subject matter expertise and requires outside help. It is critical to present your material clearly and presents your company and your work in a positive way. It can make the difference between whether or not your company continued to work with the customer or wins new business.

8.3 Conclusion

Presentational speaking is something that often has an entire course dedicated to learning the best way to present material to various audiences. This chapter cannot teach everything you need to know to successfully present material to a wide variety of situations and audiences. However, hopefully this chapter help to remind you of techniques you had previously learned and see how to apply them in engineering education and professions.

Engineering students may not consider how frequently they will be leading meetings to both internal and external parties throughout their careers. Understanding the best ways to prepare for each presentation, formal or informal, academic or industry–based, can make a difference in how your career moves forward. Presenting material clearly, concisely and correctly to senior level individuals of your company can assist you in future promotions and increased levels of responsibility. Presenting poorly can hinder your professional development and cause your superiors to doubt the quality of your work. With these concepts in mind, you can craft a presentation that will not only effectively communicate to your audience but also demonstrate your competencies in your field.

Up Next

In the final chapter of the text, ethical considerations for engineers will be considered. This includes integrity in the reporting, both in written and oral formats, honesty and accuracy with data and the appropriate handling of information, all which directly connect to technical communications. This reinforces the critical nature of what engineers say, in addition to how it is said.

Chapter 09

Ethical Engineering in Experimental Design and Technical Writing

This chapter addresses the ethical obligation engineers have to society concerning public health and safety through various engineering functions. These can include the dissemination of information, the creation of new products, the building of common infrastructure, the design of spaces, the development of products and may other functions that intersect with the world, the natural environment and global society.

9.1 Engineering Ethics

If someone asked you to define what ethics involve, you might use terms like “integrity” or having a conscience. Perhaps you would think of it in terms of values or morals. For your own personal ethics, you may feel a sense of responsibility to others or a pursuit of fairness. Each of these words touches on ethics. A more formal definition could be [1]:

A set of moral principles; a theory or system of moral values.

Merriam Webster’s dictionary further defines ethics as [1]:

The principles of conduct governing a person or group.

These two definitions hit on several key components that impact engineers:

- That the principles themselves are a system of values. Ethics involves more than just one facet of perspective but rather is a system of values to be applied to every variety of circumstance.
- The principles govern conduct. To put it bluntly, these principles dictate how you act, not necessarily how you think. Ethics involve values that determine actions. Engineers must be concerned about those things that impact how they function as engineers.
- The principles of conduct can govern a group, not just an individual. For engineers, ethics are defined within the system of values on how engineers act within their profession. This means that beyond how an individual might feel or what their personal faith might esteem, engineering ethics are focused on the practice of the engineering profession.

This content is not meant to be holistic to all topics within human ethics but rather centers around the duties and responsibilities of engineers within their place of practice.

9.2 Role of the National Society of Professional Engineers with Engineering Ethics

All licensed engineers in the United States of America are members of the National Society of Professional Engineers (NSPE). This governing body includes an Ethical Review Board in which engineers are held accountable against the NSPE Code of Ethics. This code has been affirmed by all engineers when they receive their license and all licensed engineers must uphold that code. Engineers who are thought to have violated the NSPE Code of Ethics are brought before the Ethical Review Board for further investigation. Those found in violation of the code may receive censure, suspension of their license or even be banned from practice.

The preamble of the NSPE Code of Ethics states the importance of ethical practice in engineering [2].

Engineering is an important and learned profession. As members of this profession, engineers are expected to exhibit the highest standards of honesty and integrity. Engineering has a direct and vital impact on the quality of life for all people. Accordingly, the services provided by engineers require honesty, impartiality, fairness, and equity, and must be dedicated to the protection of the public health, safety, and welfare. Engineers must perform under a standard of professional behavior that requires adherence to the highest principles of ethical conduct.

The words 'honesty", "integrity", "fairness", "equity", demonstrate the system of values that any society might cite when developing a code of conduct. But for engineers, the focus is plain. The preamble focuses on dedication to "public health, safety and welfare". This is due to the role engineers play in society. I challenge you to think of a process, product, or societal system that did not involve an engineer. Consider for a moment an operating room in a hospital: The family drove a car (which was designed and manufactured by engineers) over roads or bridges or tunnels (designed by engineers) to a building (designed by engineers), were admitted with software systems (designed by engineers) and moved through a series of processes to end up in a surgical suite. Every piece of equipment in that surgical suite was designed by an engineer. An engineer oversaw the manufacturing of the devices. An engineer designed and built the operating room where the work is taking place. If a surgical robot is assisting, who programmed that robot? Who created a robot capable of doing precision work for surgical procedures? An industrial engineer assisted in creating the protocols for arranging the tools and the process used in handing the surgeon each material required. I could go on like this for pages upon pages on every single ordinary thing people do each day all over the world. Engineers are continually impacting public health, safety and welfare. It is for our world, for our societies, for our own families, that we must uphold the highest levels of integrity in our practice.

The fundamental cannons of the NSPE Code of Ethics read [2]:

Engineers, in the fulfillment of their professional duties, shall:

1. *Hold paramount the safety, health, and welfare of the public.*
2. *Perform services only in areas of their competence.*
3. *Issue public statements only in an objective and truthful manner.*
4. *Act for each employer or client as faithful agents or trustees.*
5. *Avoid deceptive acts.*
6. *Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.*

Each of these fundamental cannons is discussed in greater detail in the code's Rules of Practice, which provides specific instructions that relate to every form of engineering, regardless of discipline or industry.

For example, as part of cannon 3 "Issue public statements only in an objective and truthful manner" there is a subsection [2]: *Engineers may express publicly technical opinions that are founded upon knowledge of the facts and competence in the subject matter.*

These subsections aim to address many areas of how the fundamental moral principles apply to the work of an engineer. These are not lofty ideals or general concepts. These subsections give specific guidance on how to interact in a given situation.

9.3 Serving Society as a Professional Engineer

It may be hard to imagine exactly how these guidelines could impact you personally, especially as a student. Ethical choices in your life right now as an engineer involve issues of academic integrity such as not cheating on an assignment or using materials posted on the internet to complete your work faster. In chapter 2 we discussed the ethical use of artificial intelligence when writing and how while some uses of AI can be helpful, not all of the uses of AI follow ethical conduct standards.

Engineers interact with all types of ethical situations, such as:

- Public safety
- Fairness
- Information security or intellectual property
- Hiring practices
- Conflicts of interest

Ethics in Practice

Below are some scenarios of experiences I've either personally faced or had my peers face within the first 12 months of their work.

Scenario 1

Your relative owns a business that could bid on a job that you are responsible for finding the appropriate contractor. Your relative has a good match for your company needs and does not have the same last name as you, making it impossible for anyone to know that you are related to them. While your bidding policies require 3 separate bids, as the engineer in charge, you know the scope of work and price point that would make a competitive offer to beat the other potential contractors. Sharing this information would make it easy to award the job to your family without anyone knowing what had occurred. Is this a conflict of interest or does this fall under the category, "it's not what you know, it's who you know".

In this case, my friend's older sister went to her sibling asking that her husband be hired for the work. They needed money and her little brother could really help them out if he awarded them the business. Only six months on the job, freshly graduated from their bachelor's degree in civil engineering, my friend was an utter wreck. It didn't feel right, but his sister was really pressuring him. He knew other people had done similar things and gotten away with it. No one would question him if he kept his mouth shut.

What would you do?

Scenario 2

You find an error in a quality record. The procedure would have you stop production immediately and perform tests on the suspect material to ensure it is ok, but the employee who made the mistake is very experienced and promises that they simply entered the data incorrectly. He insists that there is nothing wrong with the product. Your manager, when he hears which operator wrote it down wrong, shrugs and says, "I'm sure everything is fine." But it is your name on the record validating that every step of the process was performed correctly. Is this truly an issue worthy of stopping the line or is this an example of using common sense; there's no need to lose all that money by stopping production.

This took place just one month after I started working as a Production Supervisor in a pharmaceutical manufacturing facility. We were making a product to help treat children with terminal cancer. What we manufactured would be injected into the IV of a child who was dying. Should I just assume everything was ok because the worker said so? Should I follow the guidance of my boss and let it go?

What would you do?

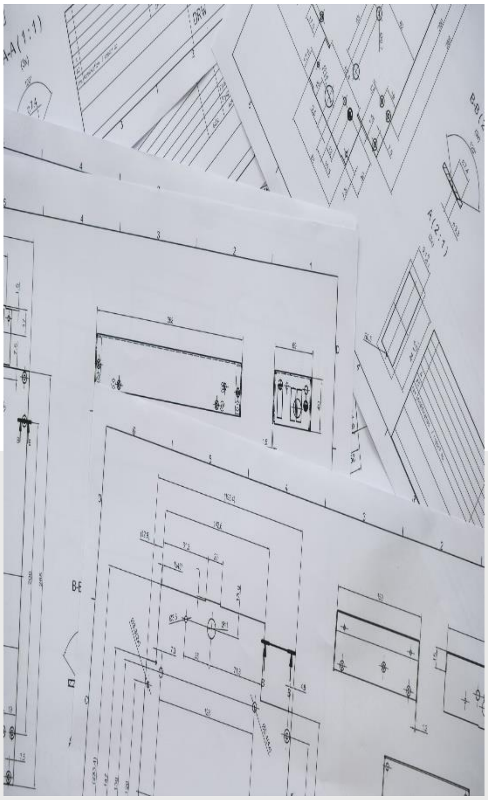
Scenario 3

You find a mistake in a technical drawing for a project already underway but you are sure the customer does not know of the error. The project is nearing completion and to fix this issue would delay the work and cost a lot of money to fix. You take it to your boss who then double checks your work and agrees that you have found a mistake. Later you learn nothing was done to correct it and the project is moving forward with the error. Do you go over their head and tell someone higher up the chain of command or do you simply think "I told my supervisor. If they don't do the right thing, that's on them, not on me."

This was the real case situation for a mechanical engineer who had graduated and gone to work at the same company he had interned at. Although he felt he had a good working relationship with his boss, he really felt the project shouldn't continue without the customer knowing the issue. He had the least seniority on the team and had already been told to not worry about it, but he still didn't feel good about it.

What would you do?

These scenarios are real scenarios that raise the question of personal ethical responsibility, corporate responsibility and how someone very quickly find themselves in a morally ambiguous situation. You will be held accountable to your actions as an engineer by the National Society of Professional Engineers. What must you do to ensure you feel confident in your actions adhering to the code?



9.4 Ethics in engineering professional organizations

The National Society of Professional Engineers is not the only organization that provides guidance for ethical conduct in engineering.

Engineering Education

The professional formation of engineers has long included the recognition of the ethical impact of engineering on society at large. When reviewing the history of formal evaluation of social competencies in engineering, a significant milestone occurred in 1997, when the national accrediting board for engineering programs, ABET (Accreditation Board for Engineering and Technology) created the Engineering Criteria 2000 (EC 2000). These criteria, which have continued to evolve over the last 20+ years, documented specific learning outcomes required of engineering educational programs to remain accredited, one of the two pathways for engineering graduates to pursue a Professional Engineering (PE) license. In this document, future engineers had to demonstrate proficiencies in multidisciplinary teams, engineering in a global context and an understanding of contemporary issues, among other technical skills [4]. This "a–k" (updated to 1–7 in 2019) criteria became a foundational element of learning objectives in engineering coursework and curriculum for all accredited engineering institutions since 2000 [5]. Furthermore, this act was lauded by the National Academy of Engineers (NAE), in their report "Adapting Engineering Education to the New Century" in which the academy noted the increasing disparity between engineering practice and engineering education. In their report, they stated that while engineering faculty had previously demonstrated a resistance to change, the increasing interdependencies of societal needs and technological solutions required engineering education to better prepare students for multidisciplinary work in a global context [6]. The call to action raised by the NAE and other organizations has been echoed by engineering education researchers ever since, with the seminal work of Donna Riley recognizing that engineering education continues to train future engineers in traditions of consumerism, individualist beliefs and functions within existing power structures, rather than within societal contexts [7]. The highly cited work of Cech notes that disengagement with social concerns is often associated with engineering due to prevailing perspective of engineering culture that suggests engineering is neutral, non–political and that technical skills should be held separate from social tasks [8]. The ideologies of technical/social dualism, individual meritocracy and depoliticization exclude public welfare from the engineering domain. More recent studies evaluating engineering education research and current engineering curriculum note that engineering faculty maintain that humanities studies are irrelevant to engineering education and present engineering problem solving devoid of social context [9].

The National Academy of Engineers continues to challenge future engineers to view taking on the global "Grand Challenges of Engineering," including one of the four main themes of engineering innovation to include enhancing the "joy of living" for the global community [10]. Roscoe et al. stated that "the solution for many pressing challenges requires engineering innovations that are guided by a keen awareness of human goals, needs, abilities and limitations" (pg. 404) [11]. This is echoed by other researchers who affirm that these skills are not innate but must be intentionally integrated into the curriculum for students to practice engineering from these perspectives

The Accreditation Board for Engineering and Technology (ABET) is the accrediting body over engineering programs around the nation. As mentioned previously, their adoption of 7 program criteria that all engineering programs should align to included information about professional ethics in a global context. Namely, their standards for accreditation include a criteria 3 Student Outcome (Outcome category 4) which states the engineering students should demonstrate "an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgements which must consider the impact of engineering solutions in global, economic, environmental and societal context." [5]

This reflects that training is required in ethical judgements as engineering students also learn technical content foundational to becoming successful engineers. As engineering students learn how to use their technical skill set to influence the world around them, they must reflect on how that influence can have a positive impact in global, economic, environmental and societal contexts. This information must be intentionally communicated to become effective in engineering practice and that process begins in engineering education.

Other Professional Organizations

Many additional organizations that address specific engineering disciplines. For example, the Institute of Industrial and Systems Engineers endorses both the ABET Code of Conduct and the NSPE Code of Ethics, blending the two documents to form a unique code for their own members that adds fundamental cannons about professional development and training of new engineers. The Society of Manufacturing Engineering (SME) bases their Code of Ethics in part on the NSPE Code of Ethics but add content specific to global manufacturing. Their document includes a fundamental principle which reads [12]:

The certified professional is dedicated to improving not only the manufacturing process, but also enterprises worldwide. This includes striving to instill a sense of concern and awareness, throughout the community, of public health, safety, conservation, and environment issues that are related to the practice of the profession, and through the application of sound engineering and management principles. Certified professionals realize that in carrying out this responsibility their individual talent and services can be more effective when combined with continuing education.

This inclusion of management practices and global enterprises reflects the nature of the various management roles for engineers in global corporations.

The Institute of Electrical and Electronic Engineers (IEEE) has similar guidelines to the NSPE Code of Ethics but adds discipline specific language, such as their professional activity requirement to [13]:

to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, to be honest and realistic in stating claims or estimates based on available data, and to credit properly the contributions of others;

The American Society of Mechanical Engineers (ASME) follows much of the language of the NSPE Code of Ethics but adds several additional cannons including [14]:

Engineers shall consider environmental impact and sustainable development in the performance of their professional duties.

This inclusion of environmental responsibility provides explicit language of how engineers impact the natural world, not only man-made systems. The American Society of Civil Engineering (ASCE) has an entire section of their Code of Ethics dedicated to the natural world in addition to content specific to clients or customers, their company and their peers in civil engineering [15].

Each profession has adapted the NSPE Code of Ethics but increased the level of responsibilities of engineers in ways that directly impact their specific discipline. Regardless of the profession, industry or discipline you align with after graduation, ethical behavior as an engineer is a critical professional skill to ensure your success and the safety of our societies and our world.

9.5 Ethical Failures of Modern Engineering

Case Studies

The National Society of Professional Engineers published case studies every year highlighting the cases brought before the Ethical Review Board and includes the relevance of the sections of the Code of Ethics in addition to the decision made by the committee. While all identifying information is removed, the basic details of each circumstance is presented to help train engineering students and young engineers about the potential ethical pitfalls that can happen in the workplace. No one sets out to be morally corrupt, but there are times when little questionable decisions can result in catastrophic consequences.

Engineering Failures

As this is being written Boeing is plagued by design failure after design failure, with whistleblowers being found dead and lawsuits arising all over the world. The United States Congress has opened several investigations against them and the Federal Aviation Administration (FAA) has had to ground numerous Boeing model planes due to reliability issues that have resulted in crashes, damaged property, injured individuals and even death. Whistleblowers have made public information about Boeing failing to address known safety issues and engineering design failures. Boeing has operated aircraft that were not properly maintained with pilots not properly trained on newly installed systems. Records have been falsified to keep action from being taken against the company. These issues are unfolding every day in the news, causing flight cancellations, delays and crashes all over the world. For every system failure, every design flaw, every falsified document, an engineer was involved at some point.

Or how about other issues like the levee failures in New Orleans during Hurricane Katrina, the explosion of the Space Shuttle Challenger or the devastation caused by the fire on DeepWater Horizon oil drilling platform? These issues all share one thing in common. There is internal documentation from the engineering forms that show engineers knew a problem existed and it was decided to proceed with the plan anyway. Each of these disasters which resulted in numerous lives lost and environmental damage that has taken decades to undo could have been prevented. Building and bridges collapsing, train derailments, consumer products spontaneously combusting, safety systems failing in computer control automobiles and countless other issues continue to make front page news. But behind every news article is an engineering who made a mistake or saw a mistake and was ignored. The reason engineering ethics matter is because no amount of money can bring back a single soul on earth.

Conclusion

It is hard to project where you will first be tested as an engineer in areas of ethical practice. For some, it happens just months after graduation. Others may go most of their career without facing an issue. But as engineers, each one of us has responsibilities to those around us, the world at large and the unexplored territories of the deep ocean and far reaches of space to conduct ourselves adhering to the highest levels of moral integrity and ethical responsibility. Your life may not depend on it, but someone else's does.

References

Chapter 1

[1]"UW-Madison Writer's Handbook," *The Writing Center*. https://writing.wisc.edu/handbook/

[2]"Museo Casa Blanca," *Discover Puerto Rico*. https://www.discoverpuertorico.com/profile/museo-casa-blanca/8488

[3]"National Register of Historic Places / City of Evansville," *www.evansvillegov.org*. https://www.evansvillegov.org/city/topic/index.php?topicid=1276&structureid=128

[4]Aaron, "The Ancient Roman Pantheon Is The Oldest Building Still In Use, Here's The Fascinating Story Of Its Survival," *TheTravel*, May 20, 2023. https://www.thetravel.com/the-story-of-the-pantheon-rome/#:~:text=The%20Pantheon%20of%20Rome%20is (accessed May 11, 2024).

[5]Cleveland Clinic, "Viruses: What They Are & How They Work," *Cleveland Clinic*, Mar. 29, 2023. https://my.clevelandclinic.org/health/body/24861-virus

[6]Nate, "35 Funny Homophone Comics Where Words Collide In The Funniest Of Ways By Bruce Worden," *Pleated Jeans*, Dec. 26, 2023. https://pleated-jeans.com/2023/12/26/funny-homophone-comics-bruce-wordenfunny-homophone-comics-bruce-worden/ (accessed May 12, 2024).

Chapter 2

[1]"How Ontrack Recovered the Data from Space Shuttle Columbia," *Ontrack*. https://www.ontrack.com/en-us/blog/kroll-ontrack-space-shuttle-columbia (accessed May 11, 2024).

Chapter 3

[1]National Geographic, "Roman Aqueducts | National Geographic Society," *education.nationalgeographic.org*, Sep. 29, 2022. https://education.nationalgeographic.org/resource/roman-aqueducts/

[2]"Leonardo Da Vinci Inventions," *Leonardo Da Vinci Inventions*, 2014. https://www.da-vinci-inventions.com/aerial-screw

[3]A. Van Helden, "Galileo | Biography, Discoveries, & Facts," *Encyclopædia Britannica*. Aug. 24, 2022. Available: https://www.britannica.com/biography/Galileo-Galilei

[4]R. S. Westfall, "Isaac Newton | Biography, Facts, Discoveries, Laws, & Inventions," *Encyclopaedia Britannica*. Oct. 03, 2018. Available: https://www.britannica.com/biography/Isaac-Newton

[5]M. Kaku, "Albert Einstein | Biography, Education, Discoveries, & Facts," *Encyclopedia Britannica*. Sep. 20, 2018. Available: https://www.britannica.com/biography/Albert-Einstein

[6]H. L. Librarians, "LibGuides: Qualitative Study Design: Methodologies," *deakin.libguides.com*. https://deakin.libguides.com/qualitative-study-designs/methodologies
[7]"The Big Bang Theory: What Are The Main Characters' Jobs?," *ScreenRant*, Apr. 09, 2021. https://screenrant.com/big-bang-theory-every-main-character-career/
[8]B. Ward, "Brick Geometry Bricks by the Bay 2018 Santa Clara, CA." Accessed: May 11, 2024. [Online]. Available: https://www.brickpile.com/wp-content/uploads/2018/07/brick-geometry-bbtb2018.pdf
[9]Chris Simms, "Occam's razor," *New Scientist*. https://www.newscientist.com/definition/occams-razor/
[10]DORITOS® Nacho Cheese Flavored Tortilla Chips | Doritos, "DORITOS® Nacho Cheese Flavored Tortilla Chips | Doritos," *Doritos.com*, 2020. https://www.doritos.com/products/doritos-nacho-cheese-flavored-tortilla-chips
[11]"Section 2.20. Scales A. Application." Accessed: May 11, 2024. [Online]. Available: https://www.nist.gov/system/files/documents/2024/01/13/NIST%20HB%2044%202024%20Section%202.20%20Scales.pdf
[12]"Extra Creamy," *reddiwip*. https://www.reddiwip.com/dairy-whipped-topping/extra-creamy
[13]T. Helmenstine, "What Is the Difference Between Accuracy and Precision?," *Science Notes and Projects*, Apr. 15, 2014. https://sciencenotes.org/what-is-the-difference-between-accuracy-and-precision/

Chapter 5

[1]"Pollution Control & Smoke Clearance in an Underground Carpark Task Objectives." Available: https://jesmondengineering.com/wp-content/uploads/2022/04/Case-Study-Car-Park-Pollution-Control-Smoke-Clearance.pdf

Chapter 6

[1]"The History and Evolution of Manufacturing – Interdisciplinary Professional Programs – UW–Madison," *Wisc.edu*, Nov. 14, 2024. https://interpro.wisc.edu/the-history-and-evolution-of-manufacturing/
[2]*Digitaldocumentsdirect.com*, 2024. https://www.digitaldocumentsdirect.com/wp-content/uploads/2023/10/sop-template-ms-word-02.webp (accessed May 11, 2024).
[3]"White paper: Customization in the Food and Beverage Industry," *siemens.com Global Website*. https://xcelerator.siemens.com/global/en/industries/food-beverage/exclusive-area/whitepaper-individualization.html (accessed May 11, 2024).
[4]"Designing the Workplace for Social Safety and Well-being | Corgan," *www.corgan.com*, Nov. 01, 2022. https://www.corgan.com/news-insights/2022/designing-the-workplace-for-social-safety-and-well-being (accessed May 11, 2024).
[5]"ABOUT HYPERLEDGER." Accessed: May 11, 2024. [Online]. Available: https://thatwhitepaperguy.com/wp-content/uploads/2020/05/Hyperledger-Blockchain-Performance-Metrics.pdf
[6]*Smartsheet.com*, 2024. https://www.smartsheet.com/sites/default/files/styles/900px/public/2022-06/IC-Healthcare-Six-Sigma-Project-Charter-Template-Example_WORD.png?itok=PhLKuJkh (accessed May 11, 2024).

[7] *Yumpu.com*, 2024. https://img.yumpu.com/24239394/1/500x640/engineering-change-notice-maxim.jpg (accessed May 11, 2024).
[8] *Windows.net*, 2024. https://fdotwww.blob.core.windows.net/sitefinity/images/default-source/content1/traffic/itsfm/images/qualityauditpics/itsfm-data-collection-audit-report-template.png?sfvrsn=5d503d5e_8 (accessed May 11, 2024).

Chapter 7

[1] Li, N., Ely, S., & Laux, C. (2017). How to use lean Six Sigma to improve service processes in higher education: A case study.
[2] Ely, S. J.; Hill, A. J., & Sparks, K. M. (2023, June), Increasing Contextualized Social Awareness through Multidisciplinary Teams in Global Service-Learning Projects Paper presented at 2023 ASEE Annual Conference & Exposition, Baltimore , Maryland. 10.18260/1-2--43661
[3]*Legaltemplates.net*, 2024. https://legaltemplates.net/wp-content/uploads/request-for-proposal-template.png (accessed May 11, 2024).
[4]*Canva.com*, 2024. https://marketplace.canva.com/EAFMoT5m8hs/1/0/1131w/canva-project-general-proposal-9N6ZStU97Z0.jpg (accessed May 11, 2024).
[5]*Okepscor.org*, 2024. https://www.okepscor.org/sites/default/files/u6/Summer%202023.jpg (accessed May 11, 2024).

Chapter 8

[1] The Decision Lab, "Primacy effect - Biases & Heuristics | The Decision Lab," *The Decision Lab*, 2019. https://thedecisionlab.com/biases/primacy-effect
[2] K. Cherry, "How Does the Recency Effect Influence Memory?," *Verywell Mind*, May 11, 2022. https://www.verywellmind.com/the-recency-effect-4685058

Chapter 9

[1]Merriam-Webster, "Definition of ETHIC," *Merriam-webster.com*, 2024. https://www.merriam-webster.com/dictionary/ethic
[2]National Society Of Professional Engineers, "NSPE Code of Ethics for Engineers," *National Society of Professional Engineers*, Jul. 2019. https://www.nspe.org/resources/ethics/code-ethics
[3]"Criteria for Accrediting Engineering Programs, 2024 - 2025," *ABET*. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2024-2025/
[4] ABET, "ABET History", About ABET, October, 2021. [Online]. Available: https://www.abet.org/about-abet/history/ [Accessed: October 30, 2022].
[5] J. Ventura, "Accreditation Criteria for Engineering Programs," in *Proceedings of the 2003 ASEE Annual Conference. Nashville, TN, USA,* June 22-25, 2003, 3560 pp. 1-8.
[6] National Academy of Engineering, "*Educating the Engineer of 2020: Adapting Engineering Education to the New Century",* Washington, DC: The National Academies Press, 2005.
[7] D. Riley, *Engineering and Social Justice,* Williston, VA: Morgan and Claypool Publishers, 2008.

[8] E. Cech, "Culture of disengagement in engineering education?," *Science, Technology and Human Values,* vol. 39, no. 1, pp. 42-72, 2014.
[9] C. Vargas-Ordonez and M. Hynes, "Engineering design and social justice: a systematized literature review," In Proc. American Society for Engineering Education, 2020.
[10] National Academy of Engineers, "NAE Grand Challenges for Engineering", Engineering Challenges, 2022. [Online]. Available: http://www.engineeringchallenges.org/challenges.aspx [Accessed: October 27, 2022].
[11] R. Roscoe, D. Becker, R. Branaghan, E. Chiou, R. Gray, S. Craig, R. Gutzwiller and N. Cooke, "Bridging Psychology and Engineering to Make Technology Work for People," *American Psychologist.* vol. 74, no. 3, pp. 394-406, 2019.
[12]"Code of Ethics." Available: https://www.sme.org/globalassets/sme.org/code-of-ethics.pdf
[13]IEEE, "IEEE Code of Ethics," *ieee.org*, Jun. 2020. https://www.ieee.org/about/corporate/governance/p7-8.html
[14]"Ethics in Engineering," *www.asme.org*. https://www.asme.org/about-asme/governance/ethics-in-engineering
[15]American Society of Civil Engineers, "Code of Ethics," *www.asce.org*, Oct. 26, 2020. https://www.asce.org/career-growth/ethics/code-of-ethics
[16] FAA, "Updates on Boeing 737-9 MAX Aircraft | Federal Aviation Administration," *Faa.gov*, Dec. 05, 2024. https://www.faa.gov/newsroom/updates-boeing-737-9-max-aircraft
[17] National Weather Service, "Hurricane Katrina - August 2005," *National Weather Service*, Aug. 2005. https://www.weather.gov/mob/katrina
[18] "genindex.htm," *www.nasa.gov*. https://www.nasa.gov/history/rogersrep/genindex.htm
[19] EPA, "Deepwater Horizon – BP Gulf of America Oil Spill," *US EPA*, Sep. 12, 2013. https://www.epa.gov/enforcement/deepwater-horizon-bp-gulf-america-oil-spill