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Lexis in chemical engineering discourse: Analyzing style in chemical engineering research articles through a rhetorical lens

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LEXIS IN CHEMICAL ENGINEERING DISCOURSE: ANALYZING STYLE IN CHEMICAL ENGINEERING RESEARCH ARTICLES THROUGH A RHETORICAL LENS

By

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ABSTRACT

This study examines the style of chemical engineering research articles to discover stylistic trends that may be applicable to authors looking to publish their own research. Rhetorical stylistic analysis was used as a research method to allow for thorough analysis of all articles in the sample. Ten research articles from the two prominent chemical engineering journals were chosen using specific criteria to constitute a sample of articles that could most accurately represent the population of chemical engineering research articles. Each article was then analyzed line by line to identify markers of chemical engineering research article style, including the following:

- Use of voice
- Examples of figurative language
- Sentence variety, length, readability
- Use of dependent clauses as a method of amplification
- Paragraphing
- Kind of diction

The small sample size prevented generalization of all the conclusions to the overall population of chemical engineering research articles, but some major trends were identified in the sample. Chemical engineering research article authors prefer sentences with no more than two clauses, actively use figurative language to achieve their communicative goals, introduce passive voice as a tool to maintain objectivity, and often use simple sentences to convey their ideas.

ACKNOWLEDGMENTS

Taking on the task of writing a thesis is no easy feat, but with proper guidance the task is no longer insurmountable. I would like to thank the members of my thesis committee—Drs. Malone, Wright, and Reardon—for their help in guiding me to the finish line that seemed impossible to cross.

TABLE OF CONTENTS

Page

LIST OF ILLUSTRATIONS

Page

LIST OF TABLES

Page

1. INTRODUCTION

Science is not equivalent to engineering. Engineers study science, engineers apply science, and engineers often work as scientists. However, engineering is not directly equivalent to science. While science explains what is, engineering creates what has never been (Ahearn, 2000, p. 59). The intricate relationship between science and engineering often blurs the boundary between the knowledge base of each, and this territorial murkiness unfortunately translates to the study of communicative practices in each discipline.

Ahearn (2000) admitted that engineering communication has largely been considered a subset of scientific communication, and, as a result, little attention has been given to engineering communication as a unique field of study (p. 57). Much attention has been paid to the role of scientific communication in the practice of science. Gross, Harmon, and Reidy (2002) studied the transition of communicative practices in scientific discourse over time. Fahnestock (1999) unearthed a plethora of exemplars for the cognitive use of figurative language in scientific discourse. Even physicist, Vande Kopple (2002), commented on the transition of spectroscopic articles from the dynamic, which focuses on actions, to the synoptic style, which focuses on things. This is by no means an exhaustive list of major research in scientific communication or the rhetoric of science, but these researchers show a tendency for communication researchers to favor scientific communication practices over engineering communication practices.

While explaining the role of rhetorical style in scientific misunderstandings, Reeves (2005) stated that "scientists are eager for scholars in communication fields to investigate what is often just as frustrating as failure in the laboratory – the failure to communicate, the failure to understand, the failure of language" (p. 267). This is undoubtedly true of scientists, but the same need to understand the discourse of their field is true of engineers. When Mathes (1972), a composition instructor by trade, was presented with the opportunity to teach scientific writing to engineering seniors and graduate students, he was initially hesitant, but after three semesters of teaching, he provided three axioms that help explain the relationship between engineering and rhetoric. These axioms characterize the relationship between engineering and communication and also illustrate how an understanding of the communicative practices of engineering can benefit engineering researchers looking to publish their research. The three axioms presented by Mathes (1972) were:

- Poor rhetoric signals poor technical knowledge
- Poor rhetoric manifests unscientific thinking
- Poor rhetoric demonstrates a lack of concern for engineering values

Mathes' (1972) axioms were based on his own observations in the classroom, but he was able to provide examples for each of his axioms. Each axiom illustrates how the rhetorical strategies of the engineering author affect the readers interpretation of his "perception of reality," the appropriateness of his methods, or the efficacy of his ability to select the most pragmatic solution to a problem (p. 122).

Halloran (1971) stated that engineers need to understand how to communicate with the public due to the necessary relationship that the two groups share. According to

Halloran (1971), “ordinary citizens” are arguably the most affected by engineering decisions and should therefore be made aware of the engineering principles that guide these decisions. Halloran (1971) concluded that a study of the communicative practices used by engineers to achieve this goal could allow for more effective dialogue between the public and engineering communities. Although Halloran (1971) advocated the use of rhetoric as a process to help engineers better communicate with the public, his suggestions are also applicable to engineering researchers who use research articles to communicate with their peers (p.23). Gross, Harmon, and Reidy (2001) stated that scientific research articles are “an effective means of securing the claims of science and an effective medium for securing the knowledge it creates” (p. ix). Therefore, the research article is an appropriate place to begin studying the communicative practices of engineering researchers.

My thesis is not the first to study engineering communication as separate from scientific communication. However, it does aim to provide insight into engineering communication through rhetorical stylistic analysis of engineering research articles in prominent chemical engineering journals. Fahnestock (2005) argued that effective language analysis should ideally include both aggregate and selective data (p. 282). Aggregate data from a large sample helps rhetoricians identify trends in communicative practices, while selective analysis of individual instances helps rhetoricians understand the rhetorical motives behind the writing choices made by authors. My thesis applies that framework to the analysis of rhetorical style in chemical engineering discourse by using aggregate data from several chemical engineering research articles to identify

communicative trends and selective analysis to explain the authors' rhetorical uses of those trends.

1.1. DEFINTION OF STYLE

Defining style is no easy task. However, *Silva Rhetoricae* managed to provide a working definition that captures the importance of style in rhetoric:

> Style concerns the artful expression of ideas. If invention addresses what is to be said; style addresses how this will be said. From a rhetorical perspective style is not incidental, superficial, or supplementary: style names how ideas are embodied in language and customized to communicative contexts. (*Silva Rhetoricae,* n.d.)

Aristotle (1991) stated that style to be good must be clear and appropriate and Cicero summarized the work of Aristotle and Theophrastus to identify four virtues of style: purity, clarity, propriety, and ornamentation (as cited in Kennedy, 1994, p. 85).

Responding to a quote about propriety and style from Cicero, Crowley and Hawhee (2004) stated that "achievement of an appropriate style requires rhetors to pay attention to the conventional rules for verbal behavior in a given context, rules that have been laid down by their culture." (p. 283). Contextual rules that guide the writing style of a genre are also present in scientific and engineering communication.

Kirkman (2005) hinted that a conventional writing style specific to scientific and engineering writing exists. Respondents to surveys conducted by Kirkman (2005) consistently stated that papers that ignore "passive, impersonal" style are "unacceptable" by a group he refers to as "they" (p. 129). "They" most likely refers to the evaluators of scientific writing, but regardless of whom the term refers to, "they" determine the

accepted style of scientific and engineering writing. This implies that the authors of scientific and engineering writing are indeed aware of a conventional style of writing that they should aim to match.

Campbell (1992) also emphasized the notion that authors communicate with an implicit understanding of the "arbitrary conventions" associated with their discipline (p. 135). However, what are these conventions? The aim of my thesis is to provide insight into the stylistic conventions that chemical engineering researchers use to communicate among themselves.

When discussing style, we must also draw a distinction between it and grammar. Grammar and style share an intricate relationship that often causes difficulty when trying to distinguish between the two. Fortunately, Corbett and Connors (1999) provided a distinction that readily applies to this study. According to Corbett and Connors (1999), grammar deals with how writer's use language, specifically words, to form meaning, while style deals with the most effective use of words to craft meaning (p. 340). Style draws upon grammar to construct meaning, but where grammar is concerned with the rules that govern language, style is concerned with the available means of communicating within a language.

1.2. RHETORICAL STYLE IN CHEMICAL ENGINEERING JOURNAL ARTICLES

The significance of any professional body is readily attributed to the quality of its publications (Freshwater, 1997, p. 48). This significance is largely due to the role of scientific and engineering research articles as the single most important means of communicating knowledge within a discipline. Scientific research articles serve as a

medium for the discussion, proposal, and often critique of novel ideas, and Gross, Harmon, and Reidy (2001) support this claim in the introduction of their research on the communication of science:

> Against widespread opinion to the contrary, we contend that the current scientific article is, on the whole, an accurate reflection of the world as science conceives it, an effective means of securing the claims of science, and an effective medium for securing the knowledge it creates. (p. ix)

Because of the importance of scientific, as well as engineering, research articles, the authors of these articles should be presented with the conventional markers of style specific to their disciplines. This information would ease the anxiety and difficulty often associated with the translation of experimentation to text within a research article (Kirkman, 2005, p. 129). Unfortunately, the information available to chemical engineering researchers regarding the style of these articles is lacking. Campbell (1992) commented on this lack of information regarding style when he discussed the ubiquity of "simplicity, clarity, and conciseness" as markers of good style (p. 131). Campbell (1992) goes on to describe different (more appropriate) tactics that can be used to maintain good style in engineering discourse: "contextualizing, inch-worming, and getting stories straight," but these markers also do not capture the conventional aspects of style used by researchers in their articles (p. 137).

An example of lacking stylistic guidelines also comes from the American Chemical Society (ACS). The editors of the *ACS Style Guide* (Coghill & Garson, 2006) stated that it is the definitive source for all information needed to write, review, submit,

and edit scholarly and scientific manuscripts. Although the style guide editors devoted an entire chapter to writing style and usage, they only scratch the surface of the conventional writing style used in the writing of chemistry research. When discussing verb voice, the editors advise future contributors to "use the active voice when it is less wordy and more direct than the passive" and "use the passive voice when the doer of the action is unknown or not important or when you would prefer not to specify the doer of the action" (Coghill & Garson, 2006, p. 42). These guidelines inform the reader about the general use of voice in chemical engineering research articles, but more in-depth analysis provides more specific guidelines for the use of verb voice in specific rhetorical situations. Rodman (1994) identified specific rhetorical uses for the active voice in each section of a typical engineering research article. Rodman's (1994) conclusions describe the conventional use of active voice in engineering research articles because she based them on the analysis of aggregate data from actual engineering research articles.

The absence of specific stylistic details in the *ACS Style Guide* (Coghill & Garson, 2006) suggests that the study of rhetorical style may be needed in engineering discourse. Although the information from the style guide is appropriate, these general guidelines for verb voice do not reflect the difficult choices that journal contributors face when presenting their research as scientific articles. More detailed information based on the practical use of verb voice in scientific articles could better explain the stylistic choices necessary to produce an effective scientific research article.

As an example, Graves (2004) studied the use of style, specifically figurative language, as an integral part of the scientific conversion of conceptual hypotheses to accepted facts and as a result exposed the absence of instruction in rhetorical style. After

observing the discursive practices of a doctoral student and two professors, Graves (2004) noted several uses of figurative language as tools to move ideas from theory to fact. During the course of her stay, Graves (2004) also discovered that one professor felt that writing is a skill that can be taught to students. However, the professor did not "articulate rhetorical concepts that might have helped students improve their work" (Graves, 2004, p. 244). Without instruction about the intricacies of rhetorical style in writing, students are forced to navigate through rhetorical landscape without any guide.

2. PREVIOUS RESEARCH

To explain verb voice in scientific research articles, Rodman (1994) studied the use of active voice in research articles from disciplines including chemical engineering, civil engineering, physics, and mineralogy (p. 311). Through her analysis, Rodman (1994) was able to identify the major uses and rhetorical purposes of active voice in the main sections of scientific research articles.

- Introduction: cite a source directly, introduce a current work, and state a scientific truth (p. 322).
- Methods: indicate the functions of equipment, introduce a figure or table, indicate how the characteristics of the sample were determined (p. 323).
- Results: introduce a figure or table, present the basis of a result, comment on the reliability of a result, present the work of other authors, present mathematical arguments (p. 325).
- Discussion: cite the work of other researchers, emphasize the work of the authors, explain or interpret results, introduce metadiscourse (p. 326).
- Conclusion: introduce metadiscourse (p. 327).

Rodman (1994) was able to utilize the combination of aggregate and selective analysis to produce results that explain trends in the use of active voice and the reasons authors use the active voice.

Gross, Harmon, and Reidy (2001) defined *style* as "any feature of a text whose focus is the syntax of sentences or the choice of words" (p. 9). This definition seems to

more readily describe grammar than style, but the methods of the analysis by Gross, Harmon, and Reidy (2001) are the important aspect of this research. While defining style, the authors also take time to illustrate that the scientific article has changed over time. This transition has resulted in the current genre being used as a medium to transfer knowledge from expert to expert. Also, visuals are not a part of style, according to the authors. Instead, the representations of information are considered a part of presentation. This is analogous to Aristotle's arrangement, but the authors wanted to include visuals along with arrangement.

Gross, Harmon, and Reidy (2001) analyzed articles from "the elite journals covering the major branches of science (astronomy, chemistry, physics, the biological sciences, and the earth sciences)." This is indicative of the type of research found regarding the rhetoric of science. Unfortunately, no one has taken time to look at engineering as a separate discipline. Although engineering does involve the "major branches of science" described by Gross, Harmon, and Reidy (2001), engineering takes science a step farther. Rather than theorize about topics that at best are applicable to small-scale testing, engineering involves pragmatic use of science on larger scales. Chemical engineering specifically evolved out of a need for large-scale production of small-scale chemical processes discovered in labs.

Gross, Harmon, and Reidy (2001) asked the following questions to discover the style of scientific articles:

- How many personal pronouns were used per total number of words?

- How many evaluative expressions were used? (author descriptions of physical objects)
- How many poetic metaphors or similes were used?
- How may passive voice constructions, dummy subjects (delay of subject), hedging expressions (expressions that use cautious or vague language), and finite verbs were used?
- How many noun phrases, noun strings, quantifying expressions, abbreviations, and citations were used?
- What was the average sentence length?
- What was the average clausal density (use of dependent and independent clauses)?

3. SAMPLE

The sample for rhetorical analysis in this study needed to be well defined to accurately define a style for chemical engineering journal articles. Implied in my study is the assumption that the published articles chosen for analysis are accurate representations of chemical engineering style. Although quantifying how closely a sample of articles matches the entirety of chemical engineering discourse is beyond the scope of this study, we can use specific criteria to increase the probability of choosing a representative sample of chemical engineering journal articles. I selected the journals and articles that comprise the sample for my study by using a stratified random sampling technique. A stratified random sample attempts to capture a representative sample of a population by establishing an exhaustively inclusive set of subpopulations or strata. This sampling technique allowed me to choose articles from each subpopulation or stratum so that my sample would be representative of the entire population. If I did not equally sample articles from each subpopulation, the sample of articles for my study would not be representative of the entire population. Sampling chemical engineering research articles without consideration of any descriptive features could allow the sample to include more articles from one journal over another, or more articles focused on fluid dynamics instead of materials engineering. By defining a rhetorical style for the discipline of chemical engineering research article, I hope to aggregate enough articles with enough variety to define a style applicable to chemical engineering research as a whole.

3.1. CRITERION 1 – COVER A WIDE RANGE OF CHEMCIAL ENGINEERING TOPICS

In a *Chemical Engineering Research and Design* editorial, Allen (2004) described some of the scientific content associated with chemical engineering: "the traditional skill-sets of reaction engineering, systems engineering, thermodynamics, transport processes and separation, may simply be constructs to provide pedagogical clarity but they nonetheless remain intensely relevant to today's problems" (p. 686). Allen (2004) also discussed fluid dynamics and unit operations as core skills that chemical engineers use to "repack" the knowledge of chemistry into industrial processes that produce products that society can use (p. 686). In addition to the chemical engineering topics mentioned by Allen, the chemical engineering discipline covers even more topics, including process safety, materials engineering, and particle science. These topics by no means explain the whole of chemical engineering, but one can see that chemical engineering encompasses a broad range of topics. No previous research that describes the stylistic trends in chemical engineering research articles exists. Therefore, the authors of these research articles may have different styles depending on the core subject area covered in the article. This assumption may not be true, but still must be considered in this preliminary analysis of chemical engineering research article style. Therefore, to accurately predict the style of chemical engineering research articles as a whole, the journal articles in the sample must cover a wide range of topic.

Sampling from a wide range of chemical engineering topics therefore helps remove the possibility of forming generalizations based on a rhetorical analysis of a subset of chemical engineering research articles. A sample consisting of articles from only one area of chemical engineering like particle technology would only yield

generalizations applicable to journal articles dealing with particle technology. Because the goal of this study is to provide an accurate description of chemical engineering discourse, the results from a sample limited to a subset of chemical engineering (e.g, particle technology) would not be beneficial.

3.2. CRITERION 2 – COME FROM HIGH IMPACT JOURNALS

Analyzing the contents of every chemical engineering research article ever written would be impractical and the exercise would quickly become redundant. Therefore, the sample of articles must come from journals that present chemical engineering research and come from high impact journals that contain "exemplars" of chemical engineering research articles. Swales (1990) discussed the role that "exemplars" play in constructing a genre. According to Swales (1990), exemplars of a genre represent accepted practices of a discourse community relative to "structure, style, content, and intended audience" (p. 58). Although Swales (1990) did not define in detail how a discourse community decides on an exemplar, the idea that select members of a genre could serve as predictors of style for the genre as a whole is central to the sample selection.

In this study, a "prototypical exemplar" refers to the articles contained in high impact journals (Swales, 1990, p. 58). When writing research articles, authors have an idea of the style they should apply to their own writing to fit within the stylistic confines of their genre. However, where does that idea of style come from? For some it may come from past experiences as a writer, but for most, I believe this idea of style is based on the style of published research articles in the discipline. Published articles serve as examples of acceptable stylistic practices based on their publication, and high-impact journals should contain the best examples of accepted stylistic practices.

High-impact journals are categorized as high-impact based on the amount of importance associated with the journal. Usually, this importance is quantified by the number of citations that reference articles within the journal and the high volume of citations support the notion that the articles in high impact journals are "prototypical exemplars" (Swales, 1990, p. 58). Each article contained within these high impact journals represents accepted stylistic standards that authors must meet in order to publish within these journals. Authors looking to publish their research within these high impact journals must adjust not only their research methods, but also the style of their writing to match the requirements of the journals themselves. Although every author has his own individual writing style, the aggregated style of the articles published within prominent journals could reveal a writing style specific to chemical engineering discourse. The importance of these journals and their role in shaping written scientific discourse make the articles contained within them accurate measures of the style of writing for a profession. As a result, far fewer journals could be analyzed to form generalizations about the properties of chemical engineering discourse as a whole.

However, high-impact journals that contain "prototypical exemplars" must be objectively identified in some way. I contend that the h-index is an accurate identifier of a journal that contains "such exemplars" (Swales, 1990, p. 58). Hirsch (2005) proposed the h-index as a measure of a scientist's "research output" based on his number of published papers and the number of times a published paper was cited (Hirsch, p. 16569). Although Hirsch (2005) intended the h-index to be used to calculate the impact of a scientist on his discipline, many researchers have adapted the h-index to predict the impact of scientific journals. Vanclay (2008) verified the effectiveness of using the h-

index to rank 180 forestry journals and found that the h-index has a strong correlation with the widely accepted journal impact factor (p. 331).

3.3. CRITERION 3 – INCLUDE ONLY CURRENT ARTICLES

This study is meant to help define the style of current chemical engineering research articles. If journal articles spanning over a number of years were included in the sample, then the generalizations from the sample might unintentionally include changes in style over time. Therefore the articles included in the sample must come from the most current year of publication (for this study, 2012). Several researchers have discussed the evolution of scientific journal articles over time. For example, Bazerman (1984) analyzed spectroscopic articles from *The Physical Review* over time and found that the style of the articles evolved over time (p. 191). Identifying the historical evolution of chemical engineering discourse is beyond the scope of this study. Therefore, articles used in the sample should be from recent issues (2012) of the high impact journals selected based on the h-index.

3.4. CRITERION 4 – INCLUDE A VAREITY OF AUTHORS

One need only open an introductory composition textbook to see authors with more experience than I state that every author has his own writing style. This style may be defined by any number of factors (previous instruction, past experiences as writers, dialect), but individual styles complicate the task of identifying a common style of discourse. Including several authors into the sample of chemical engineering articles helps remove the possibility of forming generalizations based on the writing style of an individual or group of individuals.

3.5. SAMPLE DETAILS

The *Industrial and Engineering Chemistry Research* and the *AIChE Journal*, as well as the articles contained within them, meet the four criteria outlined in the previous section. Of all American chemical engineering journals ranked by SCImago Journal and Country Ranking tool provided by Scopus, *Industrial and Engineering Chemistry Research* and *AIChE Journal* have the first and third highest h-index ratings, respectively. The second highest h-index rating belongs to *Energy and Fuels*, but because *Energy and Fuels* and *Industrial and Engineering Chemistry Research* are both published by the American Chemistry Society (ACS), had I used both in my study, the resultant data could have been influenced by the processes and guidelines proposed within the *ACS Style Guide* (Coghill & Garson, 2006). Both *Industrial and Engineering Chemistry* and the *AIChE Journal* publish articles on diverse topics: thermodynamics, transport phenomena, chemical reactions kinetics, catalysis, separations, etc. The bibliographic information for each of the selected articles in the sample is listed in Table 3.1 and Table 3.2.

Table 3.1. Selected articles from *Industrial and Engineering Chemistry Research*

#	Authors	Year	Title	# of words
1	Torres, V. M., Herndon, S., Wood, E., Al-Fadhli, F. M., & Allen, D. T.	2012	Emissions of nitrogen oxides from flares operating at low flow conditions	2879
2	Ramkumar, S., Phalak, N., & Fan, L.	2012	Calcium looping process (CLP) for enhanced steam methane reforming	4113
3	Sun, Z., Chi, H., & Fan, L.	2012	Physical and chemical mechanism for increased surface area and pore volume of CaO in water hydration	3737

Table 3.1. Selected articles from *Industrial and Engineering Chemistry Research* (contd.)

#	Authors	Year	Title	# of words
4	Alfaro, V. M. & Vilanova, R.	2012	Robust tuning and performance analysis of 2DoF PI controllers for integrating controlled processes	4986
5	Sotelo, J. L., Ovejero, G., Rodrigues, A., Alvarez, S., & Garcia, J.	2012	Removal of atenolol and isoproturon in aqueous solutions by adsorption in a fixed-bed column.	4440

Table 3.2. Selected articles from the *AIChE Journal*

#	Authors	Year	Title	# of words
6	Worz, N., Claus, P., Lang, S., & Hampe, M. J.	2012	Thermodynamics and transport properties of citral	2703
7	Mokhtar, M. A., Kuwagi, K., Takami, T., Hirano, H., & Horio, M.	2012	Validation of the similar particle assembly (SPA) model for the fluidization of Geldhart's group A and D particles	5508
8	Beck, R. & Andreassen, J.	2012	Influence of crystallization conditions on crystal morphology and size of CaCO3 and their effect on pressure filtration	7447
9	Yuan, Z., Zhang, N., Chen, B., & Zhao, J.	2012	Systematic controllability analysis for chemical processes	6144
10	Deshpande, P. A., Polisetti, S., & Madras, G.	2012	Analysis of oxide and vanadate supports for catalytic hydrogen combustion: Kinetic and mechanistic investigations	7063

The articles for the sample were randomly selected from *Industrial and Engineering Chemistry Research* and *AIChE Journal* using the criteria explained in the previous sections:

- One article from each chemical engineering topic (thermodynamics, particle science, process control, kinetics, and fluid dynamics) was chosen from each journal
- Each article was published in 2012
- Each author was only included in the sample once

Both *Industrial and Engineering Chemistry Research* and the *AIChE Journal* include equal proportions of the main chemical engineering topics (materials science, process controls, separations, reaction engineering, and fluid dynamics). Therefore, my decision to select one article from each topic in both journals is representative of the population of chemical engineering research articles. Also, time did not affect the conclusions of my study because all of the articles were sampled from 2012. To randomly select the articles from each subpopulation, I categorized all of the articles published in 2012 from *Industrial and Engineering Chemistry Research* and the *AIChE Journal* based on their respective topics and assigned each article a number. Then I used a random number generator to select the article from each subpopulation that would be included in the sample.

Ten articles were chosen based on the large amount of data produced by the analysis of each article. The small sample size can still produce generalizable results if the data have small variance from article to article in the sample. Regardless of the small sample size, my conclusions still identify trends in the data that can be used in future research.

4. METHODS

Fahnestock (2005) cautioned against performing "haphazard language analysis" when rhetorically analyzing texts (p. 282). According to Fahnestock (2005), language analysts perform "haphazard language analysis" when they choose to focus on specific markers of style without any justification for their specialized treatment. This type of language analysis, although informative, does not allow for accurate description of the conventional stylistic features associated with chemical engineering research articles. However, the combination of aggregate and selective analysis allows me to focus (with proper justification) on specific linguistic features. The aggregate analysis of text from the sample provides the justification for selective analysis of important trends.

I chose a subset of the stylistic features proposed by Corbett and Connors (1999) as a tool for capturing the aggregate data necessary for this research project. Corbett and Connors (1999) specifically identified seven features that one can "look for when analyzing prose style" (p. 360):

- Kind of diction
- Length of sentences
- Kinds of sentences
- Variety of sentence patterns
- Uses of figures of speech
- Paragraphing

Before moving forward, I must clarify some of the features listed by Corbett and Connors (1999). Although some of the features require little explanation, some features (like variety of sentence pattern) require further explanation regarding my application of Corbett and Connors' (1999) features of style. Each of the following sections explains how my analysis of the language in the sample captures these aspects of style.

4.1. KIND OF DICTION

Corbett and Connors (1999) suggested that researchers of style review the following markers when determining the kind of diction an author has chosen to use:

- Formal or informal
- Polysyllabic or monosyllabic
- Commons words or jargon
- Passive or active voice

Each of these aspects of diction contributes to a stylistic analysis, but some of these aspects conflict with the objective approach of this study. For example, although classifying prose as formal or informal would yield integral information about the style of the prose, the decision would be based on the perceptions of the individual researcher. I chose the following markers of style to avoid the subjective implications of the remaining aspects of diction:

- Use of contractions and impersonal language
- Readability
- Use of voice in transitive verbs

4.1.1. Use of Contractions and Impersonal Language. On formality, Markel (2010) stated that no standard definitions of formality in writing exist (p. 233); therefore, I chose to include stylistic markers that are associated with formality and can be objectively identified The objective markers of diction still mirror the markers proposed by Corbett and Connors (1999), but are more quantifiable. For example, the SUNY Geneseo writing guide (Schacht & Easton, 2008) suggested that formal prose is contraction-free, restrained (no slang), impersonal, properly-documented. These aspects of formality are easily identified in grammatical terms and are, as a result, more objective than the alternative measures proposed by Corbett and Connors (1999, p. 361).

The number of contractions used in the sample can easily be counted and verified, but the use of impersonal language requires further explanation. For this research project, the use of impersonal language refers to the use of personal pronouns in the sample. Personal pronouns refer to nouns or noun phrases and are categorized by person, gender, and number. Case is also considered in discussions of personal pronouns, but relative to kind of diction, only person, gender, and number apply (Klammer and Schulz, 1992, p. 88). Therefore, I counted and categorized the personal pronouns in the sample based on person, gender, and number. In this research project, I focused on the use of first and second person personal pronouns because they directly refer to people (specifically the author and the reader).

4.1.2. Common Words or Jargon. Similar to the definition of style, a definition of jargon is illusive. Hirst (2003) addressed this problem by discussing the competing definitions of jargon: bad and neutral. Although jargon can be used effectively and is not wholly negative, many definitions of jargon hold negative connotations. For example, Gowers (1954) stated that jargon was commonly referred to as "any speech that a person feels is inferior to his own" (as cited in Hirst, 2003, p. 210). However, Gowers (1954) went on to conclude that jargon was equal to the technical terms used within a discourse community. Members of the discourse community would completely understand the terms, but outsiders would find the terms "unintelligible" and confusing (as cited in Hirst, 2003, p. 211). This social aspect of jargon makes the objective study of its use in this project problematic.

Consider the use of the terms *nuclear magnetic resonance* (NMR) and *magnetic resonance imaging* (MRI). According to Hirst (2003), the former lost favor as jargon referring to the same technology because of the public's fear of the word *nuclear*. Also, Harris (1998) presented several examples that illustrate the social use of jargon that members of a discourse community use as proof of their membership. An editor uses the terms *leading* and *kerning*, a physician uses *arrhythmia* to refer to an irregular heartbeat, but a cardiologist would refer to it as *dysrhythmia*, a pilot uses *gate, line, ramp, hardstand*, or *apron* to refer to a runway but never use tarmac (Harris, 1998, p. 221). These examples illustrate the social nature of jargon that makes objective study difficult.

The social aspect of jargon forced me to remove it from the markers of kind of diction. If I decided to research jargon and common words (which are both relative to the discipline of chemical engineering) in this study, I would do so "haphazardly," to use

Fahnestock's (2005) word again. To legitimately study the use of jargon in chemical engineering research articles I would need to survey the discourse community to separate jargon (good or bad) from common word usage. Fortunately, the remaining markers of diction present an acceptable characterization.

4.1.3. Readability. Readability formulas use mathematical correlations to predict the level of difficulty users will encounter while reading a document. Although many researchers have argued against the efficacy of readability formulas by emphasizing the difficulty of quantifying the complex process of reading, readability formulas can quantify the style of a given set of prose. The use of the Flesch Ease of Reading formula in this study aims to quantify the authors' sentence constructions with respect to sentence length and number of syllables per word. The results of these calculations will provide insight about the writing style of chemical engineering authors.

One must also note the issues associated with using the Flesch Ease of Reading formula. Flesch (1948) constructed his original and revised formulas to predict the "grade level of a child who could answer correctly three-quarters of the test questions asked about a given passage" (p. 222). When revising his original readability formula, he admitted that his formula would be more applicable to adults if he had adult comprehension data, but at the time this data was not available to him. Selzer (1981) identified this emphasis on child reading levels as one of the major issues with general readability formulas (p. 26).

Also, readability formulas omit much of the intricacies associated with the reading process and comprehension. Readability formulas similar to Flesch's formula

only account for sentence and word length and ignore syntactic and semantic aspects (such as diction) of writing that also affect readability. For example, a misplaced modifier has no bearing on the readability formula but does affect the reader's ability to fully comprehend the writing (Selzer, 1981, p. 25). Connaster (1999) even argued that reading difficulty is a concept internal to individual readers and therefore cannot be measured objectively by readability formulas (p. 272).

Fortunately, these criticisms of readability formulas reflect their overuse as complete measures of readability. This study is descriptive and therefore does not use the Flesch Ease of Reading formula to improve the readability of the articles in the sample. Instead, the readability formula is used to quantify the countable aspects of style present in the sentence constructions of the various authors. The aspects of style not included in the readability formulas are treated using various methods in other sections.

I chose the Flesch Ease of Reading formula as a substitute for the number of syllables metric proposed by Corbett and Connors (1999). The Flesch Ease of Reading formula uses the number of syllables, length of sentences, and number of word per sentence to calculate the Flesch Ease of Reading Score (FRES). Although readability scores have issues that have been specifically addressed in academic literature (Connaster, 1999; Selzer, 1981), the FRES provided a numeric scale with set interpretations for its values. For example, a FRES less than 29 is associated with a graduate student reading level. If number of syllables were used as a metric in this research project, I would not be able to form accurate conclusions based on the data. The implications of the Flesch Ease of Reading Scale allow for clearer interpretation because I can use its set standards to form justified conclusions.

I used the online tool Syllable Counter (2013) to count the number of syllables in each word for the readability formula. Syllable Counter accurately counted the number of syllables in several passages when compared to my own count. Syllable Counter (2013) also provided a list of words where the syllables were counted "programmatically." This feature is necessary for my analysis because chemical engineering jargon is not present in most syllable counter databases. Syllable Counter uses algorithms to count the syllables in words that are not already in its database and provides these words to the user for manual inspection along with the predicted number of syllables. By providing the words with syllables counted "programmatically," I ensured the accuracy of the results for my analysis.

4.1.4. Voice. This study defines voice as Rude & Eaton (2011) defined it. Rude and Eaton (2011) simply defined voice by stating that it "refers to the relationship of subject and verb" (p. 234). Although many aspects of verbs can be researched, none has been researched in scientific communication more than voice. Gross, Harmon, and Reidy (2002), Hanna (2004), and Rodman (1994) each have expounded on the concept of passive voice and objectivity in science. A passive voice construction implies that the agent of a sentence is a person, but does not clearly state that someone performed an action. Scientific authors are able to use the implied agent to minimize their own agency. According to these passive voice constructions, objects and laws of nature interacted without any influence from the scientists and therefore the scientist's conclusions are objective. Although passive voice has been studied, Rodman (1994) specifically focused on the use of active voice in engineering research articles and was able to identify

rhetorical reasons for the use of active voice in each of the standard sections of an engineering research article (introduction, methods, results, analysis, conclusion).

Klammar and Schulz (1992) explained the difference (in traditional grammar) between active and passive voice. While active voice clearly communicates that an agent performs the action of a verb, passive voice "deemphasizes" the role of the agent by placing the verb's direct object in the subject position (p. 290). Passive voice can most often be identified by a form of the auxiliary verb "be" followed by a past participle. Other English verb voices exist, but this study only focuses on the active/passive distinction as these are the primary voices discussed by similar studies from Gross, Harmon, and Reidy (2002), Hanna (2004), and Rodman (1994). This study approaches the use of active voice similar to Rodman's (1994) research by identifying the use of both passive and active voice in transitive verbs.

4.2. LENGTH OF SENTENCES

To determine the length of each sentence in each article, I again used Syllable Counter. Syllable Counter counted the words in a given text by using spaces between words as separators. I individually inputted each sentence from the sample separately to verify the results produced by Syllable Counter. Some chemical engineering terms like *chemiluminesence* were not recognized by Syllable Counter, but its algorithm only used spaces to determine the number of words in a passage so the results were unaffected. Acronyms, chemical formulas, and chemical symbols used in the body text of each article were counted as the nouns for which they substituted. For example, *API* was counted as three words (*American Petroleum Institute*), CH_4 was counted as one word (*methane*), and $°C$ was counted as two words (*degrees Celsius*).

4.3. SENTENCE TYPE AND VARIETY OF SENTENCE PATTERNS

Corbett and Connors (1999) believed that the kinds of sentences an author chooses to use can explain much about the author's style. They mention Wimsatt's analysis of Samuel Johnson's prose style and how Wimsatt formed conclusions about Johnson's style based on his use of antithetical sentence structures. The grammatical types of sentences are simple, complex, compound, or compound-complex, and the definition of each category is widely accepted. Table 4.1 uses the definitions provided by Rude and Eaton (2011) in their technical editing textbook (p. 155). The functional types of sentences (statement, question, command, exclamation) also have widely accepted definitions. Because of the widely accepted definitions of these types of sentences, I will not define them here.

Table 4.1. Grammatical sentence types

Type of grammatical sentence	Definition
Simple	One independent clause
Complex	One independent clause and one dependent clause
Compound	Two independent clauses
Compound-Complex	2+ independent and 1+ dependent clauses

In their description of sentence patterns, Corbett and Connors (1999) specifically discussed the use of sentence variety and how review of authors' uses of sentence openers can "dispel many of the myths about prose style" (p. 362). As an example, they provide the results from an analysis of the prose style of several modern American writers and, in accordance with their previous statement; the results dispel a few common misconceptions about modern prose style. The results from their analysis showed that

28.75% of the sentences from the sample started with sentence openers. Using these results, Corbett and Connors (1999) emphasized the notion that authors do not spend as much time varying their sentence patterns as common opinion would have us believe (p. 363). Corbett and Connors (1999) used the distinction between each sentence type and variety in sentence pattern to help explain why authors choose specific sentence constructions when they have many options available to them.

4.4. FIGURATIVE LANGUAGE

Corbett and Connors (1999) defined figurative language as any use of language that differs from ordinary usage (p. 379). The effects of figurative language in scientific discourse have previously been studied. In support of this claim, Fahnestock (1999) used several examples of rhetorical figures in her introduction support her conclusion that scientists use rhetorical figures other than metaphor, but these examples are all from early modern treatises on science (e.g. Dalton's explanation of heat, Newton's description of light). She also explained the human brain's comparison to a computer, but still, the majority of her examples come from older sources. Fahnestock (1999) described the tendency of rhetorical scholarship to limit the discussion of the figures of speech to tropes and to limit the tropes to metaphor. This is most likely due to the standard definition of metaphor.

Corbett and Connors (1999) defined metaphor as "an implied comparison between two things of unlike nature that yet have something in common" (p. 396). Researchers are able to use this standard definition to clearly identify and explain rhetorical uses of metaphor. Fahnestock (1999) argues that a review of rhetorical

scholarship undoubtedly emphasizes the prevalence of metaphor in scientific discourse (p. 6).

According to Fahnestock (1999), rhetorical figures can also have a number of uses that include the communication of emotion/force, addition of value/ornateness, or presentation of lines of reasoning. She gave particular attention to the use of antimetabole (repeating in reverse the syntactical positions of words or phrases) in advertisements. An advertisement for cellophane stated that the miracle packaging material "Protects what it shows/Shows what it protects" (Fahnestock, 1999, p. 24). The developers of this advertisement used antimetabole to communicate the benefits of cellophane without explaining how the low-permeability of the cellulose-based film prevents penetration of air, water, oils, etc. Although this example is from an advertisement, the rhetorical effectiveness of antimetabole and other lesser known figures of speech may also be applicable to engineering research articles.

Figures of speech include figures as common as metaphor and as uncommon as zeugma. Therefore, I limited my analysis to the figures of speech described by Corbett and Connors (1999). Corbett and Connors (1999) divided their classification of figures into schemes (variation in arrangement) and tropes (variation in meaning). I used selective analysis of the schemes and tropes identified by Corbett and Connors (1999) to provide more detailed explanation of the specific uses of figurative language in the sample of this research project.

4.5. PARAGRAPHING

Corbett and Connors (1999) stated that we can define paragraphing as “a typographical device for punctuating units of thought larger than the thought conveyed by a single sentence” and went on to state that readers often expect to see paragraphs marked by “indentations of segments of thought” (p. 367). This definition seems to be more applicable to punctuation, but Corbett and Connors (1999) carefully included the organization of larger units of thought in their definition. When we look to the definition of style used in this research style, the connection between paragraphing and style becomes apparent. Style is the “artful expression of ideas” so the amount of information that authors choose to place into a paragraph to communicate their ideas is an important aspect of style. Therefore, I identified paragraphs as complete thoughts marked by indentation, and I focused on the number of sentences per paragraph as the primary measure of paragraphing.

5. RESULTS AND ANALYSIS

The results of the analysis described in the previous section are presented here in detail. Throughout this section, examples have also been provided to illustrate important conclusions drawn from the data. Each example was chosen based on its ability to accurately illustrate findings from the data and represent general instances of described phenomena.

5.1. KIND OF DICTION

The kind of diction analysis produced interesting results regarding the syllables per word, use of passive voice, and the difference in these trends in the methods and results sections. Unfortunately, no contractions were used in the sample. The implications of the use of contractions and the other kind of diction trends are addressed in the following sections.

One immediate issue with the results is the smaller sample size used in this study. However, under specific conditions, the inferences drawn from the sample data can still be reliable inferences for the overall population of chemical engineering research articles. Hughes and Hayhoe (2008) explained that inferences drawn from smaller sample sizes are more reliable when the variance in the data is smaller (p. 62). Variance is most easily quantified by the standard deviation of a given dataset. Standard deviation measures the dispersion of a given dataset (the distance of the data points from the mean). Therefore, when the standard deviation of a sample is low, the inferences drawn from that dataset are more reliable. The determination of low standard deviation is based on the

comparison between the standard deviation (σ) and the mean (μ). A low standard deviation means that relative to the mean the standard deviation is small ($\sigma/\mu < 0.15$). Ideally, I would be able to use confidence interval and hypothesis testing to justify the reliability of the conclusions as well, but confidence interval and hypothesis testing require that the data be normally distributed. Currently, no previous research has supported that any of the trends in my study are normally distributed.

5.1.1. Use of Contractions and Impersonal Language. No contractions were used throughout the entire sample, but the absence of contractions does explain something about the formality of chemical engineering research article style. Johnson-Sheehan (2007) wrote that contractions are only appropriate in informal writing because they imply a familiarity with the reader that may be inappropriate (p. A-13). This advice from Johnson-Sheehan (2007) supports the contraction data from this research project. The complete absence of contractions from the sample implies that it is a convention of chemical engineering research articles.

Although the sample is small, the contraction generalization is still justifiable. The standard deviation of the contractions used in the sample is zero because no contractions were used in the sample. Therefore, we can conclude that chemical engineering research articles do not conventionally use contractions.

The use of first and second-person personal pronouns is also limited in the sample. Table 5.1 summarizes the use of personal pronouns in the sample. No authors used *I* or *me* in the sample, but no articles from the sample had a single author. Therefore, we can see that the authors chose to use *we* instead. Although the sample did

contain instances of personal pronoun usage, the instances are insignificant when compared to the entire sample. Similar to the use of contractions, the limited use of first and second-person personal pronouns throughout the sample implies that the chemical engineering research article authors do not use personal language in their writing. The higher standard deviations for *we* and *you* are a result of the potential outliers in each (Articles 9 and 14 for *we* and Article 9 for *us*). Without those outliers, the use of personal pronouns in the sample is approximately zero for each article. Therefore, I can conclude that the minimal use of first and second-personal pronouns is a convention of chemical engineering research articles.

Table 5.1. Use of first and second-person personal pronouns

Article	**I**	**we**	**me**	**us**	**you**
1	0	0	0	0	0
2	0	0	0	0	0
3	0	3	0	0	0
4	0	9	0	0	0
5	0	0	0	0	0
6	0	2	0	0	0
7	0	4	0	1	0
8	0	0	0	0	0
9	0	4	0	0	9
10	0	14	0	0	0
Std. Dev.	0	4.62	0	0.32	2.85

5.1.2. Readability. The Flesch Reading Ease Score (FRES) is typically used to quantify the reading level of a given piece of writing by calculating a correlation expression between the total words, sentences, and syllables in the given passage and reading comprehension test scores. As a bench mark, an FRES of 0-30 marks a passage that is best understood by university graduate students. Equation (1 shows the FRES

equation in its complete form and Table 5.2 shows the standard interpretation of the FRES.

$$FRES = 206.835 - 1.015\left(\frac{total\ words}{total\ sentences}\right) - 84.6\left(\frac{total\ syllables}{total\ words}\right) \quad (1)$$

Table 5.2. FRES interpretation

FRES	Reading difficulty
< 29	Very difficult
30-49	Difficult
50-59	Fairly difficult
60-69	Standard
70-79	Fairly easy
80-89	Easy
90-100	Very easy

Table 5.3 shows the FRES for the major sections of each article in the sample. Unfortunately, the internal validity of the FRES does not allow generalization to an entire population, but, nonetheless, interesting results can be readily identified from the sample.

Table 5.3. FRES for major sections of each article

	Flesch Reading Ease Score (FRES)			
Article	Intro	Methods	Results	Conclusion
1	28.75	19.30	-11.53	-3.42
2	11.26	36.78	29.29	11.51
3	6.99	13.27	19.69	16.68
4	8.60	21.05	12.13	-1.84
5	20.53	6.43	21.34	19.12
6	8.96	28.27	20.30	20.10

Table 5.3. FRES for major sections of each article (cont.)

7	12.66	21.20	21.53	7.41
8	20.93	15.29	18.18	13.44
9	9.06	30.41	16.29	9.81
10	10.75	23.30	32.20	26.53
Avg.	13.85	21.53	17.94	11.94
Std. Dev	7.12	8.82	11.88	9.47

With the exception of two methods sections and one results section, each section of each article in the sample scored in the very difficult range on the FRES scale. However, the average readability scores for the methods and results sections are typically higher than the scores for the introduction and conclusion sections. Based on the standard interpretation of the FRES, this trend implies that the methods and results sections are typically easier to read than the introduction and conclusion sections. This difference may be small, but it does add credibility to the notion that the methods and results sections are the most rhetorically important sections to the article authors.

Sentences unencumbered by many polysyllabic words are easier to comprehend. Although the methods and results sections are still very difficult to read and comprehend, the higher readability scores also imply that the authors want their messages in these sections to reach the audience more clearly. These sections contain the primary content of the article relative to the audience needs. The methods section focuses on what was done and increases the credibility of the results, while the results section presents the data achieved through application of the content from the methods section. I suspect that these research article authors want to avoid misinterpretation in these sections because

these sections are key to evaluating the validity of their inevitable claims. Therefore, they minimize their use of polysyllabic words.

Consider the following examples, which illustrate this point. The first excerpt is from the methods section of Article 5, which scored the lowest readability score among all the methods sections in the sample (6.43). The methods section of Article 5 is an anomaly compared with its counterpart sections in the other articles. “The suspensions containing different doses of activated carbon and the solutions of atenolol or isoproturon were shaken with a magnetic stirrer at constant temperature until equilibrium was reached” (Sotelo, et al., 2012, p. 5046).

The next excerpt from Article 2 has approximately the same number of words as the excerpt from Article 5 and comes from the methods section, but contains fewer syllables. Also, the methods section in Article 2 had the highest readability score (36.78). “The methane flow rate was maintained at a constant 37 mL/min for all experiments, and the effects of temperature and steam-to-carbon ratio were investigated” (Ramkumar, et al., 2012, p. 1188).

The excerpt from Article 5 has a readability score of -5.89, while the excerpt from Article 2 has a readability score of 22.76. However, one need not know these scores to see that the main idea from Article 2 is clearer to the reader than the Article 5 excerpt. In the Article 5 excerpt, the authors intended to inform their readers that the solution of liquid and particulate matter was mixed until the mixture reached equilibrium (or the point where further mixing does not affect the mixture). Unfortunately, the reader does not receive that information until the last possible point in the sentence. Also, the authors

of this excerpt chose to condense a large amount of information into this one sentence. The large amount of information requires more words and more syllables in one sentence and therefore increases the excerpt's reading difficulty. The excerpt from Article 2, however, does not contain too much information and is clearer than the excerpt from Article 5. Even a reader with no background in chemical engineering could comprehend the message of this passage.

5.1.3. Voice. Table 5.4 summarizes the use of passive voice in each article of the sample as a percent of the transitive verbs that are passive.

Table 5.4. Use of passive voice in each article of the sample

Article	% Passive
1	63%
2	60%
3	56%
4	58%
5	53%
6	52%
7	38%
8	58%
9	31%
10	44%

Although Table 5.4 implies that the authors tended to favor passive over active voice, further examination of the results uncovered a rhetorical approach to the authors' choices of voice. Burnett (2005) advised authors to consider their choice of voice based on the audience and purpose of the writing, and the authors of the articles from the sample generally applied this advice to their own writing (p. 247). Table 5.5 displays the

total use of passive voice per section and illustrates the rhetorical uses of voice in chemical engineering research articles.

Table 5.5. Total use of passive voice in the sample per section

Sections	% Passive
Introduction	46%
Methods	66%
Results	45%
Conclusion	44%

Rhetorically, the methods section is intended to describe the actions taken by the researcher to conduct his experiments, but the shift in scientific discourse to favor "things and abstractions" has resulted in the need for semantic constructions that emphasize objectivity (Gross, Harmon, & Reidy, 2001, p. 163). In support of this trend, the sample clearly favored the use of passive voice in the methods sections of the articles. Rather than focus on their roles as agents, the authors downplay their involvement in their own research. Consider the following excerpt from the methods section of an article: "The flare tests were conducted with flare gases that were 1:4 by volume mixtures of natural gas and either propane or propylene, diluted with nitrogen to generate targeted values of heating value for the flared gases" (Torres, Herndon, Wood, Al-Fadhli, and Allen, 2012, p. 12601). This excerpt is illustrative of the passive voice constructions prevalent throughout the methods sections of the sample. Here, the authors concealed their agency by focusing their sentence on the flare tests that they conducted.

Even when the authors chose to use active voice, they still identified objects as the subjects of sentences to maintain their distance from the role of agents. However, the

objectivity of anonymity is not limited to the authors conducting the research, but also includes other researchers referenced by the authors. Credit is infrequently attributed to other researchers, but the authors from the sample often elect to once again use objects as the subjects of these reference sentences. The following excerpt illustrates this point: "IR spectroscopic studies have revealed the formation of hydroxyl groups during chemisorption" (Deshpande, Polisetti, & Madras, 2012, p. 938). Here, the authors chose to state that the "IR spectroscopic studies" revealed information, in effect referencing studies instead of the researchers who actually conducted the studies. This finding is interesting because it supports the conclusion that engineering writing prioritizes objectivity. The authors of this passage implied that the spectroscopic studies revealed information, but in reality, the researchers who conducted the studies revealed information by forming conclusions based on the spectroscopic studies. Although the scientists and engineers conduct research, they consistently refrain from attributing credit to themselves or other researchers.

The trend of maintaining objectivity through the use of direct objects as the grammatical subjects of sentences extends to other sections as well. The results sections in particular show an interesting persuasive method. Although the authors of these articles attempt to persuade their audiences into assent, the authors allow the tables, figures, and charts to handle much of the rhetorical persuasion (cf. Miller, 1979, p. 616). For example, "Figure 4 verifies the degree to which SPA models for Group D particles fluidize differently" (Mokhtar et al., 2012, p. 93). Rather than state that "we verified," the authors instead chose to once again distance themselves from the role of agents, but for a slightly different purpose. The use of tables, figures, and charts as the creators of

argument increases the objectivity of the research. A figure is an object that has no emotions or bias and does not introduce subjective judgments to the verification of fluidization variety among SPA models. This rhetorical device acts as semantic shield against criticism because the sentence's focus is on the figure instead of the author. The reader is subtly lulled into the idea that the results of their research are objective and therefore more acceptable as valid and truthful.

5.2. SENTENCES

The following sections describe the inferences drawn from the data regarding the sentence-level analysis of the data. Even at the sentence level, the sample seems to follow the stylistic variation trend in the methods and results sections.

5.2.1. Length of Sentences. The sentence length data also supports the concept of clarity in the methods and results sections. Table 5.6 shows that the average number of words per sentence is somewhat lower than the other sections, but a more detailed analysis also supports this conclusion. The 95% confidence intervals for each section are listed in Table 5.7. The CI range for the methods section shows that the true population mean for the words per sentence in research article methods sections is most likely lower than the true population mean of the other sections. However, the small sample size may skew the data in such a way that it is does not capture the true population description. For this reason, the CI data from the sample can only imply a conclusion. These assumptions cannot be taken as absolute without a larger sample size and a study intended to research the average sentence length of engineering research articles.

Table 5.6. Average number of words per sentence for each section in the sample

	Words per sentence			
Article	Intro	Methods	Results	Conclusion
1	30.4	24.4	28.7	23.2
2	26.1	18.9	22.8	29.5
3	30.6	24.3	25.9	28.3
4	27.9	28.6	28.8	35.1
5	24.3	22.1	29.0	32.9
6	19.4	18.8	17.3	19.8
7	25.8	25.0	27.2	24.3
8	23.8	25.9	27.3	28.7
9	23.3	19.8	21.8	22.6
10	23.2	17.1	20.4	22.2
Avg.	25.5	22.5	24.9	26.7
Std. Dev	3.4	3.7	4.1	5.0

Table 5.7. 95% Confidence Intervals (CI) for words per sentence in each section

Section	95% CI lower limit	95% CI upper limit
Introduction	22.88	27.92
Methods	19.83	25.14
Results	21.89	27.50
Conclusion	23.08	30.26
Overall	23.53	26.24

Further study into the average sentence length of sentences in engineering research articles may also be warranted by the approximately normal distribution of the words per sentence for the overall sample. Figure 5.1 shows an approximate normal distribution for the words per sentence from every section in the sample.

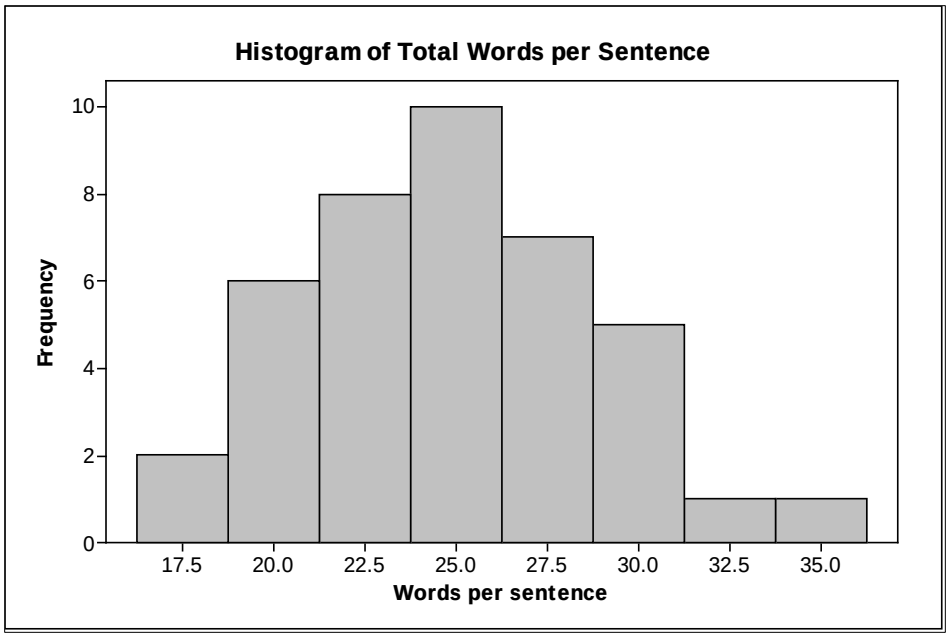

Figure 5.1. Histogram of total words per sentence in sample

This histogram represents the potential for a normal distribution in the words per sentence from engineering research articles. Further, more robust, testing would be necessary to validate the claim that this data follows a normal distribution, but the shape of the histogram in Figure 5.1 remains interesting. A normal distribution in this statistic would allow future research to rely on the assumptions implied from data with a normal distribution (symmetry, Z-tests, etc.) and open up new avenues for understanding how engineers use language to communicate engineering research. Also, other aspects of language may fit the same pattern. With the ability to perform Z-tests on single means, researchers could begin to quantify the use of language with greater certainty, but once again, further research is required to verify the accuracy of the histogram from this relatively small sample.

5.2.2. Kinds and Variety of Sentences. Corbett and Connors (1999) stated that an in-depth analysis of written discourse might invalidate several common conceptions about how we use language. One specific example provided by Corbett and Connors (1999) showed that authors might not vary sentences as much as they are advised to in writing guidelines (p. 363). Coincidentally, the data from this study seems to imply the same conclusion proposed by Corbett and Connors (1999). Table 5.8 shows that simple sentences dominate the composition of engineering research articles. Also, compound-complex sentence usage is small throughout the sample.

Table 5.8. Frequency of grammatical sentence types in sample

Article	% Simple	% Complex	% Compound	% Compound-complex
1	57.27%	32.73%	4.55%	5.45%
2	65.22%	28.26%	5.43%	1.09%
3	58.33%	36.54%	3.21%	1.92%
4	60.80%	31.82%	4.55%	2.84%
5	63.07%	30.68%	3.41%	2.84%
6	78.10%	14.29%	6.67%	0.95%
7	53.48%	44.35%	2.17%	0.00%
8	53.15%	39.37%	6.69%	0.79%
9	69.35%	21.46%	4.98%	4.21%
10	66.28%	17.44%	13.08%	3.20%

Declarative sentences are also prevalent in the sample. However, unlike the grammatical sentence types, the data about functional sentence types seems to fall in line with the low sentence variety trend proposed by Corbett and Connors (1999). Table 5.9 displays the sample data regarding functional types of sentences. 99% of all sentences in

the sample were used to communicate a statement and one would expect this to be true of engineering writing. The article authors must navigate a rhetorical landscape where objectivity supersedes persuasion. Authors in the sample used declarative statements to describe a phenomenon, state a fact, or explain an idea to the reader. These rhetorical purposes allow the author to maintain his objectivity and inform the reader by using some of the trends described in the previous sections (passive voice and impersonal language). A statement does not require the author to drop this shield to communicate his point and therefore allows him to maintain the illusion that he and others had no direct role in the study. However, a question, exclamation, or command requires the author to engage in a persuasive dialogue with the reader. This direct communication with the reader begins to expose the illusion of objectivity because the author is no longer a passive observer of science. Instead, the author begins to directly persuade his audience by showing that he and not science is making the argument through his use of interrogative, imperative, and exclamatory sentences. Therefore, to maintain their illusion, authors must minimize their use of questions, commands, and exclamations.

Table 5.9. Frequency of functional types of sentences

Article	Declarative	Interrogative	Imperative	Exclamatory
1	110	0	0	0
2	185	0	0	0
3	156	0	0	0
4	176	0	0	0
5	176	0	0	0
6	105	0	0	0
7	226	2	2	0
8	254	1	0	0
9	248	2	11	0
10	344	0	0	0

Although the authors in the sample overwhelmingly use the declarative statement to communicate their ideas, specific exceptions to this trend demonstrate the authors' uses of rhetorical strategies to communicate their messages more effectively. The ACS Style Guide suggested that authors provide enough information in the methods section to allow other researchers to replicate the experiment and produce comparable results (Coghill & Garson, 2006, p. 22). In the methods section of Article 9, the authors chose to use imperative sentences to instruct the reader on the steps necessary to replicate their methods. The following excerpt from Yuan, Zhang, Chen, and Zhao (2012) is indicative of the numerous imperative statements: "STEP 1: Obtain the steady-state maps between the manipulated and controlled variables" (p. 3098).

The other methods sections of the sample typically use passive voice and declarative statements to provide the reader with the necessary experimental information. A more typical writing of this excerpt would have stated: "The manipulated and controlled variables were obtained between the steady-state maps." However, Yuan, Zhang, Chen, and Zhao (2012) instead provided specific instructions that allow the reader to accurately replicate the proposed methodology. Both the imperative or declarative alternatives communicate the same message, but the imperative version allows the reader to reproduce the methodology of the research article without encountering any ambiguity. Rather than omit the researcher's role in the methodology through passive voice, Yuan, Zhang, Chen, and Zhao (2012) have shifted the role to the reader. The implied "you" subject of an imperative command allows the author to invoke his agency via a surrogate (i. e., the reader).

Although the use of imperative commands in the methods sections may have some merit, declarative statements are clearly favored by researchers to communicate their research methodology. Some readers may frown upon the use of imperative sentences for a number of reasons.

- too similar to the methods sections of undergraduate lab reports
- too dissimilar from the "typical" style of the engineering research article methods section
- too personal with the implied "you" subject

These claims do have merit, but one cannot deny that the imperative statement is a useful alternative that still allows the author to rhetorically deemphasize his role as the agent in his research. Further research involving the usability testing of both declarative and imperative alternatives would be necessary to determine if either alternative is more effective than the other. The interrogative sentences are discussed in further detail in the figurative language section because each use in the sample was an example of a rhetorical question (erotema).

The average number of clauses per sentence for each article is shown in Table 5.10. Unlike other syntactical data, the number of clauses per sentence showed little variation from article to article. Although the data comes from a small sample, the high internal validity (low variation in data points) may allow for generalization to the larger population of chemical engineering research articles.

Table 5.10. Average clauses per sentence for each article

Article	Clauses per sentence
1	1.59
2	1.48
3	1.57
4	1.60
5	1.62
6	1.27
7	1.61
8	1.63
9	1.47
10	1.42

The high internal validity may allow for generalization, but the average clauses per sentence in Article 6 seem to be an outlier relative to the other data points. Table 5.11 shows the statistical results for the sample data and supports the role of Article 6 as an outlier. The confidence interval for the sample without Article 6 is slightly smaller and narrows the possible values of the true mean. This implies that the true clauses per sentence mean falls somewhere between 1.49 and 1.61. A true mean between 1.49 and 1.61 shows that chemical engineering authors often prefer sentences with either one or two clauses. In support of this claim, only 5% of all sentences in the sample had more than two clauses.

Table 5.11. Statistical analysis of clauses per sentence

	Lower CI limit	Upper CI limit	Sample Mean	Sample Std. Dev.
With Article 6	1.44	1.61	1.53	0.116
Without Article 6	1.49	1.61	1.55	0.078

Figure 5.2 shows the average number of clauses per sentence for each section of the overall sample. In this sample, the methods section contains the fewest clauses per sentence. As stated earlier, this may be due to the need to maintain clarity in the methods section so that readers can easily comprehend the methodology of the authors. Subordinate clauses often add information critical to the understanding of a sentence, but also complicate the overall message of a sentence.

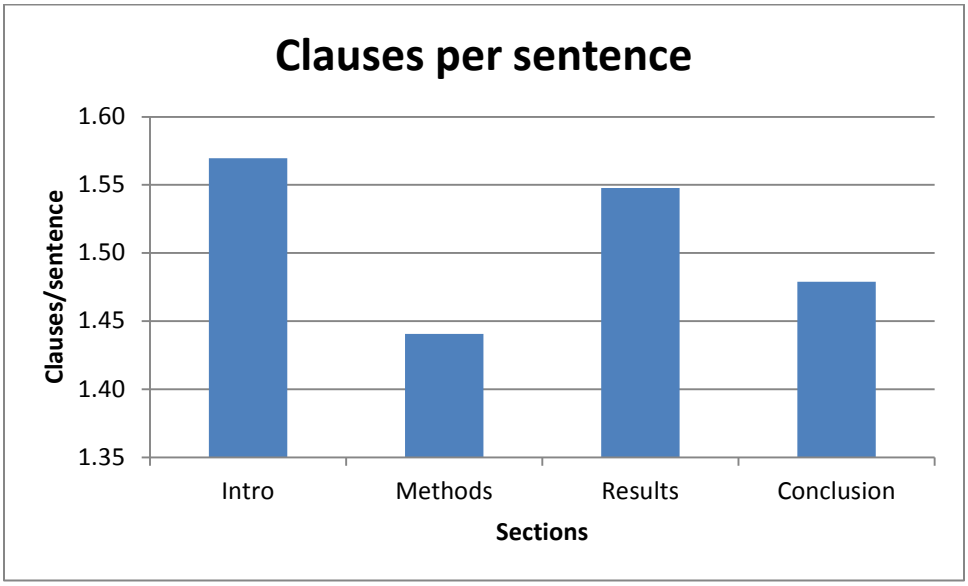

Figure 5.2. Clauses per sentence for each section

Three main types of dependent clauses were used to expand on ideas in the sample: adverbial, adjectival, and nominal. Table 5.12 displays the use of these clauses in the sample and seems to imply specific rhetorical implementation of the adjectival relative clause in the methods sections. This implementation is most likely due to the author's common choice to provide the reader with more information about the new

nouns they introduce in this section. The following excerpt from Alfaro and Villanova (2012) is an example of the expansion on new nouns: "Moreover, for each Θ_C obtained, the closed-loop control system robustness is measured using the maximum sensitivity, which is defined as follows" (p. 13185). Here, Alfaro and Villanova (2012) introduced the concept of maximum sensitivity to their algorithm. They do not assume that the reader is familiar with the calculations used to determine system robustness in the study, so they provide the reader with the mathematical definition of maximum sensitivity (a key factor in system robustness). The intriguing aspect of this information is the method that Alfaro and Villanova (2012) used to introduce this new information. They could have chosen to use a new sentence, but instead, they chose to use a relative clause to introduce the definition of maximum sensitivity.

Table 5.12. Use of dependent clauses

	Dependent Clauses		
Sections	% Adverbial	% Adjectival	% Nominal
Introduction	31%	57%	12%
Methods	34%	55%	10%
Results	34%	35%	31%
Conclusion	41%	33%	26%

5.2.3. Sentence Openers. Figure 5.3 shows the use of sentence openers in each of the major article sections of the sample. Prepositional phrases had the most overall uses (344), followed by adverbs (simple adverbs, conjunctive adverbs, etc.) like "however" (235), then subordinate clauses (83), and other sentence openers (72). The

"other" category of sentence openers includes types that were not used often in the sample: participial phrases, infinitive phrases, adjectival phrases, and gerundive phrases.

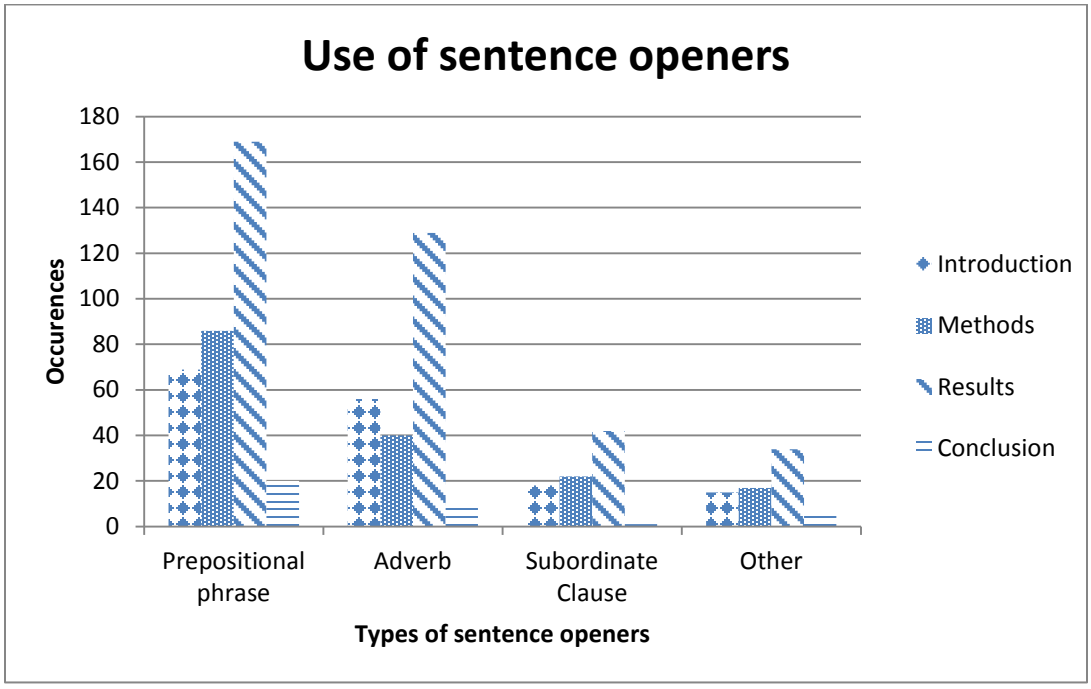

Figure 5.3. Use of sentence openers in sample

The results sections of the sample contained 50% of the total use of sentence openers in the sample. The large use of sentence openers in these sections may be due to the rhetorical purpose of the Results section. Rhetorically, the Results section of an engineering research article is the most important. The Results section summarizes collected data and justifies conclusions drawn from that data (Coghill and Garson, 2006, p. 27). The need for justification requires careful sentence construction to maintain the reader's interest when communicating the conclusions of the research. Also, the use of

subordinate clauses allows the authors to make inferences from their data without overstating their claims (hedging).

5.3. FIGURATIVE LANGUAGE

Few examples of figurative language were present in the sample. This does not prove that chemical engineering research article authors do not conventionally use figurative language in their writing, but it implies that these authors tend to avoid figurative language. The absence of figurative language in the sample complicates aggregate analysis of the data. However, I was able to record instances of figurative language during the analysis of the sample text including: parallelism, erotema, ellipsis, hypophora, and simile.

I relied on the descriptions of tropes and schemes provided by Corbett and Connors (1999) to identify figurative language in the sample. Their descriptions were used as a checklist that I referred to when reading through sample articles.

5.3.1. Parallelism . Corbett and Connors (1999) defined *parallelism* as "similarity of structure in a pair or series of related words, phrases, or clauses" (p. 381). Besides establishing similarity, parallelism also shows that the author has taken time to coherently organize his thoughts. Ignoring this foundational aspect of rhetoric and grammar can confuse the reader, and as shown by the previous findings, chemical engineering research authors strive for clarity in their messages.

The authors studied in the sample used parallelism more than any other figure of speech, and the following excerpt illustrates its use.

> The CLP comprises three reactors – the carbonation reactor, or carbonator, where thermodynamics constrain the reforming and the WGS reaction is overcome by the incessant removal of the CO_2 product and high quality H_2 is produced along with $CaCO_3$; the calciner where the CaO is regenerated and a sequestration-ready CO_2 stream is produced; and the hydrator where the regenerated sorbent is reactivated to improve its recyclability. (Ramkumar, Phalak, Fan, 2012, p. 1187)

Ramkumar, Phalak, and Fan (2012) used the same structure (noun + "where" + relative clause) to establish that the carbonation reactor, calciner, and hydrator are all equal parts of the CLP (closed-loop process). Also, they have condensed a plethora of information into one sentence without overtly increasing its complexity. The authors have established a pattern for the reader to follow (in this case, noun + "where" + relative clause), and the reader uses this pattern to anticipate the information that will be provided to him as he continues to read.

Other authors in the sample also used parallelism to prepare readers for the explanation of mathematical equations. The methods sections of the chemical engineering research articles in the sample always included equations and descriptions of the equation parameters. Authors often took advantage of parallelism to reduce the amount of text necessary to explain what each variable of an equation represented.

5.3.2. Erotema. Fahnestock (1999) discussed the rhetorical question (erotema) while covering Quintilian's views on the figures of thought. According to Fahnestock (1999), the figures of thought (such as erotema) "specify interactions between speaker and audience and reciprocal intentions and effects" (p. 197). Although one would not

expect authors of chemical engineering research articles to build relationships with their audiences through the use of rhetorical questions, several instances of erotema were present in the sample text. The following two excerpts are examples of erotema from the sample: “Other important questions treated in this section are: what is the influence of crystal size on filtration behavior? In what way do super saturation, stirring speed, and calcium carbonate concentration affect crystal growth, nucleation, and as a consequence, filtration behavior?” (Beck & Andreassen, p. 109). “How does the stability and phase behavior vary with process design and operation?” (Yuan et al., p. 3098).

Practically, the authors used these questions to clearly identify the material they plan to cover in the remainder of their article. By posing these questions, the authors have effectively narrowed the scope of their article to avoid refutation outside this scope, established the parameters of their research methods, and engaged the readers of their article. Also, note that the authors of the first and second excerpt chose not to directly answer their own questions. The lack of a direct answer supports the idea that these questions were more likely added to the text to build a relationship with the reader.

The relationship built through the use of erotema is interesting to consider. Throughout the entire sample, many authors used passive voice to emphasize objectivity in their research, but these instances of erotema violate that objectivity. The authors present these questions to their readers in their own voices and for a moment acknowledge that they are conversing with their readers. These questions, although practical, also ask for acceptance of the author’s way of thinking. Implicit in the formulation of “important questions” in the first excerpt is the subtle pact that the reader makes with the author. By continuing to read, the reader has no doubt answered the

author's question in the affirmative and as a result has confidence in the author's ability to present his case because both author and reader are on equal footing.

5.3.3. Hypophora. Hypophora is similar to erotema, but the details of the rhetorical question are slightly different. Erotema does not require the author to answer his rhetorical question, but, according to Fahnestock (1999), hypophora is the use of both the rhetorical question and a direct answer (p. 196). The effects of direct communication between author and reader associated with erotema are still applicable with hypophora, but the answer provided by the author sets up a unique framework in which the author can communicate his message.

The following excerpt serves as a good example of hypophora in chemical engineering discourse: "However, what type of numerical algorithm should be developed?" (Mokhtar et al., p. 88). Here, the authors posed a question directly to their readers. The authors chose to slowly answer this question, but eventually provided the answer, the Similar Particle Assembly (SPA) model. The question posed by the authors is clearly directed at the reader, but the answer to their question is aimed at the reader as well. The answer to the question may imply the absence of a reader (the authors are speaking to themselves), but it still represents direct communication with the reader. The authors are communicating with themselves and their readers simultaneously and persuade the reader to accept an idea as fact based on the authors' ability to answer their own question. Although the effect of this direct communication with the reader is similar to erotema, an author who chooses to use hypophora takes the interaction between author and reader a step farther by commanding the reader to accept a specific idea. This

question and answer reduces the ability of the reader to draw his own conclusions from the question because the conclusions have already been packaged for him.

From the author's perspective, hypophora can be a clever tool to ensure that the reader is interpreting one meaning from his writing. Also, the use of hypophora establishes a subtle expert-novice relationship between the author and the reader. The author provides the answer to his own question because he is the expert in the discussion and must indoctrinate the novice reader into accession with his ideas.

5.3.4. Ellipsis. Corbett and Connors (1999) defined *ellipsis* as the "deliberate omission of a word or of words which are readily implied by the context" (p. 387). The omission of implied words allows authors to minimize the amount of words necessary to communicate their point. Throughout the sample, authors occasionally chose to use ellipsis to explain the unknown factors of their equations. An example of ellipsis from the sample shows how engineering research article authors can use figurative language to communicate their ideas in fewer words. The following excerpt comes from the methods section of an article from the sample:

> We considered first the integrating second-order plus dead-time (ISOPDT) model given by the following:
>
> $$P(s) = \frac{Ke^{-1s}}{s(Ts+1)}$$
>
> where K is the gain, T the time constant, and L the dead-time. (Alfaro & Vilanova, 2012, p. 13185)

Here, the authors chose to omit words in three places where they were implied by the context of the sentence. First, the dependent clause ("given by the following") omits the subordinator ("which") and verb ("is") because neither is required to understand that clause is subordinate to the previous independent clause. However, the second and third omissions are of like kind. The last three dependent clauses in the sentence explain the unknown variables of the dead-time model, but the clause ("where K is the gain") is the only clause that does not omit the verb *is*. This first clause establishes a pattern that the reader can then use to interpret the remaining two clauses even though they omit the necessary verb (*is*).

The omissions also create a rhythm to the writing that is different from the prose encountered in other sections of the article. This rhythm and the "economy of expression" described by Corbett and Connors (1999) may be the reason for the use of ellipsis to explain unknown factors.

5.3.5. Simile. Similes relate the unfamiliar to the familiar to assist readers in comprehending new ideas. Similes are similar to metaphors, but lack the direct relationship created when authors use metaphor. Rather than promote a direct comparison, a simile implies a relationship between unlike objects or ideas. In chemical engineering research articles, authors are more often than not relating new information to their readers and sometimes choose to use simile to relate the new concepts to older, more familiar concepts. However, the sample also contained an instance of simile that helped to describe a visual calcite formation. Beck and Andreassen (2012) used terms *needle-like, plate-like,* and *cube-like* to describe the appearance of calcite crystals in their experiment. They could have referred to these formations by using any designation (a/b/c

or 1/2/3), but instead they chose to use familiar commonplace items to describe their calcite formations. Figure 5.4, Figure 5.5, and Figure 5.6 are microscopic images of the calcite crystals referenced by Beck and Andreassen (2012, p. 113).

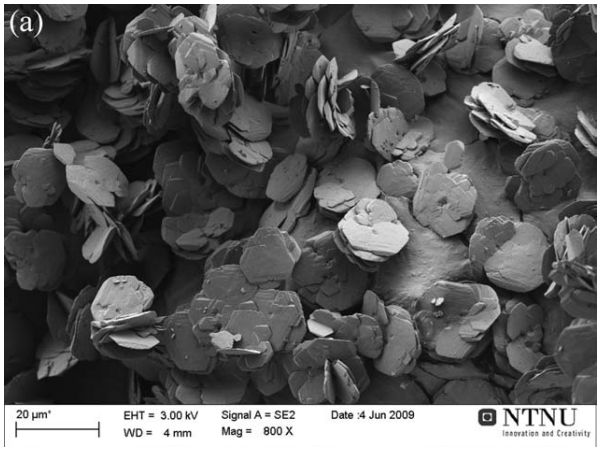

Figure 5.4. "Plate-like" calcite crystals

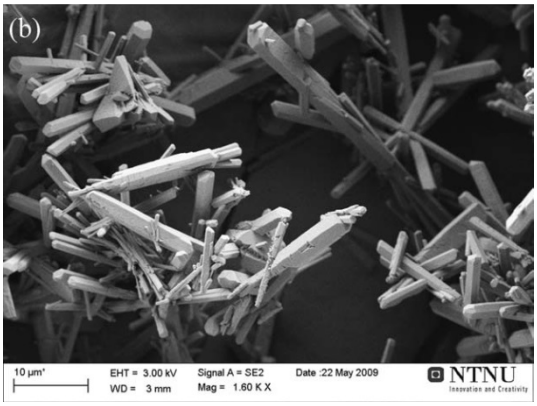

Figure 5.5. "Needle-like" calcite crystals

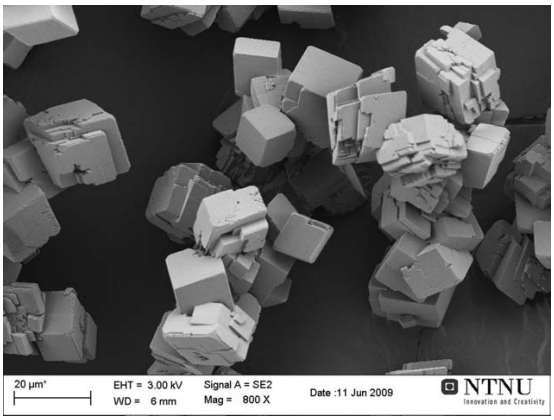

Figure 5.6. "Cube-like" calcite crystals

Although the “needle-like” description may be slightly questionable, the use of simile to reference these calcite crystals is continued throughout the article. Beck and Adreassen’s (2012) use of simile allows the reader to quickly associate the formation with its referent in the article. This association creates a cognitive link that readers use when interpreting the more detailed aspects of the experiment. Later in the article, Beck and Andreassen (2012) described how these crystals precipitated out of solution and how the shape factor of these crystals may give some clue into how these crystals formed. Had the authors chosen to use a generic referent like a/b/c for the crystals, the readers would not have been able to instantly visualize the actual particles, and their understanding of the material would have been impacted.

5.4. PARAGRAPHING

Similar to the other results, the data regarding sentences per paragraph cannot be generalized to the entire population of chemical engineering research articles. The standard deviation from each section listed in Table 5.13 shows that the variance in the

sample data does not provide enough evidence to validate generalization. However, some interesting trends were present in the sections of the sample with low number of sentences per paragraph.

Table 5.13. Sentences per paragraph per section

	Sentences/paragraph			
Article	Intro	Methods	Results	Conclusion
1	4.5	5.0	6.2	5.0
2	5.5	7.0	8.1	6.0
3	7.0	5.1	5.3	10.0
4	3.1	1.5	1.8	1.2
5	3.5	3.9	2.3	3.0
6	5.7	5.1	5.3	3.3
7	7.8	6.4	9.8	2.4
8	5.7	2.4	7.0	4.8
9	7.1	5.0	5.0	3.6
10	10.0	7.3	5.7	5.0
Avg.	6.0	4.9	5.6	4.4
Std. Dev	2.1	1.9	2.4	2.4

Each article from the sample contains at least one single-sentence paragraph. The following excerpt demonstrates this phenomenon:

> This [the figure that shows the optimized controller parameters] shows the influence of the controlled process dynamics and the desired robustness over the controller parameters required to meet the target step responses.

> The controller parameters obtained from the optimization procedure are used to fit the controller parameter equations of the proposed model reference robust tuning (MoReRT).
>
> The normalized controller parameters can be obtained with the following equations. (Alfaro & Vilanova, 2012, p. 13189).

Although these sentences stand alone as a single paragraph (indentation of first line) they do not meet the traditional definition of a paragraph. Corbett and Connors (1999) specifically stated that paragraphs convey larger units of thought that individual sentences cannot convey alone. However, these single-sentence "paragraphs" are actually a part of a larger unit of thought related to their surrounding "paragraphs." In the provided example, the authors needed to emphasize the link that their derivation of optimized controller parameters (first sentence) had with the parameter equations of their proposed MoReRT (third sentence). Without the second sentence, the reader must infer the connection between the first and third sentences from the results of the provided figure and the listed equations. Although the author has marked each of these sentences as an individual "paragraph," each sentence is actually part of a larger unit of thought that should have been marked as an individual paragraph. Each example of a single-sentence paragraph followed this same logical reasoning.

5.5. SUMMARY OF MAJOR TRENDS

Although all of the data presented is valid in some way, the small sample size of this study prevents generalization of identified trends to the overall population of chemical engineering research articles. However, some observations seemed prevalent

enough to be described as major trends. These major findings include the following observations about chemical engineering research article authors:

- prefer to use sentences with no more than two clauses
- actively use figurative language to achieve their communicative goals
- introduce passive voice as a tool to maintain objectivity
- often use simple sentences to convey their ideas
- do not actively vary sentence structure

6. DISCUSSION AND FUTURE RESEARCH

Research always invites criticism from the researcher after all of the data has been collected. This study was no different. After analyzing the data collected from the study, I considered two things I would have changed in the research: increase the sample size and focus on specific markers of style. In these sections, I explain the effect that these changes would have and the opportunities they present for future research.

6.1. SAMPLE SIZE

The goal of this study was to identify stylistic trends based on close analysis of actual research articles. However, when performing such detailed analysis, a large sample quickly becomes unmanageable. For this reason, I used a stratified random sample to construct a sample that was representative of the entire population. The sample captured relevant data about the population, but the variation in most of the data did not allow for generalization to the overall population of chemical engineering research articles.

With the exception of the major trends discussed in the previous section, the sample data varied too widely to form any solid conclusions. For example, the standard deviations in the Flesch Reading Ease Scores were equal to nearly half of the average. Fortunately, I was still able to describe the trends in the sample, and this analysis could still prove useful with further study. The Flesch Reading Ease Scores implied that the methods section of a chemical engineering research article is stylistically different from the other sections of the typical article, so further study could focus on specific variations

in the number of syllables, sentences, and words for each methods section of a larger sample. Other data (higher percentage of simple sentences, lower sentence variety, etc.) also seemed to imply a stark contrast in the style of the methods section, and a focus on the methods section instead of the entire article may prove fruitful in discovering the rhetorical differences that separate it from the remaining sections.

6.2. FOCUS ON INDIVIDUAL MARKERS OF STYLE

This study was the first that I am aware of to study the style of chemical engineering journal articles in this way. As a result, the study aimed to describe trends in chemical engineering research article style. Future research projects should each focus entirely on individual markers: rhetorical use of active voice, use of figurative language to build relationships between author and reader, etc.

Others have already begun to focus on individual aspects of style and produce interesting results. One example comes from Rodman's (1994) study on the use of active voice in scientific discourse. Because she was able to specifically isolate uses of active voice, she was able to create a large list of rhetorical cases for active voice in writing. This type of research project allows those interested in style to focus on one aspect of style and serves as a template for future research of chemical engineering communication.

Although the explanation of trends in this study did not match the level of detailed shown by Rodman (1994), it did identify trends that can be researched in depth to provide further explanation. The major trends discussed in the results section could all warrant specific attention, and the use of figurative language in engineering communication

seems to yield interesting results that one would not initially expect to find. In future studies, researchers should take the advice of Gross, Harmon, and Reidy (2002) and focus on individual markers of style.

7. CONCLUSION

From the start, this study had a large scope which seemed daunting. Countless chemical engineering research articles have been written, so any project that aims to describe the style of these articles as a whole will be difficult. Also, quantitatively analyzing the style of written text is an arduous task without standard procedures. Thankfully, Corbett and Connors (1999) provided a starting point that I was able to adapt to the purposes of this study, but quantifying written language still remains a difficult task. Consider the criticism that has been levied on readability formulas.

Overcoming the difficulty of this project, I was able to show that close analysis of chemical engineering literature can provide evidence for and against common conceptions associated with chemical engineering discourse. The most interesting result was the discovery that, contrary to popular belief, chemical engineering authors do not devote much effort to varying their sentence structure. However, the study also supported the belief that authors use passive voice as a tool to maintain the appearance of objectivity.

Regardless of the confirmation or refutation of common beliefs, this study was able to uncover important trends in the communication of chemical engineering research and provide rhetorical justification for their application. As a result, future research can focus on individual trends provided by the analysis of this sample of chemical engineering research articles. Future research can draw upon the findings of this study to

understand more about the way communication in engineering is similar and different from science.

Chemical engineering is still finding its niche as a discipline separate from its mechanical and electrical engineering roots. The study of communicative practices in chemical engineering literature may provide an opportunity for chemical engineering to further establish itself as a unique discipline. I cannot speak on the style of other engineering disciplines, but the trends identified in this study may be different enough from those disciplines to separate chemical engineering journal articles as unique from their counterparts. Regardless, understanding the communication practices of chemical engineering can provide technical communicators as well as rhetoricians with insights into the communicative practices of all disciplines (mechanical engineering, electrical engineering, chemistry) that the chemical engineering knowledge base draws from. Hopefully, others will be able to see this study and also draw upon it for future research into how engineering communicators craft arguments from experimental results.

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Upon completing the M. S. in Technical Communication, he will attend Texas Tech University to begin work on his PhD in Rhetoric and Technical Communication.