SCIENCE WRITING: SPECIALIST AND NON-SPECIALIST GENRE AND STYLE FROM THE LATE 19TH CENTURY AND THE EARLY 21ST CENTURY

By

Kara Marker

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Approved by:

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Dr. Gregory Wickliff

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Dr. Heather Vorhies

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Dr. Aaron Toscano

ABSTRACT

KARA MARKER. Science Writing: Specialist and Non-specialist Genre and Style from the Late 19^{th} Century and the Early 21^{st} Century. (Under the direction of DR. GREGORY WICKLIFF)

The first scientific journal was established in the 17th century. Over the last 140 years, science writing has developed along two clear lines targeting specialist and non-specialist audiences. In the 19th century, specialist publications *Nature* and *Science* and new periodicals targeting the non-specialist student of science *Popular Science* and *Scientific American* were founded. Now, in the first decades of the 21st century, writing in specialized scientific journals has become highly technical and often inaccessible to anyone outside of the field. The profession of popular science writing has also become more vital than ever as writers attempt to translate the important messages in scientific findings to a common language that the public, which funds most science research in the U.S., can understand. Identifying and understanding the development of key differences in style and genre between 21st century specialist and non-specialist writing is necessary for bridging the gap between science and the public. Additionally, tracking the genre's evolution over time reveals the key similarities and differences in the authors' purposes, audiences' expectations, and conventions of the science journal article as a whole. To accomplish these goals, I present a genre and style analysis of science writing from three key periods of time: the 17th century, the late 19th century, and the early 21st century. For the decades of the 19th and 21st centuries, I analyze selected articles to compare features in selected specialist (*Nature, Science*) and non-specialist (*Popular Science, Scientific American*) journal articles.

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CHAPTER 1: INTRODUCTION

Science writing reflects many changes in style and genre, from the 17th century when the first scientific journal in English was published, *Philosophical Transactions* (1665), to the 19th century when the genre developed into separate specialist and non-specialist forms. Yet more genre shifts had occurred by the 21st century, making it difficult to recognize that the popular and specialist articles evolved from a common ancestor. This thesis examines the frequency and range of rhetorical choices in the selected sample of science writing and explores what those choices suggest about an author's purpose, the audience's expectations, and how media and genre have shifted over time. The discussion presents a rhetorical analysis of 32 popular and specialist scientific articles. Half are drawn from printed sources published between 1880 and 1890, and half from electronic sources published between 2005 and 2015.

My analysis builds on the work of Jeanne Fahnestock, Charles Bazerman, Alan Gross, Joseph Harmon, Lawrence Prelli, and Katherine Rowan to categorize and analyze a wide range of genre and style features of the selected articles. These scholars have conducted studies and discussed ideas relevant to my analysis, and their work provides a vital foundation upon which I build my research. Fahnestock (1998) argues that when a scientific report travels from specialist to non-specialist publications, a change in rhetorical situation, there is a shift in genre from forensic to epideictic, citing two of Aristotle's three types of persuasive speech (333). These changes in rhetorical situation and genre, audience, and purpose, she argues, affect the style of writing in predictable ways. Fahnestock (2004) also illustrates how arguments on scientific issues travel from text to text by considering how certain figures of speech persist from version to version. She argues that analyzing the differences between specialist and non-specialist writing consists of more than just evaluating the differences in scientific accuracy: "at issue is how a scientific argument can be adapted for different audiences with different needs, interests, and background knowledge and yet remain recognizably the same argument" (8).

As Bazerman (1988, 1999) has done, I will approach scientific writing as a social practice, as a kind of work conducted by authors for particular audiences and purposes and through particular media as they make arguments for discovering new truths and try to popularize their findings or inventions. Bazerman (1988) argues that language is a socially structured creation, and "regularized forms of writing," like specialist and non-specialist science writing, "are social institutions, interacting with other social institutions" (21). As I analyze and compare textual features in different genres of science writing from different centuries, I base my analysis on Bazerman's idea that "the formation of genre reveals the forces to which textual features respond" (62). However, I also argue as Bazerman does that changes and variations in science texts mean more than the definition of a style and a genre, they "represent continuing realizations of social activity within social structured situations" (128).

With Thomas Kuhn (1962), I see science as making knowledge not only in a consistent way that builds upon the work of others, but also through periodic revolutions where old paradigms cannot answer new questions that arise: "the successive transition from one paradigm to another via revolution is the usual developmental pattern of mature science" (12). Between revolutions, Kuhn describes "normal science" as "research firmly based upon one or more past scientific achievements that some particular scientific community acknowledges for a time as supplying the foundation for its further practice" (10). To understand how science writing has evolved over time, one must first understand how the science itself has evolved, as well as the factors that drive its evolution. Kuhn argues that scientific revolutions are caused by a paradigm change, which are caused by malfunctions in existing paradigms that lead to a crisis: "scientific revolutions are here taken to be those non-cumulative developmental episodes in which an older paradigm is replaced in whole or in part by an incompatible new one" (92). Kuhn also points out that revolutions - paradigm changes - cause scientists to change their worldview, to "see the world of their research engagement differently" (111).

With Alan Gross and Joseph Harmon, I understand that evaluating style in scientific writing is important as feature of science, with style being something that "scholars of science - rhetoricians, of course, but philosophers and historians as well - regularly select when they analyze scientific texts" (9). They also argue that "descriptive prose lacks the power a technical vocabulary gives: the ability to communicate common patterns well below the surface of the often misleading impressions of the senses" (19). Gross, Harmon, and Reidy explain that scientific articles changed over time and will likely continue to change because experiments become increasingly complex, pushing scientists to rely on tables and figures as references (30). Although, no matter how much the scientific article changes, they also argue that, at least between 17th century and 20th century science writing, authors shared a "relentless focus on the natural world as an object of explanation and the need to argue into place facts and theories about it" (17-18).

Prelli also argues that the "analysis of the rhetorical features of scientific communication can reveal aspects of doing science that are not otherwise readily perceived" (218). Prelli, like Bazerman, argues that science writing is strategic and is created to become accepted as reasonable by a specialist audience based on a kind of logic for treating the topic that the readers and authors share, like the need to provide a particular kind and number of examples for support in a given field of study (257). With Prelli, through Aristotle, I recognize that scientists persuade readers through appeals to their credibility and even to emotions, as well as through logic and mathematics. Pulling from Aristotle, Lawrence Prelli claims that scientific rhetoric often treats topics in certain ways through topoi, or conventional strategies for making an argument: "I have observed what rhetors dealing with science do, and I have found that they do what general theory of rhetoric predicts they will do" (257).

Rowan (1989) argues that it is necessary to understand the author's purpose to be able to explain and evaluate language use (161). She demonstrates this necessity and illustrates the stylistic differences between specialist and non-specialist writing by comparing the two genres when scientist-authors and science writers write on the same topic (176). Rowan argues that past analyses of science writing, specialist and non-specialist, have produced flawed conclusions because researchers did not consider the different goals among authors of different genres (162). Rowan states that the reason is an "inadequate appreciation of the distinctive goals pursued by popular and professional science writers" (162). By considering the different goals of each genre, I, like Rowan, can explain "why professional and popular science texts share some rhetorical and stylistic features but not others" (163). Additionally, goals impact style choices: "Because they have these differing emphases, professional and popular science writers have different motivating purposes in mind" (166). Rowan (1991) also argues that science writers need to understand their audience to help their audience understand science. That communication goes beyond using simple language and figurative language to explain concepts. Writing has to overcome counterintuitive ideas like gravity and motion and lay theories. Rowan argues that science writers need to explain scientific ideas effectively, and "writers need to be aware of the kinds of scientific ideas that are difficult because of their implausibility and of the text strategies that can help readers overcome compelling lay theories and comprehend more accepted notions" (372).

As a theoretical framework, I adopt Bazerman's (1988) idea of science as a "sociolinguistic system" materialized from the "socially contexted language choices of language users" (149). I embrace Kuhn's (1962) concept of a paradigm as defining scientific revolutions and normal science. I accept that "to desert the paradigm is to cease practicing the science it defines," but desertions do occur, and when they do they are the "pivots about which scientific revolutions turn" (34). Scientific rhetoric is constrained and structured by criteria associated with the scientific method (Prelli 257). Lastly, I adopt Fahnestock's idea of genre shift in light of a change in rhetorical situation and combine this with a variation of Rowan's analytic approach to categorizing features of genre and style in scientific writing, to present a detailed comparison between specialist and non-specialist science writing of the late 19th century and early 21st century.

1.1 Why study science writing?

Whether from specialist or non-specialist sources, science writing is the medium responsible for reaching the public with information on the latest scientific advances, including findings in medicine, the environment, and physics. Findings in medicine inform people about their health and the diseases of the world; findings in environmental science illustrate how the Earth is changing and what that means for the future; and findings in physics and chemistry aim to answer the hard questions: Where did life begin? Where will life end? What's the point of it all? As Jeroen De Ridder (2014) argues, those who believe in the idea of "scientism" believe that science makes philosophy and philosophical answers to similar questions irrelevant, with science being the answer to any and all questions people of the world might have about their existence. And S. Michael Halloran (1978) argues that "science/technology has become the most important source of legitimacy for ideas, policies, commodities - in short, for all the loci of choice and commitment in modern life" (86). Science writing needs to deliver a strong message to avoid misinformation. Not everyone can be an expert, and the non-experts rely on science writing to learn how the world works. Without a solid connection between specialist and non-specialist writing, the non-experts of the world may give up on trying to make sense of otherwise credible scientific findings, as in the current debates over the human causes of climate change. Rowan (1991) agrees: "the conflict between lay and scientific accounts can lead people to reject, ignore, or systematically misunderstand fundamental aspects of science, aspects that can affect their health and safety" (372).

Effective authors consider the audience's needs and expectations in the context of any form of writing. This consideration is especially true in science writing, because the distribution of claims is so important. In today's political and social climate, it is too common for people to read science writing with distrust even if those authors are experts in their field. The non-scientist often chooses to believe instead in something false or misguided because it fits better with a particular cultural belief. The basic difficulty of persuading non-specialists who may not assign credibility to scientific authors will only be exacerbated by science writing that is highly technical or otherwise styled and presented in such a way that it is difficult to comprehend for the non-specialist.

Over the past century and a half, the genres of the British and American scientific article and the popular science article have developed and evolved a great deal. In their book *The Scientific Literature: A Guided Tour,* Joseph E. Harmon and Alan G. Gross (2007) discuss the evolution of scientific writing, which began with printed books and personal correspondence before it transitioned into scholarly articles (2). As the scientific revolution spread throughout England, other European countries, and in America, Harmon and Gross explain, the "accelerated pace of scientific activity compelled philosophers to communicate their recent findings through personal correspondence" with the understanding that, although the letters were addressed to a particular recipient as per tradition, they could expect multiple natural philosophers to read their research findings (2). During the 17th century, natural philosophers promoted use of the "plain style" to improve clarity in science writing. According to Elizabeth Tebeaux, components of the plain style include direct statements, shorter sentences, and words with a "single meaning," because the plain style does not include "specious tropes," "superfluity," or "rhetorical elements" like the metaphor (54). These are instead the qualities of the "luxurious style" away from which scientists and other writers wanted to move.

In the modern era, the separation that grew between specialist and non-specialist writing calls for a fresh perspective on analyzing scientific writing. For example, in

“Preserving the Figure: Consistency in the Presentation of Scientific Arguments,” Jeanne Fahnestock discusses how scientific arguments change between specialist and non-specialist writing: “at issue is how a scientific argument can be adapted for different audiences with different needs, interests, and background knowledge and yet remain recognizably the same argument” (8). The same issue develops for communicating facts in scientific writing between sources like *Science* and sources like *Popular Science.* By the 19th century, the academic journal article had become more specialized in an increasing number of scientific disciplines. Popular science magazine articles increased in their number and variety, too. With the development of the internet, specialized and popular science articles are now, in the 21st century, most often distributed as online publications, with the possibilities for linking that this creates. A genre and style analysis of a representative sample of articles shows how the audiences, purposes, and contents have changed across time and media. Scientists read the academic journal article to stay updated in a particular field and to study specific methods for use in their own research. Research findings are reported in prestigious refereed scholarly journals like *Nature* (1869) and *Science* (1880). A non-scientist reads a popular article to gain a basic understanding of broad topics, based on articles that they find interesting or which boast findings of a new discovery. In his article “Discourse studies of scientific popularization: questioning the boundaries,” Greg Myers critiques the idea that scientific articles are only simplified to become suitable for the public, arguing against the idea that the popularization of science is a one-way process (265).

I am also interested in uncovering and describing rhetorical strategies that continue to function in science writing, from the time that the British natural philosophers in the 17th century first published in *Philosophical Transactions*, to new, online rhetorical strategies used by specialists in the 21st century. How have the audiences, purposes, and media for science writing and publishing changed within the genre of the periodical article? What were and are the social motives for publishing scientific articles? For example, in *The Languages of Edison's Light* Charles Bazerman discusses Thomas Edison's experience of being pressured to publish due to competition, explaining that the "necessity of claiming priority in the face of competition drove Edison to rapid and complete disclosure and demonstration at the right moment" (28).

Accessing information in the 21st century has never been easier, and the world of 19th century publishing is documented well online through the distribution of digital scans, also. However, convincing readers of arguments for the truth has also never been harder. Whether it is the need to be able to critique a specialist's methods to decipher what is more or less credible, or the need to understand specialized vocabulary to comprehend an article, understanding arguments for truth about any given topic requires more than just a Google search and a page of "relevant" results. In the 21st century, the quantity of electronically published research can make it difficult for each work to appear in a keyword or relevance search. The new genre feature of a keyword or search term list addresses this audience need in part. Fahnestock acknowledges a problem in science writing that I will address: "the absence of clear, figurally expressed core arguments in original, research reports may work against the ability of new research to travel to other audiences" (23-24).

This thesis explores how scientific articles written in English functioned in the late 19th century, and how they have functioned in the early 21st century for a global audience. I also note trends that are likely to shape science communication in the future. I will be focusing specifically on the authors' purposes, the audience's needs and expectations, and the medium's potential and limits, as well as the text and illustrations of each article.

In its entirety, this thesis will present a unique analysis. It will include some fundamental comparisons between the earliest examples of formal scientific writing in the 17th century through the British *Philosophical Transactions* – a time of stylistic revolution for natural philosophers – and scientific writing in its 19th and 21st century forms. As Myers points out, by comparing popular science articles like *Scientific American* and research articles in scholarly journals like *Nature,* we can observe "differences in textual form, in the sentence subjects, grammatical voice, verb choices, modality and hedging, and, of course, rhetorical structure" (266).

The thesis explores the developments within the genres and style of popular and specialist scientific writing that have developed since 1880 in the United States especially. It reveals the rhetorical strategies that authors have used to accommodate audiences with different levels of background knowledge on the subject matter over time. It demonstrates how scientists whose work is included in the sample texts have adapted their writing for the social situation. It considers both the limits and the potential of science writing in specialized and popular periodical articles.

CHAPTER 2: LITERATURE REVIEW

The body of literature that surrounds science and science writing is rich with history, philosophy, and rhetoric. The history of the plain style, the academic revolution, and the scientific article provide a historical context for comparing style and genre of science writing from different periods in time. The discussion of science as an institution, how science changes during revolutions, and the relationship between science and progress provides a framework for analyzing an author's purpose and a reader's expectations. My research extends from the 17th century to the 21st century, focusing more on specialist discourse than non-specialist discourse. This review provides a beginning look into new conventions of internet age science communication and how it has shaped developing genres.

2.1 17th century science writing

Scientific writing at the end of the 17th century went through a significant stylistic change as members of the natural philosophy community called for a transition to the plain style, unadorned by rhetorical devices such as figurative language and appeals to pathos. The new style would be focused on "the truth," on observable facets of nature, as well as objectivity and plainness in discourse. With the transition to the plain style, the scientific writing genre began to change drastically, starting with a stylistic purgatory period experienced by scientific writing caught in between the old style, a flowery, luxurious prose, and the new plain style, prose based on facts that omits rhetorical devices that take the reader's attention away from the facts of observations and experiments. Natural philosophers of the time, such as Francis Bacon, argued that words can be misleading, and a careful choice of words was required to convey a concise message and to prevent the production of "idle fancies" (Vickers 1989, 8).

It is important to understand how various scholars defined the plain style. Elizabeth Tebeaux (2014) describes the plain style as "unadorned sentences about emphasizing tight subject-verb-object structure" (29). Gross, Harmon, and Reidy argue that the "word 'plain' definitely applies when it comes to neutral, inornate language," but "it does not apply to sentence structure" (40). According to Tebeaux, components of the plain style include direct statements, shorter sentences, and words with a "single meaning," and she argues that the plain style does not include "specious tropes," "superfluity," or "rhetorical elements" like the metaphor (54). These are the qualities of the "luxurious style" away from which scientists and other writers wanted to move.

Carol Lipson (1985) describes Francis Bacon's adherence to the plain style as "simplifying sentence structures," avoiding redundant phrases, writing "succinctly" and with clarity, and rejecting superfluity (144). Bacon's "plain" language is not "plain in the sense of merely using ordinary, simple language," Lipson argues (145). In fact, Bacon considers language or words described as common, ordinary, or existing to carry multiple meanings that can cause misunderstandings, that obstruct clarity. Because of this, Bacon instead considers creating a completely new language, as he is inspired by the symbols created and used in mathematics. Bacon's new language would, in theory, focus on improving clarity by "giving new, more logical names to phenomena whose names [Bacon] finds unsystematic" (148). However, with the birth of a new language comes the birth of "jargon-based prose of modern technical and scientific writing," Lipson points out. She refers to jargon, specialized terms, and a "special lexicon" as potential problems that would result from Bacon's new language, and these problems are certainly familiar in modern-day scientific writing (146). Like Tebeaux, Richard F. Jones (1930) describes the language of the seventeenth century before the plain style – also referred to as the naked style - as "luxuriant," and Jones uses many phrases to describe the transition to plain language, including an "organized revolt," a "condemnation of the old," and a "new standard of expression" (977).

What caused the shift to the plain style? Tebeaux (2014) offers two reasons: for instruction or teaching, and for the "middle-class English reader" who could not read Latin (29). The initial push toward the plain style was simultaneously based on a push for clarity and objectivity in writing as well as an opposition to rhetorical devices. Like any author who writes with a particular audience in mind, writers of how-to books eventually realized that the language of those books needed to be different from fiction and "religious works" that are read meditatively or leisurely (55). For scientists, and potentially also for authors writing for an audience who reads to learn to do, ideas about the style of writing changed because they became more concerned about communicating the absolute truth. As science advanced, concerns about properly telling the public about discoveries advanced as well. Whether for science or for instruction, writers of the plain style were focused on "conveying information," which desperately called for a style that "preserved the spoken quality of instructions while being direct and concise" (Tebeaux 2014, 55).

The 17th century opposition to rhetoric also played a large role in natural philosophers' preference of the plain style: "to the seventeenth-century amateurs of science, rhetoric was just an elaborate system of verbal mannerisms, with no relationship to thought or reality, and thus no intellectual significance (Halloran 1978, 79). They deplored this idea of rhetoric and instead clung to the idea of the plain style. Sprat and others believed that rhetoric "had to do with words only; science was knowledge of things, and as such could have no use for an art of verbal cosmetics. A true scientist would not use words to please an audience, but merely to point his colleagues toward the things that were his real concern" (79-80).

The style of science writing was also changing because scientific research was changing. Natural philosophers wanted science writing to be more objective and free from "ornaments of speech, similitudes, treasury of eloquence, and such like emptiness" (Vickers 1989, 9). Their plan of action revolved around focusing on science, the "natural world," and "purging language of its imperfections" to accurately communicate truths of the natural world (9). They wanted a form of writing that was raw so any extra words did not take away from the focus of observation of nature. What Vickers calls "antiquities" as part of "literary traditions" were to be abandoned (9). Vickers cites Robert Hooke's complaint concerning the present explanations of the concept of light, that their word choice did not describe the concept clearly: "writers having 'spoken of it as it were Metaphorically and by Similitudes,' their science consisting of 'Rhetorical Embellishments, and no way tending to the Physical Explanation of its Effects and Proprieties'" (10). Hooke's complaint matches the complaints of others, like Bacon, who were vying for the plain style because the current style of writing was focusing on what they perceived as the wrong parts, "Rhetorical Embellishments" instead of "Effects and Properties," a subjective narrative instead of an objective account. Just as Lipson describes Bacon's consideration of creating a completely new language and his inspiration by the symbols created and used in mathematics, Vickers describes the idea expressed by members of the Royal Society that the development of "another lexicon, of established "technical words," should be prepared" (19). In their defense, natural philosophers claimed that "no equivalent existed in English for the 'hard words' or technical terms of the sciences" (19). The new lexicon and the transition to the plain style was so important to the members of the Royal Society that they set up a committee in 1664 devoted to improving the English language to fit their needs.

Fear of misunderstanding also played a role in the transition to the plain style. Natural philosophers were afraid that eloquence, "overly grandiose rhetoric," not only blocks the reception of logic, but it also "destroys meaning" (Tillery 2005, 281). Appeals to pathos in writing, through eloquence and in meaning, created problems for both the writer and the reader: eloquent discourse is likely to "challenge the rhetor's ability to create meaning as well as the audience's ability to acquire it" (281). In response to the problems of logic and meaning when eloquence is present in scientific discourse, some Royal Society members saw an opportunity for the "redemption of humanity" by "reforming language as well as knowledge" (280). William H. Youngren (1968) describes a "growing distrust of figurative language and the free-ranging imagination" as a major factor behind the transition to the plain style (159). Writers from all genres were beginning to associate clear, objective writing with the truth, and anything that was not in the plain style was often thought of as untrustworthy (160 – 161). Instead, writers trusted the "clear literal statement, stylistic balance and sound sense" (160 – 161). Like Tebeaux, Youngren makes continuous references to and stresses the importance of writing with clarity. Richard F. Jones (1930) takes Youngren's idea of the "distrust of figurative language" to mean that the plain language movement is both pro-plain and anti-subjective. Jones describes how natural philosophers in the second half of the seventeenth century were learning more about certain stylistic changes they wanted to make to improve the clarity and overall quality of their writing, to promote the idea that science leads to probabilities and not absolute truths: "the substitution of general for technical terms, the preference for skeptical as opposed to dogmatic modes of thought and speech, the horror of pedantry, the trend toward precision of word and idea, and the attempt to make literature approximate conversation" (1008).

Gender and an anxiety about women's increasing levels of literacy may have been a motive for change as well. Part of the transition to the plain style seemed to stem from natural philosophers who wanted to steer scientific discourse away from "elements associated with femininity" toward a style that was more "masculine" (Tillery 2005, 273). In their crusade against rhetorical devices such as appeals to pathos in scientific discourse, men of the Royal Society were driven by an anxiety that such devices would prevent the reader from reaching the truth of the writing, as they could be distracted by passions. Women science writers of the time, with no place in the Royal Society, "were likely to eschew its rhetoric of control," and thus, they experienced the revolution of scientific discourse very differently, an aspect of the 17th century scientific revolution that has been little explored (276). According to Tebeaux, women writers used both a personal and objective plain style, even though the Royal Society was more concerned with the objective plain style, which rejected "ornamental figures and 'emotive diction'" (275).

Despite the intentions of natural philosophers at the time to improve communication of the facts, the change to the plain style ultimately was an overreaction to flowery, subjective prose. Merrill Whitburn et al. (1978) argue that “in reacting against ornateness, however, scientists developed the ideal of a plain style that is itself problematic” (349). The initial intention for transitioning to the plain style was to better communicate the truth, yet sometime between the 17th century and the present, the plain style evolved into a jargon-based, specialized language that only those sharing in a specialized study can understand. Could the natural philosophers of the 17th century Royal Society have predicted how technical and specialized science would become? If the plain style produces truly a focus on facts, would it be accurate to say that present-day scientific writing is based on the plain style? During the scientific revolution of the 17th century, natural philosophers were worried that a writer would become more “intrigued with rhetorical devices than the search for truth” (Whitburn et al. 1978, 350). Whitburn et al. argue that the ideal of a plain style should be interrogated – it should be contested – considering the foundation behind the drive of the proponents of the plain style: “revolutions are typically reactions against excesses, and the reactions are often as excessive as the original abuses” (352). While the members of the Royal Society were having their discussions on style, their counterparts across the ocean had similar ideas.

Did Americans independently come to the same conclusion as the Royal Society as far as the appropriate style for writing about scientific findings being the plain style? Margaret W. Batschelet (1988) describes how Sprat and other proponents of the plain style influenced American natural philosophers as the 17th century came to a close. She points out that the Puritan sermon, which provided a foundation for American science writing, was a “prose model which fulfilled many of the Royal Society’s demands [and] was admirably suited to their purposes” (288). The organization of the Puritan sermon was uniform, presented in sections with headings such as text, doctrine, and uses. Those who delivered and read the sermons “stressed the importance of a clear, logical connection between the sections” (289). The genre of the Puritan sermon continuously accentuated content above everything else. Authors of sermons were concerned about readers and listeners, as Batschelet calls the Puritan sermon “reader-based prose” (289). Also, the Puritan sermon was designed to avoid “foreign phrases which the people do not understand,” indicating the author’s acknowledgment of the audience’s needs (289).

Scientific writing from the 17th century, whether influenced by the plain style or not, was heavily laden with observations and reports of natural events, technological and medical advances, and travelogues, but it would be several centuries before anything resembling the contemporary scientific article would appear: “despite our current belief in experiment as one of the foundations of science, only a small part of the volumes examined up to 1800 were devoted to reporting on experiments” (Bazerman 1988, 65). Compared to 21st century specialist writing, 17th century findings “are described vaguely and qualitatively, as though the phenomena of nature were robust, uniform, and self-evident. As disputes arise over reported results, writers become more careful about reporting what they see, and measurement takes a greater role” (72). As opposed to scientific writing from the 21st century, “early scientific articles seek to establish credibility more by means of reliable testimony than by technical details, more by qualitative experience than by quantitative experiment and observation in support of theory” (Gross, Harmon, and Reidy 34).

Gross, Harmon, and Reidy argue that even in the late 17th century, the maturation of an international style of scientific writing was already underway (40). The 17th century scientific article often tells a story, with authors using many first-person personal pronouns and proper names. Bazerman (1988) adds that several important stylistic features of the early *Philosophical Transactions* included "chatty informativeness; the assumption that the readers are knowledgeable about the subject at hand and are therefore only looking for the latest news, which they will largely know how to interpret; and the consistently complimentary tone, aimed at encouraging continued cooperation" (131). Gross, Harmon, and Reidy describe it as "bookkeeping of nature" instead of a "synthesis of factual information into a unified theory" (4). Many articles from this era were also written to be read out loud, "before a learned audience sharing a curiosity about nature and technology" (43). However, in their study of 17th century science writing, the authors found that English prose in this context is "largely objective and impersonal" (37).

2.2 The Academic Revolution, Circa 1865

The scientific community and its discourse underwent great changes in the 19th century, especially in the United States. The post-Civil War years between 1865 and 1910 were particularly formative for the American research university, which developed as "a series of research groups" responding to rising opportunities as part of an academic revolution (Veysey 172; Etzkowitz 110). In addition to the traditional task of teaching, faculty began to adopt research as a key university function (Etzkowitz 110). Braeman lists several factors that made academic reform possible in this time period:

> European, especially German, models; the availability of surplus capital; the declining influence and enrollments of the old-time college; the knowledge explosion; and the growing irrelevance of the traditional curriculum, with its emphasis upon mental discipline, the inculcation of piety, and character-building, in an increasingly secularized and urban world. (172)

Etzkowitz agrees that the birth of the American research university was largely connected to finances, citing a "lack of a formal research funding system" as putting pressure on "individual and collective initiatives to obtain resources and to support original investigation" (109).

However, academic reformers were divided, mainly between practicality and research for its own sake. As of 1910 the "prevailing philosophy" became an "uneasy marriage of utility and research in which utility was the dominant partner" (Veysey 172). Before 1890, intellectuals argued about the purpose of the university; after 1890 they argued about the management of the university. Veysey argues that the administrative centralization that developed in the last decade of the 19th century was the "most significant feature of the academic structure that emerged" (173). This administrative centralization was vital for the university system to counter internal diversity and fragmentation as well as to maintain the research university as an institution.

The research university's place in society during its formative years slowly replaced the country's churches as a reservoir of "intellectual and cultural leaders" who would represent the country's democratic culture as its "arbiters and generators" (Jewett 792). The belief in the potential of science, what Jewett calls "scientific democracy," became “an alternative to liberal Protestantism, though it did not stand in opposition to liberal Protestantism” (792).

Through the birth of the research university, science offered Americans a means for promoting democratic practices by translating findings from research to industry. Ultimately, Jewett argues, the scientific democracy movement failed to achieve its political goals, but it did promote the growth of scientific authority overall (792). The social mission of the research university helped it reach even the “discontented minority” as the institution grew to be the “center for scientific and scholarly research,” and the primary products of that research became articles and books (Veysey 173). And despite the changes that occurred in science as a result of the academic revolution, 19th century science writing had changed but still looked more like its “17th century origins than the highly compressed, neutral, monotonal prose of the late 20th century” (Gross, Harmon, and Reidy 137). Science writing would go through significant changes before it resembled what we know today as contemporary science writing.

2.3 Popularization and specialization in the 19th Century

The popularization of science also played a role in establishing the modern research university. Jewett states that American scientific democracy “found a popular audience in the last few decades of the nineteenth century, thanks to the publishing efforts of Edward L. Youmans, the founder of *Popular Science Monthly*” (Jewett 792). For as the American research university was finding its feet and learning to walk, science writing was evolving in two directions: publication in specialized journals written for an often small audience with scientific expertise, and non-specialist journals written for an audience with little expertise, members of which were mainly interested in simply staying informed about the latest scientific findings. Fahnestock (2004) defines science popularization as a “special case of a general process by which versions of a core message travel to or are adapted for different contexts” and a non-specialist reader as one who is either not a scientist at all or a “scientist outside the narrow field represented by a particular research report” (7-8, 11). Professionalization and specialization of the 19th century also resulted in new identities for the scientist, “nurtured and reinforced by such social factors as the proliferation of societies for the special sciences” (Gross, Harmon, and Reidy 118).

Myers argues that part of the reason for this split was that scientists were interested in refining their field, deviating from the norm of the past two centuries that allowed admission to the scientific community for all gentlemen with sufficient resources and time to engage in scientific research: “one by one, disciplines were institutionalized and amateurs excluded” (Myers 268). When specialist publications started becoming difficult to read for individuals outside of a given field, it was often due to “increasing precision and detail of method and result” that developed as a result of changing accessibility of experimental demonstrations for journal readers (Bazerman 1988 73). Experiments grew longer, arguments grew longer, and the articles as a whole grew longer. Gross, Harmon, and Reidy concur that moving toward uniformity and formalization had a lasting change on the reader-author dynamic: “more and more, specialization and professionalization excluded from the readership of the scientific literature the self-instructed enthusiast for whom science was a part-time occupation or hobby, in favor of individuals institutionally trained at an advanced level and earning their living by means of science alone” (118). As self-instructed enthusiasts were excluded, they found their way to non-specialist publications like *Popular Science* and *Scientific American* because, although they were not professionally practicing science, they could still stay up to date on the latest findings.

Bazerman echos the statement by Gross, Harmon, and Reidy that science in the 19th century was changing as it became a profession, not a hobby: “prestige lent legitimacy to the work itself. It is one thing to mix chemicals in the back shed at the estate; it is another to be in contact with a secretive brotherhood of suspect alchemists; and it is quite another to participate in open demonstrations as part of a prestigious social institution” (138). Those enthusiasts who were not members of the social institution of scientific research instead became readers of non-specialist publications, which further distinguished them from their more prestigious and educated peers.

The distinction between scientists and non-scientists would ultimately be very influential in the massive growth of scientific research that would follow in the coming decades. Eventually, specialization and the idea of an “expert” would become tightly refined: “experts become less expert as soon as they step outside their very limited specialism” (Myers 268). Another factor that led to the increased specialization and professionalization in the 19th century was the development of the connection between science as a profession and journal publication, which rose steadily and steeply during the 19th century. Gross, Harmon, and Reidy argue that this resulted in an “influx of individual articles primarily aimed at subject-matter experts” and that it “spawned the first specialty journals in natural history” (117). With the creation of specialty journals, scientific specialists had a place to publish specific findings that may not have interested other, more generally-practicing scientists. Specialty journals allowed scientists to form smaller and smaller groups based on very specific aspects of science that each group wanted to study.

Greg Myers also argues that the 19th century split between specialist and non-specialist writing represented the dominant or canonical view that there are “two separate discourses, one within scientific institutions and one outside them” (Myers 266). As I will demonstrate, the popular and specialist genres began to evolve. And as science writing became adapted either for specialists or non-specialists but not both, differences in writing style followed. As Myers argues, “there will certainly be some differences in textual form, in the sentence subjects, grammatical voice, verb choices, modality and hedging, and, of course, the rhetorical structure” (266). In addition to affecting textual features of the scientific style, specialization and professionalization also benefited scientist-authors by protecting them from “facing the judgment of the entire scientific community” (Bazerman 1988, 145). Instead, scientists publishing in a specialized journal would only draw readers with similar specialties, lowering the odds that a scientist outside of the field would criticize their work. The majority of scientists who would read their publications would be those who understood the intricacies of the specialty.

According to Kuhn (1962), a scientist in a scientific group picks up where the textbook leaves off. Instead of writing articles intended for “anyone who might be interested in the subject matter of the field,” they prepare articles “addressed only to professional colleagues, the men whose knowledge of a shared paradigm can be assumed and who prove to be the only ones able to read the papers addressed to them” (20). The process of specialization and professionalization allowed scientists sharing different paradigms to connect and communicate through specialist journals. Kuhn also states that the scientific specializations that continue utilizing the textbook for research communication purposes are usually those that are "still so loosely drawn that the layman may hope to follow progress by reading the practitioners' original reports" (20).

Kuhn describes the beginning of specialization, the development of a new science that includes increasing rigidity, refining concepts, and developing an esoteric vocabulary (64). Revolution also plays a role, in both the creation of a new science and the extended specialization of an existing science: "revolution narrows the scope of the community's professional concerns, increases the extent of its specialization, and attenuates its communication with other groups, both scientific and lay" (169). Paradigms determine operations, measurements, and manipulations, but not just inside the laboratory, Kuhn argues, and because of this, "scientists with different paradigms engage in different concrete laboratory manipulations" (126).

Lastly, Brouse points out a problem with professionalism in that it negatively affects a scientist's writing, that "the man writing with an eye to publication in his journal feels he must live up to the image of the profession. The image of professionalism in writing is too often significant opacity" (76). The scientist filters his writing to fit the specialized journal instead of writing directly from his research findings.

2.4 The scientific research article in the 19th and 21st Centuries

Studying the scientific article, as opposed to the textbook or other science writing, is important because it is "an accurate reflection of the world as science conceives it, an effective means of securing the claims of science, and an efficient medium for communicating the knowledge it creates" (Gross, Harmon, and Reidy ix). Textbooks are the "pedagogic vehicles for the perpetuation of normal science," but the scientific article has the potential to push the boundaries of paradigms (Kuhn 136). English prose in scientific writing is efficient because it is intended to be objective, and objective because it is intended to be efficient. Gross, Harmon, and Reidy argue that it is also so because its purpose is to "lay bare for close scrutiny the arguments that scientists make in establishing new facts and explanations about the material world" (216).

Myers argues that "in the dominant view of popularization, a research article (preferably just one) is the ultimate source of undiluted and undistorted science" (270). In the 17th century though, the scientific research article was yet to be born; printed books and handwritten letters were its ancestors, providing revelations about the natural world that spawned the scientific revolution" (Harmon and Gross 2007, 1). Letters as a form of scientific writing were addressed to a recipient, but other than that, they were very different from traditional letters of correspondence. Instead, natural philosophers would write these letters "with the understanding that they would be passed on to others" (2). And as the scientific article began to take its form, science as a profession was still developing, and the reader was forced to trust the author for the facts they read in the article, which often included "qualitative experience more than experiment and measurement in support of theory" (4). Although technically considered letters, letters conveying scientific messages for the purpose of dispersing scientific information were nearly as long as books at the time. Bazerman (1988) argues that the scarcity of "experimental accounts" before 1880 "should remind us how much the importance we attach to experiments is a function of the rise of the experimental article as a favored way of formulating and discussing science" (65). Before the rise of the experiment in scientific writing, authors and readers relied on long, descriptive narratives for persuasion of findings.

Glasper and Peate (2013) describe the modern academic journal article as productive writing with either original research results or a review of existing results (964). Academic journal articles also include a double-blind peer review prior to publication, where the authors do not know who is reviewing their paper and the reviewers do not know whose paper it is that they are reviewing. According to Glasper and Peate, scientists publish because "publication in peer-reviewed journals enables scientists to communicate their results to the rest of the scientific community; it can also give you a lasting record of your contribution to the body of knowledge" (964).

At their own level, scientists also need to consider their audience. Glasper and Peate argue that scientists writing papers should first consider who they intend their readers to be before they determine the level and content of their writing. For example, when a specialist writes for other colleagues in the same field, it is safe to assume that those colleagues will have more background knowledge on a particular research topic than colleagues outside of the field (but who are colleagues nonetheless; scientists do not have non-scientists in mind when they are writing scientific articles). Glasper and Peate advise to "never take it for granted that your readers know what you are talking about. Always substantiate your comments and signpost the reader to further reading with relevant references" (965). They also instruct scientists to "keep your language simple, accessible and clear. Do not alienate your readers by using jargon and convoluted sentences" (965). But the discussion of my research findings will show that in the genre of the contemporary science article written for specialist readers, jargon abounds.

The genre of the contemporary scientific article is also governed by both an assumed style and an assumed structure, including an abstract, list of authors, the authors' affiliations, an introduction, a methods and results sections that corresponds to tables and figures, a discussion of the results, a conclusion, and a long list of citations. Harmon, Gross, and Reidy (2001) found that late 20th century science writing contained significantly higher numbers of citations compared to past generations, a practice that began in the 19th century: there was a "substantial rise in citational density, reflecting a more complete immersion of articles within diverse argumentative contexts and further intensifying the information load carried by scientific prose" (170). Bazerman argues that through writing citations, "researchers recognized that their work meant more for being part of a socially legitimized, critical, socially interactive, and cumulative communal process centered on publication in socially recognized forums, screened by gatekeepers, facing public criticism, being cited by others, and being accepted into a codified literature" (139). Kuhn takes group integration as represented in journal publication as the "primary indicator of mature science" (139). Bazerman described the inclusion of citations in a scientific article as "informal and irregular recognitions of debt" that eventually became a network of "close interlinking of the current work with the on-going research and theory which formed a codified network of the literature" (139).

Including citations is also a form of persuasion through ethos, a rhetorical strategy to convince a critical audience that something happened when they did not see it. Bazerman points out that if "the author/observer is a credible witness, following all proper procedures thoughtfully and carefully," the audience or reader is more likely to understanding their writing as the truth (140). Alongside the inclusion of citations in a scientific article in the creation of ethos is academic credentials, such as the "PhD" or the "MD." Bazerman argues that "academic credentials today serve something of the same general function of lending credibility, but only in the most general union-card manner. That is, credentials permit one to present results, but the results must stand on other grounds" (141). Thus, an appeal to ethos cannot convince the scientific journal reader on its own: "as findings and theory develop, consistency of results with other results aids in the persuasion" (141). In the earlier centuries, when appealing to ethos and establishing credibility was not so readily available via credentials and citations, "the burden of persuasion fell on detailed accounts" (141).

Combined with titles and other genre features, citations have formed "a master finding system, a visible acknowledgement that scientific articles are meant less to be read than to be mined as a resource for further investigation" (Gross, Harmon, and Reidy 2001, 42). Gross, Harmon, and Reidy argue that "put in economic terms, citation reflects the intellectual payment from one researcher to another for having provided information that can be employed in a more productive way" (170). Halloran sees the ethos of science as a means for viewing scientific writing as rhetorical: "which means both the character of the individual scientist and the spirit he [or she] shares with other scientists by virtue of which science can be a community, a human barnyard in which people are at once cooperative and competitive, altruistic and selfish, logical and emotional" (86).

As the 20th century came to a close, science had complete hegemony (Gross, Harmon, and Reidy 23). At this point, scientific prose became centered on the activities of science rather than the scientist: "modern scientific style has been adapted from a natural language where people are the central characters occupying the subject position to a specialized discourse where things and abstractions have become the foci of attention" (163). Gross, Harmon, and Reidy argue that the voice of the author is much less of a focus compared to stating findings and providing evidence, "sometimes to the point of cold-bloodedness" (165). At this point, English has become the international discourse of science (163). The so-called "gatekeepers of science," those on the peer review boards and editorial boards of certain publications, have pressured scientific writing into falling in line with certain stylistic and presentational standards (162).

2.5 Purposes of specialized scientist-authors

There have always been many purposes for publishing a scientific article: making new knowledge, contesting or verifying the claims of others, establishing the credibility of new methods, establishing prestige, producing support for promotion in employment, generating external funding. Nosek, Spies, and Motyl (2012) discuss the incentive structures in modern academic science writing. There are many incentives for publishing research in academic journals - especially in elite journals such as *Nature* and *Science* - outside of the pure desire to tell the world about carefully researched scientific discoveries. According to Kuhn, scientists find purpose for their work in being useful, exploring exciting new territory, the desire to establish order, and the "drive to test established knowledge" (37-38). But scientists' actions are also influenced by job and career advancement and security, quality of life, self-esteem or validation, and securing grant money. Halloran argues that the culture of science as a profession shifts emphasis more toward "winning the agreement of other scientists; the worth of an intricate methodology is largely a matter of whether it has the confidence of a scientific community" (82). All of these motives and more may even lead scientists to publish results that are false or misleading, Nosek et al. argue. And these incentives affect scientists at all levels of academia, from the novice undergraduate to the accomplished senior scientist. The phrase “publish or perish” is indoctrinated in scientists from the time they begin to seek membership and acceptance into a professional community.

According to Nosek et al., the incentives for producing research that is accurate and those for producing research that is publishable are conflicting motivations. The solution they offer is to make “incentives for getting it right competitive with the incentives for getting it published” (616). Does this include employing harsher punishments for knowingly publishing false or misleading results? Potentially. Nosek et al. argue that the temptation to stretch the truth may not always be a conscious event: “our incentives for professional successes can be at odds with scientific practices that improve confidence in the truth of findings” (616). This conflict of interest interferes with a scientist’s focus on objectivity while conducting and writing about research. Knowingly or not, a scientist could make subjective decisions motivated by self-serving incentives for professional advancement through article publications.

Incentives to publish false or misleading research also come from the desire to create new or novel findings. Journal editors are less interested in replication studies - those that test the findings made in past studies. The dismissal of replication studies “incentivizes novelty over truth,” exacerbating the existing temptation to publish false or misleading research (617). Nosek et al. also mention that negative results are less likely to be published than positive results. Additionally, because rejection rates for journal submissions are so high (between 70 and 90 percent of all articles submitted), meeting the criteria for a certain journal is paramount for scientists wishing to publish their results: “success for publishing is partly a function of social savvy of knowing what is publishable and empirical savvy in obtaining publishable results” (616). Between 2009 and 2013, *Nature* received 53,631 manuscripts, but published just 4,139. That gives it an acceptance rate of 7.7 percent. Because of the stiff competition for space in the journal, *Science* now accepts less than seven percent of the original research papers submitted (Editorial criteria and processes). Thus, journal editors are potentially contributing to scientists’ tendency to favor publishable research over accurate research as much as the scientists themselves.

Creating and maintaining ethos in scientific publication is more complicated than punishing scientists who simply publish made-up data. The production of false or misleading research can “occur without intention” (617). Nosek et al. suggest encouraging “good behavior” with changes made to “normative scientific culture and practices and incentive structures that promote and sustain those practices” (618). Whether it is realistic to expect these changes to occur or to instill change in the scientific community still uncertain.

2.6 Purposes of non-specialist science writers

The non-specialist article is often one that cites academic articles as its source: “science news stories, for example, routinely cite an authorizing version of their material published in *Science* or *Nature* or in some other journal that the science journalist has seen in a prepublication copy” (Fahnestock 2004, 7). The science writer who takes a complicated scientific idea from an academic source and writes it into a story that the non-specialist could understand is bridging the “enormous gap between the public’s right to know and the public’s ability to understand” (Fahnestock 1986, 331). Rowan (1989) explains that the scientist-author and science writers share a common goal on the most basic level: inform the reader (164). For non-specialist writers in particular, Rowan argues that their goal is to establish the novelty and relevance of their topic either to make money or "educate the masses" (165).

And when a scientific claim moves from specialist writing to non-specialist writing, it is more than style that changes. The writing exists in a different genre with altered purpose as well. Non-specialist writing is more likely to be more focused on appealing to the non-specialist reader, which is part of the reason Fahnestock describes this type of writing as "accommodating." Non-specialist writing is also more likely to include quotes from scientists involved in the original study that the article is based on, but the language the scientist uses in the quote is different than the language they use in their academic papers: "accommodated pieces often contain direct quotations from the scientists in wording more straightforward than they are likely to use in writing" (Fahnestock 1986, 339).

Non-specialist science articles are also more likely to contain rhetorical figures. Francis Bacon sometimes defended the use of literary devices for "teaching low-level readers" but also sometimes for "specialist readers for whom the subject matter may be new" (Lipson 1985, 147). Some 17th century scientists insisted that science writing should be clear, but not boring: "A philosopher's style should not 'disgust his reader by its flatness'" (Vickers 1989, 10).

Fahnestock (2004) argues for the benefits of using figurative language: "it should be especially effective to express an argument in figured language because, by definition, figures were noticed as forms in the language in the first place because they produce memorable, epigrammatic phrasing" (10). With capturing the attention of their audience in mind more so than impressing their audience with facts and credibility, non-specialist science writers are more likely to use figurative language and other rhetorical figures. Similarly to Fahnestock, Gross, Harmon, and Reidy defend the metaphor: "metaphor and simile - far from being a peripheral literary device outside the realm of poetry and fire-and-brimstone sermons - are central to language and thought, even in the sciences" (38).

Fahnestock (2004) describes the pieces of science writing that originate from an academic article but are rewritten to suit a less specialized audience as "accommodations," which can be differentiated from their specialist source in several ways: they "drop the math and they avoid acronyms," they are "accompanied by a visual of some kind," and they use "simplified diagrams" or photographs (12). Fahnestock argues that these accommodations fit somewhere between specialist writing in academic journals and non-specialist writing in popular magazines, that they "constitute their own genre, with a constellation of special features serving epideictic and deliberative purposes" (13).

De Ridder (2014) warns of the problems that accompany the production of non-specialist writing to accommodate the reader: "some science popularizers come up with woefully inadequate characterizations of key concepts and offer very crude arguments for and against positions that they're discussing" (28). While it is important to make the information available to the general public via explanations and analogies, the science writer has to understand the scientific concept well to prevent the production of writing that is misleading or inconclusive. This thesis focuses on the genre and style of science articles, but De Ridder points out that the issues also extend to other kinds of science writing: "if we combed through other popular science books, the list could surely be extended: wild extrapolations from the scientific data, undue reliance on scientific results at the cost of ignoring common sense, presenting a simplistic picture that glosses over scientific uncertainties and/or philosophical complexities, etc" (33).

2.7 Science as an institution

Language is a socially structured institution. As a form of language, Bazerman argues, the "new institution of journal publication proliferates social roles" (143). Bazerman describes the genre of science writing as a "socially recognized, repeated strategy for achieving similar goals in situations socially perceived as being similar" (62). Genre guides a writer's choices in different circumstances, and genre lets the reader know what to expect. And if someone wants to be a scientist, they have to also participate in the social activity of writing and publishing: "As the character of scientific communication changed from the late seventeenth century to today, publication became essential to research and integrated the working scientists into a communications network" (Bazerman 1988, 138).

De Ridder (2014) describes 21st century science as a highly specialized institution whose "inner workings are virtually inaccessible to lay audiences," meaning that although the general public has access to non-specialist science writing and other sources of popular science information, they will never be able to access scientific research in the same way scientists do (23). Popular or non-specialist science writing is one access point for the non-scientists, members of the general public to stay informed about current scientific developments.

De Ridder (2014) introduces the idea of “scientism,” a phenomenon he describes as the “view that science is the only genuine source of knowledge about ourselves and the universe we live in” (23). De Ridder discusses the effect of scientism on non-specialist readers in popular science writing, an effect which is especially prominent because lay audiences are particularly prone to overlooking scientific assumptions: “most whom will not be sensitized to such matters as a result of, say, formal training in epistemology or philosophy of science” (23). He also offers an important perspective into popular science writing in the 21st century, mainly how beliefs held and choices made by scientists or science writers can affect the audience’s understanding of a text.

2.8 Rhetoric in science

S. Michael Halloran (1978) argues for studying rhetoric in science as it provides a “useful perspective from which to examine the work and discourse of scientists” (78). Halloran focuses on Aristotle’s metaphor of geographic location, topoi, which elucidates the distinction between rhetoric, which is accessible by anyone (common places), and science, which is accessible only by the most qualified (special places). Modern science writing evolved from an “intellectual climate that led its early practitioners to define their enterprise by its supposed opposition to rhetoric,” and yet Halloran states that Sprat and his followers would “today be regarded as somewhat naive” (79, 80). As an explanation Halloran says that “science is no longer the specialized pursuit Aristotle and Thomas Sprat envisioned but has become instead the dominant modern ideology” (86). Bazerman states that “what appears to philosophy of science as the problem of empiricism, appears to rhetoric as the problem of persuasive evidence, and to literary theory as the problem of representation” (62).

Citing Aristotle's three types of persuasive speech according to purpose, audience, situation, and the time domain considered, Fahnestock (1986) considers original scientific reports to be forensic, with a focus on establishing validity, and deliberative, with a focus on creating a reason for reporting (333). But accommodations, she argues, are epideictic, as their main purpose is to celebrate rather than validate and make claims about the value of scientific discoveries. The effect of epideictic rhetoric on non-specialist writing stems from the "adjustment of new information to an audience's already held values and assumptions" (334). And if a scientific concept cannot be communicated via wonder or application, "it is not likely to make its way to a wider audience" (334). In persuading non-specialist readers, Fahnestock (2004) argues that the metaphor has limitations, and going beyond the metaphor with other rhetorical figures is necessary to effectively clarify concepts. Fahnestock explains that metaphor is "not a vehicle for expressing claims and reasons. Instead, certain schemes - not tropes but figures that specify syntactic forms like the antithesis - were identified by Aristotle and by subsequent rhetoricians as both general forms of argument and memorable forms of expression" (9).

Bazerman explains that to "persuade someone of something you must show them what you have found. That is, an event in nature is not an empirical fact with scientific meaning until it is seen, identified, and labeled as having a particular meaning" (140).

Bazerman (1988) says it's no surprise that "people have different interests in communicating, that they disagree, that they will understand statements differently," but what is surprising is that "statements emerge over time, that for all practical purposes these statements represent an overwhelming consensus as the best of currently available formulations" (14). A scientist's rhetorical choices are often "self-conscious responses to perceived rhetorical problems; sometimes they are unselfconscious impromptu inventions; sometimes they are slow and imperceptible shifts" (15).

2.9 Scientific revolutions and progress

Kuhn argues that evolution of science advances through revolutions, which are result of paradigm shifts. Paradigms guide scientific research, and paradigm changes "cause scientists to see the world of their research-engagement differently" (Kuhn 111). A paradigm for one scientific group is not the same paradigm for other groups. Therefore, paradigms can "simultaneously determine several traditions of normal science that overlap without being coextensive" (50). During a scientific revolution, the rejection of a paradigm always means that another paradigm is being accepted, and the "judgement leading to that decision involves the comparison of both paradigms with nature *and* with each other" (78). Before a paradigm change occurs, existing paradigms must first be tested. And Kuhn states that paradigm tests occur only after "after persistent failure to solve a noteworthy puzzle has given rise to crisis. And even then, it occurs only after the sense of crisis has evoked an alternate candidate for paradigm" (144).

Scientific revolutions are caused by a paradigm change, a change inspired by malfunctions that led to a crisis. However, some revolutions may only be evident to the scientists whose paradigms are being changed. For these scientists, a revolution changes the way they see and respond to the world. However, Kuhn argues that some things remain the same: "postrevolutionary science invariably includes many of the same manipulations, performed with the same instruments and described in the same terms, as its prerevolutionary predecessor" (129)

Kuhn's idea of normal science consists of the work that most scientists produce during their careers, work that is based on a commitment to a certain paradigm or group of paradigms. Kuhn calls them "mopping-up operations" and an "attempt to force nature into the preformed and relatively inflexible box that the paradigm supplies" (24). Before normal science can be disrupted by the destruction of old paradigms and the creation of new paradigms, there must first be a "period of pronounced professional insecurity" where those practicing normal scientists fail to produce research based on existing paradigms, for as Kuhn argues, "failure of existing rules is the prelude to a search for new ones" (68).

Why are many scientific revolutions invisible? Kuhn argues that it is because "both scientists and laymen take much of their image of creative scientific activity from an authoritative source that systematically disguises - partly for important functional reasons - the existence and significance of scientific revolutions" (135). Scientific texts, especially in textbooks, are written as if science is a cumulative process: "misconstructions render revolutions invisible; the arrangement of the still visible material in science texts implies a process that, if it existed, would deny revolutions a function" (139).

Kuhn also questions the idea of scientific progress, asking: "does a field make progress because it is a science, or is it a science because it makes progress?" (161) Is science innately a field of progress? What makes scientific progress different from progress in art, politics, and philosophy? One answer might be that the scientific community is a supremely efficient instrument for maximizing the number and precision of the problem solved through paradigm change" (168). De Ridder argues that the “progress and results of science are so magnificent that it is easy to think that, where knowledge is concerned, science can do anything” (26). Gross, Harmon, and Reidy argue that we should not categorize changes in style, presentation, and argument among pieces of science writing in different periods of time as “progress” (29). Halloran argues that “scientific progress is not simply a matter of filling in more and more details in a representational picture of physical reality. Rather, scientists invent conceptual schemes that ‘fit’ reality in complex and subtle ways.” (Halloran 80). Ultimately, Kuhn concludes that the idea of progress is defined by the individuals making it, while Halloran might avoid using the term “progress” in favor of merely describing changes in the work and activities of science, including writing.

CHAPTER 3: METHODS

To describe changes across time in the work and activities of science, I focused on changes in the genre and style of the scientific article. I began by reviewing four articles from 17th century, at the dawn of science writing, and marking what I found to be key features of genre and style from *Philosophical Transactions*. Once I identified those features, I turned to a close reading of selected science articles from the late 19th century and the early 21st century. I analyzed 32 science articles drawn from periodical publications, 16 aimed at specialist and 16 aimed at non-specialist audiences. I selected articles from the prestigious specialized journals *Nature* and *Science*, and from the popular periodicals *Scientific American* and *Popular Science*. I grouped my findings into three main categories: genre features, style features, and text readability and comprehension.

3.1 Establishing a baseline

Gross, Harmon, and Reidy in their book *Communicating Science: The Scientific Article from the 17th Century to the Present* first discuss the communicative features of science writing from 1665-1700 “as a baseline for comparison with later centuries” (34). I adopted this method to establish a baseline for discussing style and genre features in the comparisons between specialist and non-specialists, 21st century and 19th century science writing. While analyzing a sample of four 17th century articles from *Philosophical Transactions*, I found evidence for key genre and style features including journal prefaces, name and place references, and diverse pronoun use. Detailed findings of the significance of these features are presented in the discussion and conclusion below.

3.2 Definitions of terms

In this thesis, I use the terms "specialist" and "non-specialist" to describe authors, readers, and publications. Specialist authors, readers, and publications are those involving *Nature* and *Science.* Non-specialist authors, readers, and publications are those involving *Popular Science* and *Scientific American*. Specialist authors and readers are scientific experts, and non-specialist authors and readers are not. However, it is important to mention, as Fahnestock (2004) points out, "a non-specialist reader can be a label applied to a scientist outside the narrow field represented by a particular research report" (11). For example, a molecular biologist reading a *Nature* article about physics could also be considered a non-specialist reader, since the scientist is not reading within their field of study. But for the purposes of this thesis, the specialist can be thought of as the scientist, and the non-specialist can be thought of as the non-scientist.

In this thesis, "scientist-author" refers to a scientist who writes articles as part of their professional responsibilities for prestigious peer-reviewed publications like *Science* and *Nature*, addressed to specialist readers. "Science writer" refers to a non-specialist author who writes about science in publications designed and marketed for non-specialist readers such as *Popular Science* and *Scientific American*. I found that in the 19th century, there was almost no distinction between a scientist-author and a science writer; the natural philosophers and the writers of science were one and the same. The term "scientist" was not coined until 1833 by William Whewell in England, who sought a parallel term for someone working in the profession of science, similar to that of a paid "artist." For articles written in the late 19th century and early 21st century, it is important to differentiate between the two types of authors when discussing genre and style in science writing. As Fahnestock (2004) adds, “there are certainly differences between the accommodations written by colleagues [scientist-authors] and those written by science journalists [science writers]” (11). Additionally, “a non-specialist reader can be a label applied to a scientist outside the narrow field represented by a particular research report” (Fahnestock 2004, 11).

Another important term to define is scientific “jargon.” Rowan (1989) defines jargon like this: “jargon has several meanings, one of which is neutral and the other negative. Neutrally defined, it refers to the ‘technical terminology or characteristic idiom of a special activity or group’; its negative definition refers to the inappropriate use of ‘obscure and often pretentious language marked by circumlocutions and long words’” (171). Like Rowan, I first determine whether the texts use any specialized terms and then discuss whether their use is consistent or inconsistent with authorial goals. Jargon can also be thought of as “specialized language” or “confusing nomenclature” (171; Rowan 1991, 370). How simple does language have to be in order for it not to be considered “jargon”? While an answer to that question may deserve a thesis all on its own, Greg Myers writes that “surveys show again and again that members of the public cannot be counted on to know any specific piece of scientific information, however basic” (268). He also argues that non-scientists are more likely to understand a scientific concept if it affects their own life, like parents who have a child afflicted with a rare disease. Lastly, Myers’s definition of jargon states that it is “highly specialized technical slang that is unique to an occupational or professional group. Jargon is at first understood only by insiders; later, it becomes known more widely” (330).

3.3 Potential problems

Based on the research of other scholars who have done similar projects, I kept in mind while conducting my research issues they mentioned. For example, Fahnestock (2004) wrote that “for the analyst of textual variants or versions on any subject, the methodological problems are the same: first how to establish that there is a family resemblance among texts (i.e., that they are about roughly the same issue based on what they have in common), and second, how to describe their differences and to what those differences should be attributed” (8). Fahnestock is describing a methodology she used to compare specialist and non-specialist writing both written on the same topic. This idea is still related to what I am doing, however, the articles I chose in specialist and non-specialist publications are not necessary written on the same subject. Like Fahnestock, I want to make sure that I am identifying the most important style and genre features and am attributing those features to the appropriate author purposes and reader expectations.

3.4 History of primary sources

3.4.1 Philosophical Transactions

David A. Kronick considers the *Philosophical Transactions* to be the first scientific journal, founded in 1665 in London by Henry Oldenburg, the secretary of the Royal Society of London at the time. “Although not a scientist himself,” Bazerman (1988) writes, “[Oldenburg] saw his mission to advance science through increased communication” (129). Kronick claims that the *Transactions* “fully deserves to be called the first scientific periodical” despite the French publication *Journal des Scavans* being founded two months prior (243). This is partly because the *Journal des Scavans* was more of a “general literary periodical” than a scientific periodical, and the *Transactions* was devoted to science from the beginning (243). Gross, Harmon, and Reidy describe the

Journal des Scavans as “closer to what we think of today as a government-funded research institute” where “science was the principal occupation of its members” (32). Additionally, *Transactions* “quickly became the preeminent scientific journal of the seventeenth century and maintained that position throughout the following century” and it “provided momentum to the scientific movement that still continues today” (243). Bazerman (1988) argues that the *Transactions* constitute the foundation of “the development of scientific journal writing in English through the nineteenth century” (63).

The founding of the *Transactions* originated from “the desire for a periodical publication to meet the needs of a constantly broadening audience for news of the world of scholarship and science” (244). Natural philosophers were already communicating with one another via written letters, and they wanted to print that information for wider dissemination. In the beginning, Oldenburg filtered each submission from colleagues “through his voice,” focusing specifically on “those aspects he thought his readers might find most newsworthy” (Bazerman 1988, 131). Eventually, the contributors who sent Oldenburg content in the beginning years of the *Transactions* became a more “distinctive and important voice than the newscarrier,” and over time, Oldenburg began more and more to let his contributors “speak for themselves, turning them into authors” (132).

According to Gross, Harmon, and Reidy, organizations like the Royal Society “had within their ranks most of the authors, readers, and journal editors of 17th-century science. They also created the social networks needed to establish what constituted acceptable communicative and argumentative practices in science” (32). This group was a “fairly large, loose-knit group of amateurs and ‘natural philosophers’ in and around London - some extraordinarily talented, some with nothing more extraordinary than an above-average curiosity about the natural world" (32). The Royal Society made its first "public avowal of its custodianship" with the *Transactions* in 1753, nearly a century after Oldenburg first founded the journal (245). Before that, publishing of the *Transactions* was Oldenburg's responsibility. However, the journal was "published under the Royal Society license granted in their first charter" (245). Additionally, there were several contradictions questioning the relationship between the *Transactions* and the Royal Society after Oldenburg's death until the Royal Society eventually claimed the journal as its own. For example, the Royal Society took the liberty of prohibiting the publication of certain papers, the contents of which they did not deem acceptable for the *Transactions*, indicating editorial control. Additionally, the *Transactions* was not published during the summer months when the Royal Society did not meet (246).

Why didn't the Royal Society claim responsibility for the *Transactions* from the beginning? At first, financial problems were the main obstacle. And when the Royal Society did adopt the journal officially in 1753, Kronick reports that it was largely to mend the journal's poor reputation that had developed as a result of certain papers it had published that were considered by some to be trivial (246).

The frequency of the printing of the *Transactions* was irregular in its infancy (250). Oldenburg intended to publish the journal every month on the first Monday, but the plague and other setbacks prevented a regular printing schedule. According to Kronick, early distribution of the *Transactions* was likely between 500 and 1000 in the time between its founding and its official adoption by the Royal Society. In 1752, researchers recorded that each printing of the *Transactions* resulted in 750 copies, provided free to members and available for 25 cents to the public, about $75 in today's money (252). Selected papers were also published in Latin, which at the time was "still the language of the scholarly world" (254). These articles tended to be between 1000 and 3000 words in length, with long titles that indicated who the author was and to whom he was addressing his letter. They contained about 30 percent passive language, and they used parenthesis often to elaborate on different ideas and statements.

3.4.2 Popular Science

Popular Science, a monthly magazine that was founded in 1872, expresses its claim as the "What's New and What's Next" publication. *Popular Science* and its writers followed the times: automobiles at the very beginning of the 19th century, battlefront technology in the 40s, and psychedelic drugs in the 60s. One adventurous reporter, Rob Gannon, tried the hallucinogenic drug LSD just so he could write about his experience. Known as "*Popular Science Monthly*" in its infancy, the magazine quickly began presenting a diverse array of subjects beyond just "pure science." For example, topics in 1916 included aviation, radio technologies, and air conditioning.

The magazine also has a history of paying careful attention to its readers' needs and feedback. In the 1990s, a large-scale study of *Popular Science* subscribers showed that they are "twice as likely as the general population to embrace technological changes in their personal and professional lives."

Circulation at *Popular Science* grew from 350,000 subscribers in 1928 to 550,000 in 1945 and 1.6 million in the 1970s. The magazine entered the world of the internet in 1996, launching their website popsci.com. In 2016, *Popular Science* began publishing on a bimonthly schedule, sending out six larger issues every year instead of twelve for the first time. Before this transition, *Popular Science* was recorded as the the fifth-oldest continuously published monthly magazine in the world, falling behind only classics like *Harper's Magazine* and *Scientific American.*

3.4.3 Scientific American

Scientific American began in 1845 as a weekly broadsheet subtitled “The Advocate of Industry and Enterprise, and Journal of Mechanical and Other Improvements.” Just five years into publication, *Scientific American* founded the first branch of the U.S. Patent Agency. The publication gathered steam with stories of the Industrial Revolution, automobiles and new speed records, and by identifying and reporting on “emerging trends” like flight, radio, and television. In 1948, the owners of *Scientific American* “insisted that the majority of the articles be written by the people who actually did the work described” (2). This claim is still true, and authors since have included nobel laureates.

In 2009, Nature Publishing Group, now a division of Springer Nature that also publishes the academic journal *Nature,* took control of *Scientific American.* This union was at the center of Nature Publishing Group’s “newly-formed consumer media division, meeting the needs of the general public” (3).

Scientific American is now published in 14 different languages, is read in more than 30 countries, has more than three million readers worldwide, and more than five million “global online unique visitors monthly” (4). *Scientific American* is the oldest continuously published magazine in the United States and the “leading authoritative publication for science in the general media” (Springer Nature 1). In the first half of the 19th century, *Scientific American* reportedly had a weekly circulation of more than 25,000, a number which grew to 50,000 by the end of the century.

In "The Languages of Edison's Light," Charles Bazerman (1999) describes *Scientific American* as "long established as a premier organ for the new culture of invention" (127). The journal was more than a way to communicate with people. *Scientific American* "promoted an ideal of science situated in American pragmatism and in the workshop" (127-128). Thomas Edison published his first letter in *Scientific American* in 1874 in an attempt to "establish a presence" as a "man of science" (Bazerman 129).

3.4.4 Nature

Nature is considered the "leading weekly, international scientific journal" (1). The journal was founded in 1869 and *Nature* was at one time the official publication of the British Association for the Advancement of Science. *Nature*'s original mission statement focused on publishing results, recognizing science, helping scientists, and ensuring its readers stayed up to date on what was going on in the scientific community. *Nature*'s articles, in the beginning, usually fell under the categories of discoveries, academia, or reports of meetings. In 1950, peer review first began being utilized in *Nature* articles.

Fahnestock (2004) claims that both *Science's* and *Nature*'s international circulation is "arguably closer to mainstream media than others" and highlights the journal's high Institute for Scientific Information (ISI) impact rating (Fahnestock 10). *Nature* now boasts more than six million visitors per month to their website, nature.com.

3.4.5 Science

Science was first published in 1880 with the help of Thomas Edison, who convinced a journalist named John Michels to found it (Bazerman 132). Alexander Graham Bell later took over in 1883 as a financial backer for *Science.* An editorial toward the front of the journal made it clear that the contents would be supervised by a panel of "recognized authorities in each of the fields (Bazerman 132). In addition to scientific articles, *Science* would publish notes about meetings of various scientific societies.

Like *Nature*, *Science* in the 21st century has multiple online journals that specialize on topics such as immunology and robotics. *Science* is published by the American Association for the Advancement of Science (AAAS), the "world's oldest and largest general science organization" which claims to be "a voice for science and scientists everywhere" (1). Currently, *Science* is published weekly, reaching about one million people worldwide. Key goals of *Science* editors are to publish influential papers that will "significantly advance scientific understanding" (2). Fahnestock (2004) lists *Science*'s international circulation as "arguably closer to mainstream media than others" (10).

3.5 Selections from primary sources for analysis:

For this study, I analyzed a total of 36 articles. Four were drawn from the 17th century *Philosophical Transactions* as a way to identify the some of the "original" genre features of the scientific article. Then I selected four articles each from within one decade of the 19th century and one decade of the 21st century in *Popular Science, Scientific American, Nature*, and *Science*. In each case, I chose to analyze the first full-length science article appearing in each issue. The specific volumes I analyzed are listed below, and a complete list of the articles studied can be found in Appendix A.

Philosophical Transactions

1. 1683, Vol. 13
2. 1684, Vol. 14

3. 1693, vol. 17
4. 1694, vol. 18

Popular Science

1. January 2005, vol. 266, no. 1
2. December 2005, vol. 267, no. 6
3. January 2015, vol. 286, no.1
4. December 2015, vol. 287, No. 6
5. January 1880, vol. 16
6. December 1880, vol. 18
7. January 1890, vol. 36,
8. December 1890, vol. 38

With *Popular Science*, I chose to analyze the first article in the first and last issue of the year under “Headlines” for January and December 2005. There was no “Headlines” section in January 2015 so I chose the article closest to the article style in 2005, an article under the heading “Featuring.” In December 2015, some of the feature articles were in the style of “Q&A,” while others were short pieces written about technology. This issue was largely dependent on infographics and short pieces of text. Therefore, I chose the first article textually similar to the others I’ve analyzed thus far, an article included under the “Next” subsection from the “Departments” section.

Scientific American

1. January 2005, vol. 292, no. 1
2. December 2005, vol. 293, no. 6

3. January 2015, vol. 312, no. 1
4. December 2010, vol. 303, no. 6
5. January 1880, vol. 42, no. 1
6. December 1880, vol. 43, no. 23
7. January 1890, vol. 62, no. 1
8. December 1890, vol. 63, no. 23

In 1880, *Scientific American* published issues weekly, whereas in 2005 and 2015 they published issues monthly. For the 1880 issues, I chose to analyze pieces from the first issue of the month from both January and December.

Nature

1. January 2005, vol. 453, no. 7021
2. December 2005, vol. 438, no. 7068
3. January 2015, vol. 517, no. 7532
4. December 2015, vol. 528, no. 7580
5. January 1880, vol. 121, no. 531
6. December 1880, vol. 23, no. 581
7. June 1890, vol. 42, no. 1078
8. December 1890, vol. 43, no. 1102

For *Nature*, I chose the first publication in both January and December of each year, and I analyzed the first article of each chosen publication.

In 1880 and 1890, the *Nature* archive was not organized by month, just by volume and number, so I chose the first and last number of each year to have published an article. For example, for 1890 I selected the third to last number because the second to last and last did not publish articles, only shorter items such as “Book Reviews” and “Editorial.” Each issue I analyzed for *Nature* between 1880 and 1890 published just one article. *Nature* issues 2005-2015 each contained two or three articles, and I analyzed the first in each set.

What does an “article” mean? According to *Nature’s* “Nautilus Authors Blog,” articles are “original reports whose conclusions represent a substantial advance in understanding of an important problem and have immediate, far-reaching implications. Letters are short reports of original research focused on an outstanding finding whose importance means that it will be of interest to scientists in other fields” (Clark 2009).

Science

1. January 2005, vol. 307, issue 5706
2. December 2005, vol. 310, issue 5753
3. January 2015, vol. 347, issue 6217
4. December 2015, vol. 350, issue 6265
5. July 1880, vol. 1, issue 1
6. December 1880, vol. 1, issue. 24
7. January 1890, vol. 15, issue 361
8. December 1890, vol. 16, issue 409

I selected the first issue in both January and December of each year, and I analyzed the first article of each chosen issue. In 1880, the first *Science* issue was published in July. This issue contained three pieces of published work, and I determined the third to be most similar to a research article.

3.6 Reading Comprehension Tests

In addition to the key genre markers identified in my review of each article, I wanted to be able to gauge the relative “plainness” of the style of each article. To do so, I turned to conventional algorithms that yield numerical index or approximate “grade level” for each piece of writing. For this analysis, I used Microsoft’s version of the Flesch Reading Ease score, Microsoft’s version of the Flesch-Kincaid Grade Level score, and the Gunning Fog index to obtain numerical measures of the relative readability of each primary source.

The Flesch Reading Ease score is based on a formula developed by Rudolf Flesch in 1949. The formula combines the average syllables per words and words per sentence to factor in word difficulty and “syntactic complexity,” respectively (Stockmeyer 2009). The Flesch Reading Ease score produces a value between zero and 100, with the scores closest to zero being the most difficult to read and those closest to 100 being the easiest. Stockmeyer describes readability tests, the Flesch Reading Ease score included, as a way to “evaluate how understandable” a selection of writing is. He also puts the Flesch Reading Ease score into perspective by pointing out that some states “require that insurance reading policies score at least 40” on the readability test, and that “Flesch himself set the minimum score for plain English at 60” (2009).

The Flesch-Kincaid Grade Level score is the result of a recreation of Flesch's 1949 formula that analyzes a text to produce a reading grade level. This is a measurement of the "minimum education level required for a reader to understand" a certain text (2009). As a result of a 1993 study that reported the average adult American's reading level to be seventh grade, Microsoft "recommends aiming for a Flesch-Kincaid score of 7.0 to 8.0 for most documents" (2009).

In defense of both readability tests, Stockmeyer lists word length and sentence length as among the "primary causes of reading difficulty" (2009). Although Microsoft's version of the Flesch Reading Ease score and the Flesch-Kincaid Grade level score is just one of many iterations of Flesch's and Kincaid's original formulas, I use the Microsoft version consistently throughout my analysis, maximizing the significance of the conclusions I draw from comparisons made.

The Gunning Fog Index, the result of chemist-turned-newspaper editor Robert Gunning and his efforts to help businesses, publications, and other groups improve their writing in the 1940s, is the third readability test I used to measure and compare the writing of my primary sources (Gunning 1969). Among other types of writers Gunning worked with scientists and engineers, primarily those in research environments writing technical reports, while he was developing and testing the Gunning Fog Index (1969). Gunning, while reflecting on the utilization of the Gunning Fog Index after two decades since its birth, describes the measurement as an "effective warning system against drifting into needless complexity in the mechanics of writing" (1969).

Gunning, who interestingly prefers the idea of "clear writing" as opposed to "readability" tests, built his index based on a formula slightly different than that of

Flesch: the sum of the average sentence length of a piece of writing and the percent of words with three or more syllables followed by multiplying the sum by 0.4 (Bogert 1985). Like the Flesch-Kincaid Grade Level score, the result of the Gunning Fog Index formula is "roughly equivalent" to a grade reading level (1985). One potential problem that Bogert points out is that although Gunning's formula is based on sentence and word length, "making sentences shorter does not necessarily make them more readable" (1985).

After assessing two decades of the index's use, Gunning suggests two possible explanations for why more complex writing developed over time in publications such as *Time* and *Reader's Digest*. First, it could be argued that with more people becoming educated and reaching higher levels of academia, more complex writing is necessary and the result of a natural progression of writing. Second, and the more likely to be true according to Gunning, "writing standards on many popular magazines have been relaxed" (Gunning 1969). So the idea is that instead of some publications, like *Time* and *Reader's Digest*, becoming more complex, other publications are actually becoming simpler, and the Gunning Fog Index formula adjusts to make *Time* and *Reader's Digest* seem like they have become more complex over time.

Rowan (1991) calls for a balance between using simple language and "conceptual tools" to improve comprehension of a piece of writing (370). On one hand, the "study of how word and sentence complexity affects text comprehension, readability research offers considerable evidence that these factors are associated with text comprehension and reading ease" (Rowan 370). But she also maintains that there's more to comprehension than words and sentences: “simple language does nothing to make ideas more understandable” (370).

I also note that none of these indices include measures for the readability of graphics or mathematical equations, though both are often present in scientific articles.

3.7 Genre and Style Guidelines

To be able to critique issues of genre and style in the selected articles, I turned to a popular handbook for its presentation of definitions and conventions. I drew definitions from the Gerald Alred et. al. 2015 11th edition *Handbook of Technical Writing.* Alred et. al. argue that they designed the handbook to serve as a comprehensive resource for both academic and professional audiences” and to “reflect the demands of an increasingly technological, global, and cross-cultural workplace” (v). Their definitions and presentations of genre conventions provide a starting point for my analysis of rhetorical features like figurative language in the genre and style of the articles I selected to analyze.

3.8 Rhetorical Features of Philosophical Transactions

3.8.1 Title Length and Readability/Comprehension Tests

Four *Philosophical Transactions* articles analyzed from the late 17th century had an average 2998 words per article, although one article (8022 words) was largely responsible for skewing this average. On average, the articles have 29.75 words in their title (See Table 1). This relatively large number is reflective of each title not only describing the contents of the article but also describing when and where the article was written, who wrote it, and who the author presented it to. For example, a 1693 article had the title “An Account of the Earthquakes in Sicilia, on the Ninth and Eleventh of January

1692/3 Translated from an Italian Letter Wrote from Sicily by the Noble Vincentius Bonajutus, and Communicated to the Royal Society by the Learned Marcellus Malpighius, Physician to His Present Holiness."

As described in each title, each article had just one author, unless the "Learned Marcellus Malpighius" from *Philosophical Transactions* 1693 is counted as an author in addition to "the Noble Vincentius Bonajutus," in which case this article had two authors (See Table 1).

On average, the *Philosophical Transactions* articles had an average Gunning Fog Index of 15.54, which means that, according to the Index's formula, a reader needs to have the formal education of a college junior to be able to understand the text on the first reading. The Gunning Fog Index takes into account sentence length and the number of complex (more than three syllables) words. On average the articles contained 9.9 percent words with three or more syllables.

Similar to the Gunning Fog Index is the Flesch-Kincaid Reading Level formula, which takes into account total words, sentence length, and syllables, emphasizing sentences over words, to produce a score that corresponds with the United States grade level required to understand the text. The average Flesch-Kincaid Reading Level score of the four articles was 14.88, which is nearly the grade level of a college junior (See Table 2).

The Flesch Reading Ease score also takes into account words, sentence, and syllables, and emphasizes syllables over words and sentences. The higher the Flesch Reading Ease score, the easier the material is to read. The scale ranges from 100 (around a fifth-grade reading level) to 30 (around a college graduate reading level). The average Flesch Reading Ease score for the four articles was 49.9 (See Table 2).

Lastly, the four articles scored an average 38.68 percent passive sentences.

Table 1: Baseline Data - Authors, Article length, and title length

	# Authors	**# Words in article**	**# Words in title**
Philosophical Transactions 1683	1	1431	11
Philosophical Transactions 1684	1	8022	37
Philosophical Transactions 1693	1	342	29
Philosophical Transactions 1694	2	2197	42

Table 2: Baseline Data - Reading Comprehension

	Gunning Fog Index	Flesch Reading Ease	Flesch-Kincaid Reading Level	% Passive Sentences
Philosophical Transactions 1683	15.52	49.9	16.4	12.5
Philosophical Transactions 1684	17.24	42.7	16.7	25
Philosophical Transactions 1693	15.61	50	14.7	50
Philosophical Transactions 1694	13.8	57	11.7	27.2

I analyzed the first article in each issue of *Philosophical Transactions* that I reviewed. The articles from 1683 and 1684 included a preface to the article. In the 1683 article, the preface describes the purpose of the *Philosophical Transactions*, clarifying that the journal was "not to be looked upon as the business of the Royal Society" and explaining that its entries were included for "preserving many experiments, which, not enough for a book, would else be lost" (2). The book was the prestigious genre in the late 17th century. According to Harmon and Gross (2007), "printed books and not scientific articles communicated the 'new Philosophy' and revelations about the natural world that spawned the scientific revolution" of the 17th century (1). The 1683 article listed the contents of the issue as a preface to the first article. In that particular issue, there were three letters published in total. The articles I analyzed printed the title in a font much larger than the actual article text, with the exception of the article from 1683, where the title was written in the same size font as the article text. Also, in that article, which was an account of "Captain Sturmy" and "Captain Collins Commander of the Merlin Yeacht" descending into a hole, it seems that the editor of the *Philosophical Transactions* took accounts told from the point of view of Sturmy and of Collins and provided the context of their respective journeys with his own account (2, 4). Each of the four articles included the first word of the next page at the bottom of each page, a catchword, to make sure the pages would be compiled in the proper order. However, the journal pages were also numbered, so they could have kept track with the order of the pages that way. Each of the articles included many mentions of places (especially in the 1683 article about the City of Prusa) and names that imply that the authors and editors expected each reader to have a certain level of background knowledge about people and geography. Additionally, the

1694 article included a quote from “Pontanus” in latin, which only a select group of learned men would be able to understand: “*Dubio nunc verbere subter; quassari aut sursum sublato pondere ferri”* translated as “Doubt now under the lash; the lifting of the weight to be carried in an upward injure” (4).

Each of the four articles used the pronoun “we,” although there was only one article that potentially had two authors. All of the articles except for the article by Robert Boyle about making phosphorus also used the pronoun “I,” and the second 1694 article about earthquakes in Sicilia used “you” and “your”: “With these difficulties I find my self encompassed in this relation which you have commanded from me of the natural events and effects of the late earthquake, of which there were some whereof we yet are in suspense” (2). Although the title of this article already indicates that it is a letter (An Account of the Earthquakes in Sicilia, on the Ninth and Eleventh of January, 1692/3 Translated from an Italian Letter…”), the usage of these pronouns remind the reader, especially a modern reader, that the article was written as a piece of correspondence. I interpret the use of “we” as potentially either the voice of the individual standing in for the group or a reference to a collaboration between the author and the editor.

Two of the articles contained figures. In the 1683 article, a pair of drawings labeled “A scale of yards,” presumably the Pen-Park-Hole mentioned in the title and in the article, preceded the article. Unlike in 21st century specialist articles, the genre convention of referencing the figures in the article text was not apparent in this 17th century article. At the very end of the article, there was also a table of observations labeled “The Profile and Ground-Plot of the Concave in Pen Park, before described” (6). In the 1694 article, the author included a long, three-column table spanning two pages labeled “The Number of the former Inhabitants of the Cities and Countries in Sicilia, that were destroyed either wholly or in part by the Earthquake, as likewise of those that perished therein” (9). The table listed cities in one column, “the number of people before the earthquake” in another column, and “the number of those killed” in the last column (9). The latter two values were summed up at the end of the table. With the inclusions of these figures, in the 17th century, we see the beginning of the genre conventions for figures and tables in scientific articles.

3.8.2 Sentence-level Style Features

The four *Philosophical Transactions* articles I analyzed averaged 7.25 parenthetical clarifications, a feature explained further in the analysis of rhetorical features in 19th and 21st century science articles (See Table 3). Two of the articles contained idiomatic expressions, each article contained at least one example of personification, two articles contained similes, one article utilized two metaphors, and one article invoked imagery twice (See Table 3). There was an average subjective language usage of one percent. One article opened with a narrative. Other than these features, the articles were largely absent of other stylistic features mentioned in more detail in the analysis below.

Table 3: Baseline Data - Style Features

	% Subjective language used	**Imagery used**	**Figurative language used**	**Parenthetical Clarifications**
Philosophical Transactions 1683	0.56	0	4	3
Philosophical Transactions	0.72	0	1	18

1684				
Philosophical Transactions 1693	1.76	0	4	6
Philosophical Transactions 1694	0.91	2	6	2

3.9 Analysis of Rhetorical Features in 19th and 21st Century Science Articles

My hypothesis was that I would find some similarities but significant differences in genre and style in scientific articles across time, and that there would be clear differences between periodicals aimed at specialist versus those written primarily for non-specialist readers. Interestingly, my analysis revealed strong similarities among all the 19th century writing, for both specialist and non-specialist readers, and a similarity between the 19th century writing and the 21st century non-specialist writing. However, 21st century specialist writing clearly differs from the other categories in terms of what genre and style features it incorporates and avoids. In this section, I will discuss examples of each genre and style feature in each time period. The guiding question is: does each genre's incorporation of particular genre and style features illustrate the author's purpose, the audience's expectations, and the limitations of the science writing medium in that time period?

A secondary part of the data analysis is the evaluation of text comprehension and readability using the readability tests the Gunning Fog Index and the Flesch-Kincaid Grade Level Score. As discussed previously, these tests are effective to a point at using mathematical formulas to illustrate a text's readability using sentence and word length, but this information has to be paired with the analysis of rhetorical figures in order to truly make meaningful comparisons between the different texts from different genres and time periods. Both the 17th century and 19th century articles contained high percentages of passive language, much higher than the passive language in 21st century articles.

3.9.1 Genre Features - Pronouns and Authorial Point of View

About half of the articles from the 19th century were clearly written by one author, and the other half had no author's name listed. According to Bazerman (1988), if there is not an author listed, the assumption is that it was the journal's editor making the contribution: "most information passes through the voice of the editor who simply reports on things he has found out about from a variety of sources" (75). Yet, many of these anonymous articles included both "I" and "we" as pronouns, and some included "one" and "you." In these cases, I asked, who is "we"? Or, who is "you"? Sometimes, "we" is understood as "scientists," such as "we fear the expense of the apparatus will always be against its introduction in domestic establishments" (*Science* 1880, 276). "We scientists" can also specifically mean the scientists involved in the particular study, as in "we have already the accurate word megasporangium for the ovule, and I propose to speak of the so-called ovary" (*Nature* 1890, 141). And sometimes "we" is understood as "humans" or "people in general," like in "that it was successfully accomplished we all know" (*Science* 1880, 277). From a January 1880 article in *Nature*, written by Charles Darwin, one case of "we" seems like Darwin and a colleague that he describes working with: "but we found out after a time that a daily visit to a pond" (207). In another case, it seems like "we" is used as "we scientists": "we have, however, much better evidence on this head, in the fact of two individuals of the same form of heterostyled plants" (207).

Another instance of uncertain pronoun references appeared when authors mention other individuals by only referencing their last name. One contemporary convention is to write out an author's full name in the first reference in the text, then to use the last name only thereafter. But in the 19th century examples I analyzed, this was not the case. The full name of the person referred to was never given. By leaving out their first name, their affiliation, and often their title, the author is assuming that the reader already knows who the individual is - they do not need further explanation. This is one assumption of many that I will talk about that implies authors of 19th century science writing expect their readers to be of a certain academic or scientific caliber, and that the community of readers was small and familiar to each other. However, I will also argue that 21st century specialist authors also expect their readers to have a certain level of expertise, although their assumptions are expressed in a different way, through jargon. Assumptions of this type occur often in 19th century science writing, from both specialist and non-specialist publications. For example, a December 1890 article from *Science* mentions "Professor Koch" and "Drs. Salmon and Smith." A January 1890 article from *Scientific American* mentioned "Mr. Edison." Multiple other examples of this phenomenon exist in this time period, including "Prof. Page" and "Mr. Siemens" from *Science* in 1880 and "Mr. Eyton," "Rev. Dr. Goodacre," and "Mr. Blyth" from *Nature* in 1880.

Three out of the 16 19th century articles included author names with their credentials, which included "MD" and "Esq." "MD" implies a medical degree, but "Esq." does not necessarily imply that an individual has a certain degree. Rather, in British society, it signifies a sign of respect given to men of higher social rank, above the rank of gentleman and below the rank of knight (Thompson 2006). For example, an article in

Science in 1880 was authored by Francis P. Upton, Esq. (*Science* 1880). In a *Popular Science* article from December 1880, the author mentions a colleague known as "D.W. Craig Esq." The credential "PhD" only appears in one of the 19th century articles.

In several instances in the 19th century, authors sometimes tended to focus more on the person who made a discovery, not the discovery itself. One author praised Edison for his "great inventive powers" and discussed in detail the progress he made while inventing: "Mr. Edison feels very confident of success, since his troubles so far have all been in transferring the power from the armature to the driving wheels. He thinks that if the armature is only reliable, experiment will lead to proper mechanical devices…" (*Science* 1880, 277). In a January 1890 *Scientific American* article, the author described the "mechanisms of man" as "however ingenious, they are never perfect, and human watchfulness and foresight [are] not to be depended upon" (2). Lastly, a December 1880 *Science* article discussed how "Professor Koch has been working for the benefit of mankind" (311). This phenomenon was almost exclusively seen in 19th century writing from both specialist and non-specialist articles, however; one *Popular Science* article from December 2005 mentioned "an all-star team of scientists" and "legions of scientists." In these cases, the metaphoric athletic team or army gets the credit for having made significant scientific progress.

3.9.2 Assumption of background knowledge: social hierarchy, expertise, and exclusivity

Multiple authors from the 19th century in specialist and non-specialist genres alike implied that they expected their reader to have a certain level of background knowledge in science and in the most recent scientific findings of the time. This implication seems directed at a group of learned individuals that most science writers from the 19th century expected to be their audience. It is like Bazerman (1988) writes: “Each article’s attention to the anticipated audience can be seen in the knowledge and attitudes the text assumes that the readers will have” (25). For example, in the December 1880 article from *Popular Science*, the author wrote that “those who do comprehend and recognize these two types of hysteria will have little difficulty in comprehending the general nature of this jumping” (5). The author is directing this toward the readers who are familiar with the science of hysteria, addressing the more informed portion of the audience while simultaneously suggesting that the other, less informed portion may not need to even try to understand the jumping.

In *Scientific American* January 1890, the author writes: “The promoters of this system say that it is an easy matter to make the insulation” (1). Easy for whom? Easy for the author and for those with a similar level of knowledge? Someone reading this article who had no idea how to make the insulation would likely feel like an outsider. Although *Scientific American* is supposedly a scientific publication more concerned with the general population rather than a population of scientists, it still seems that this author expects his readers to afford the author credibility because of the ease with which they complete needed technical tasks.

In a 19th century *Science* article, one author mentions the “well-known land of Karagwe south of this river” and in another article, an author writes about “the reader with a knowledge of recent events can easily compare them with the facts here recorded…” (*Science* 1890, 2; *Science* 1880, 277). The first phrase is similar to the above phrase about making insulation. Who knows well the land of Karagwe? The scientists with the time and resources to travel? It is likely not the average American reader. The second example implies a sense of prestige for the reader the author mentions. Here the author places the reader who is knowledgeable about recent events higher in the social hierarchy than the reader who is not knowledgeable, who cannot easily make sense of the facts recorded by the author.

3.9.3 Signs of specialization and professionalization

In 19th century writing, with an academic revolution underway after the U.S. Civil War, scientists were specializing in different fields and subfields of science, and science as a profession was becoming more popular and more institutionalized with the birth and growth of the American research university. Evidence of this time of change and transition can be found in the 19th century articles I analyzed, from both specialist and non-specialist genres. For example, in *Scientific American* January 1880, the author writes that “the high value of this work can be fully appreciated only by those familiar with the influence which his inventions have had…” (2). Along with implying a social hierarchy and the assumed expertise of the author’s preferred reader - the phenomenon discussed above - this sentence indicates that scientists were entering specialties and thus expected scientists from the same specialty to have a unique ability to understand their research most effectively.

The same article also mentions “the science of meteorology” and that “no intelligent person need be afraid of undertaking the practical study of meteorology by means of them” (2, 3). In *Scientific American* December 1880, the author contrasts the “physician” and the work of specialized science to that of “quacks,” those unprofessional and unspecialized practitioners whose work and opinions are not on the same level as professional scientists. In several other 19th century articles, the writers indicate the presence of four different scientific specialties: geology, chemistry, biology, and ornithology. *Science* January 1890 writes “all these are matters for geologists” and *Science* December 1890 describes something that “the chemists know as albumose” (2, 310). *Nature* December 1890 mentions biologists, and *Nature* January 1880 mentions ornithologists (201, 3).

In *Scientific American* January 1880, the author writes: “We can imagine no occupation more agreeable and profitable during these long winter evenings, or the leisure days which are so common in winter, than their construction and erection in the garret, the barn, or the shop-loft” (3). This example, discussing the building of meteorology instruments such as the barometer, metallic thermometers, sun thermometer, and the rain gauge, illustrates how scientists in specialities felt about their work, how they held their specialty high in regard compared to other occupations.

3.9.4 Symbols, numbers, and Latin terms

The authors of 19th century writing were inconsistent with using and spelling out numbers. In one article alone, the same writer wrote out “two hundred and fifty,” used numerals to write “400,” used numerals to write “35,” and the number “7” (*Scientific American* 1890). In 19th century writing, authors also spelled out the words “one o’clock” when writing about times, instead of “1:00” (*Scientific American* 1890). Writing fractions, 19th century authors wrote “55 and 4/10,” where the four is on top of the ten (*Popular Science* 1890, 4). 19th century writers also wrote the word “percent” as two separate words: “per cent” (*Popular Science* 1890, 3).

Alred et. al. indicate that “foreign expressions should be used only if they serve a real need” but also “most borrowings occurred so long ago that we seldom recognize the borrowed terms" (237-238). Usage of Latin occurred exclusively in specialist articles; in the 21st century authors used an average 8.88 Latin words per article. For example, in one 2005 *Science* article about the malaria parasite *Plasmodium*, the authors talk about the different species of parasite via their Latin names, such as *Plasmodium falciparum* (82). In the 19th century authors used an average 10.63 Latin words per article. For example, in *Nature* 1890, an article describing an experiment with fish referred to the specific species names in Latin, such as "*Doris bilamellata"* (201). In *Science* 1890, the author wrote that "if you were to make a plan *in relievo* of what has been described above, the first thing that would strike you would be, that what had been taken out of that abyss or trough you had been heaped up in the enormous range," with *in relievo* being a Latin phrase meaning "in relief" (2).

In 21st century specialist writing, authors use the symbol "%" instead of "percent" or "per cent." They also use "~" instead of "about" or "approximately" and use ">" and "<" instead of "greater than" or "less than." And instead of writing numbers as fractions, specialist writers from the modern period write numbers as decimals, such as "55.40" instead of "55 and 4/10." Alred et. al. indicates that "*percent* (or *per cent*) is normally used instead of the symbol % (except in tables, where space is at a premium)" (445). For numbers, Alred et. al. says to "write numbers from zero to ten as words and numbers above ten as numerals. Spell out approximate numbers" (414). Alred et. al. recommends using symbols as long as the author is "certain that your readers will understand its meaning or place the symbol in parenthesis following its spelled-out term the first time it appears. Never use a symbol when readers would more readily understand the full term" (613).

3.9.5 Abbreviations and acronyms

21st century specialist writing was unique in its use of abbreviations and acronyms. Alred et. al. recommend using abbreviations only if it is "certain that your readers will understand them as readily as they would the terms for which the abbreviations stand" (2). Apart from a few acronyms included in two 21st century non-specialist articles, the 21st century specialist articles were the only pieces of writing to make use of acronyms. One article, in *Science* January 2005, employed 14 different acronyms. While the authors did spell out the meaning of the acronym the first time they introduced it in the text, as recommended by Alred et. al., the text inevitably became crowded with acronyms. Yet for a specialist reader who is used to certain acronyms within their field, sifting through a text dense with those acronyms is much easier as that reader as already begun associated the acronym with its given concept.

3.9.6 Providing examples and explaining jargon

Clear in-text explanations of jargon were scarce across all four categories. 21st century non-specialist articles were most likely to explain jargon used, and examples of 21st century specialist writing were the most likely to use jargon and the least likely to provide an explanation. Authors working in the 21st century specialist article genre assume that the readers share expertise with the article's authors. Ironically, 21st century specialist articles most frequently incorporated phrases like "for example," "examples include," "this is exemplified by" and "such as." However, these "examples" add little information for the secondary audience, for the non-specialist. While one may consider this as explaining jargon, it is truly more like elaborating on jargon for the fellow specialist who may be vaguely familiar with the term but needs to be reminded of the details. In the introduction section of a *Nature* January 2015 article discussing regulatory functions of the ribosome, the authors write "for example, RPL38, one of the 80 ribosomal proteins of the eukaryotic ribosome, helps establish the mammalian body by selectively facilitating the translation of subsets of *Hox* mRNAs" (33). Likely all scientists and even a few non-scientist enthusiasts would be familiar with ribosomes and eukaryotes. Most non-scientist enthusiasts and some non-enthusiasts would at least recognize those words. But add in "translation of subsets of *Hox* mRNAs" and the example is very unlikely to help anyone who is not a specialist reader to understand what RPL38 is and how it relates to regulatory functions of the ribosome.

19th century specialist and non-specialist writing incorporates examples in the same way. In *Scientific American* January 1890, while writing about incandescent light, the author writes: "For example, if the electromotive force of the primary or street current is 500 volts, and the electromotive force of the secondary current is required to be 50 volts, the primary coil will require ten times as many convolutions as the secondary" (2). At this point, the author has not explained the meanings of electromotive force, currents, or volts. So although the author provides a detailed example, if the reader did not know what he was talking about before this point, the example does not change anything about the reader's understanding. Similarly, in *Popular Science* December 1890, the author provides a few scientific examples: "the physicist thinks of the extremely delicate reciprocal actions of the two forces, such as the rotation by the current plane of polarization" (1). However, just as in the 21st century examples, the author is explaining a concept with more technical terms that would not help someone less familiar with physics to understand the article's meaning.

Unsurprisingly, 21st century non-specialist writing was the most likely to explain jargon, followed by 19th century non-specialist writing and 19th century specialist writing. In *Popular Science* December 2005, the author explained 8,000 pounds of "Dyn-O-Gel" as "an amount capable of absorbing 4,000 tons of water" (2). In *Scientific American* December 2005, the author explains that "microcredit" is another word for "small-scale loans" (1). In *Popular Science* December 1880, the author writes: "although called 'Jumpers,' they only *jump* in a minority of the experiments, the word jumping really included all such phenomena as lifting the shoulders, raising the hands, striking, throwing, crying, and tumbling" (3). And in *Nature* December 1890, the author explains the one-celled embryo: "i.e. the immediate product of the conjugation of ovum and sperm" (141).

3.9.7 Pathos

Appeals to pathos, or an "appeal to human emotions" were most common in 21st century non-specialist articles, although a few instances of its application were found in 19th century articles, including one in *Science* (Crowley and Hawhee 2012, 170). Pathos is a powerful tool of making a story memorable or meaningful for the reader, a tool that relies on the reader's human emotions to have an impact. Crowley and Hawhee explain that in the modern era, pathos is used in English to "refer to any quality in an experience that arouses emotions" (170). For example, in *Popular Science* January 1880, the author is reporting the differing opinions on vaccination for various infectious diseases. One vaccinator reportedly said, "if I had the desire to describe one third of the victims ruined by vaccination, the blood would stand still in your veins." (1). Another said, according to the author, "I have seen hundreds of children killed by it" (1). The idea of victims, especially children, and the implications of there being a large number of victims is clearly an appeal to human emotions, as the average person feels sadness when hearing about children dying. And the phrase "the blood would stand still in your veins" is ominous and threatening.

In *Scientific American* December 1890, the author is describing a certain place he saw during his journey: "this locality has always been regarded as one of the most dangerous points on the coast, and wrecked mariners have sometimes been stranded on the island for weeks without being able to communicate with those who might rescue them" (352). The idea of being stranded, unable to communicate, in a desolate place is likely to strike fear in the hearts of many readers, many of whom probably imagine themselves in such a situation and frightfully ponder the fate of any of the wrecked mariners who found themselves stranded.

In *Popular Science* December 2005 in an article about hurricanes, the author spends most of the article describing hurricanes and their trends, how to prevent them, and how they have changed over time. The article is very scientific in tone and straight-to-the-point, until the very end where the author quotes a man "who lost his home during Hurricane Frances" (3). This is one of the last thoughts the reader has before finishing the article and moving on to another activity, giving this appeal to pathos more power.

In *Popular Science* January 2015, the first paragraph of the article about autonomous drones describes the discovery and death of Osama bin Laden in 2011, an event that caught the attention of nearly every eye in the U.S., and most people across the world: “There, President Barack Obama and his national security advisers watched as a team of Navy SEALs infiltrated the walled compound and killed its chief resident, Osama bin Laden” (1). This particular appeal to pathos is a clever choice of rhetorical figure because the author knows that nearly all of the article’s readers will be able to relate to this anecdote. If the reader was not watching the television when bin Laden was killed, then they knew someone who was. The power of pathos to bring emotions and memories to the surface is great and beginning the article with this powerful rhetorical figure likely grasped the reader’s attention and kept the reader’s eyes glued to the pages, either the physical magazine or online article, preventing them from skipping to another story or clicking away to another webpage. This is beneficial for the writer, who wants people to read his stories and remember his words.

In *Popular Science* December 2015, the appeal to pathos is not within the text of the article itself, but instead highlighted as a statistic aside the text of the article: “5.5 - Number of people worldwide, in billions, without access to painkillers” (1). The article, which is otherwise brief and informative, benefits greatly from this appeal to pathos. First, it is brief and catches the eye. It also induces the reader to imagine what life would be like without easy access to painkillers for a headache or muscle pain. After they paint a picture of that painkiller-less life, the reader can easily feel pity for the 5.5 billion people who actually live that life. Lastly, statistics are easy to remember and convenient for many readers to share with the people in their lives. For the writer of popular science, the more people talking about the work, the better.

3.9.8 Advertisements

Throughout each *Popular Science* and *Scientific American* publication from the 21st century, especially at the beginning of the magazine, one-page and two-page spreads contained advertisements for cars like Chevrolet and Lexus, technology companies like Nokia and Microsoft, and other entities like Citi, Viagra, Geico, UPS, and Fidelity Investments. On average, advertisements took up 47 percent of non-specialist issues. Throughout each *Nature* and *Science* publication from the 21st century, there were advertisements for companies selling lab equipment, such as Bio-Rad's Droplet Digital PCR Systems, New England Biolabs, and R&D Systems. Both publications, but particularly *Nature*, also place advertisements publicizing their own partner publications, such as *Science Advances*, *Nature Immunology*, and *Nature Reviews Microbiology*. On average, advertisements took up 44 percent of specialist issues. Because these journals charge scientists to publish articles in their journals and charge readers to purchase the journal either online or in print, it is financially beneficial for them to include advertisements for their partner journals.

3.9.9 Images, Tables, and Figures

21st century specialist articles had an average of 5.5 figures and tables per article. All but one article contained color. Figures ranged from complicated bar charts and phylogenies to cartoon contour maps and immunoblots. Although all of the figures and tables contained detailed captions to go along with each diagram, the captions were highly technical and would not help anyone already unfamiliar with the type of diagram used to understand what the data was illustrating.

3.9.10 Authors, words, and citations

All of the articles from the 19th century and the non-specialist articles from the 21st century either had one author or the author was not listed. However, specialist articles from the 21st century had, on average, 24.25 authors listed. Specialist and non-specialist articles from the 21st century actually had nearly the same average number of words in the title (10.625, 10.875), an average which was nearly twice as much as the average title lengths for either 19th century genres (5.75 non-specialist, 6.375 specialist; See Table 4). As far as total words in the article, 21st century specialist articles had the highest average (3357) by far: 310% higher than 21st century non-specialist articles (819.5), 80% higher than 19th century specialist articles (1540.84), and 30% higher than 19th century non-specialist articles (2223.375; See Table 4). On average, 21st century specialist articles included 42 citations. None of the 21st century non-specialist articles included citations, but two 19th century non-specialist articles included citations and four 19th century specialist articles included citations (See Table 5).

Table 4: Genre Features 1

Category	Average # Authors	Average # Words in Article	Average # Words in Title
21st Century PopSci	1	930.25	14.75
21st Century SciAm	1	708.75	7
19th Century PopSci	1	3469.75	7
19th Century SciAm	N/A	977	4.5
21st Century Nature	6.75	3352	9.75

21st Century Science	41.75	3362	11.5
19th Century Nature	1	1272.675	8.75
19th Century Science	1	1809	4

Table 5: Genre Features 2

Category	**Abbreviations & Acronyms**	**Words in Latin**	**Citations**	**Tables, Figures, and Images**
21st Century PopSci	3	0	0	9
21st Century SciAm	0	0	0	5
19th Century PopSci	0	0	15	1
19th Century SciAm	0	0	0	0
21st Century Nature	23	11	176	24
21st Century Science	45	60	160	20
19th Century Nature	0	84	9	1
19th Century Science	0	1	0	0

Several additional genre markers were unique to the articles I analyzed from the 21st century, most from the specialist articles. For example, only 21st century specialist articles displayed abstracts, located at the beginning of the article below the list of authors and before the main body of text. Abstracts sum up the main findings and importance of the research being reported in the article. These articles also contained, as a footnote on the first or second pages, information on each author's affiliation, usually their university or institution where they are employed. Sometimes there was an asterisk next to a particular authors name, which was later denoted as representing "these authors contributed equally to this work" (Science 2005, 45).

21st century specialist articles also contained a few unique additions before the references or citations listed at the end of each article: information or a hyperlink to other material related to the article that can be found online. In Nature this section was called "Online Content," and in Science it was called "Supporting Online Material." Also before the references section was a brief note on the dates of the article being received and of being accepted.

After the references section were several small sections unique to the 21st century specialist article: "supplementary information," "acknowledgements," "author contributions," "author information," "competing interests statement," and "correspondence." The acknowledgments section included information about cooperations and collaborations involved in the research as well as any grants that were used to fund the research. The author contributions section gave detailed information about which author provided which service during the publishing of the paper (project supervision, experiment design, manuscript writing). The author information section provided information on reprinting and permissions information, and a hyperlink and an email address were included. The competing interests statement, although not included in all of the 21st century specialist articles I analyzed, stated that “The authors declare that they have no competing financial interests” (Nature 2005, 38). The correspondence section provided a name and an email address for “requests for materials” (Nature 2005, 38).

Both 21st century specialist and non-specialist articles had the inclusion of headings and subheadings in common. For example, in *Popular Science* 2015, headings included “New Wars, New Crafts” and “The Disappearing Drone.” In *Science* January 2015, subheadings included “materials and methods summary” and “Rapidly evolving genes and genomes.” In all of the articles, the font of the headings and subheadings was bolded.

3.9.11 Style Features - Figurative language

Alred et. al describe figurative language as “an imaginative comparison, either stated or implied, between two things that are basically not alike but have at least one thing in common” (231). In the 21st century, articles included in the non-specialist publications *Scientific American* and *Popular Science* were 87% more likely to use figurative language than the specialist publications *Nature* and *Science*. However, there was virtually no difference in figurative language use between specialist and non-specialist writing in the 19th century; both types of publications made use of these rhetorical strategies. Altogether, articles from 21st non-specialist articles, 19th century specialist articles, and 19th century non-specialist articles all made regular use of figurative language. In this analysis figurative language includes but is not limited to metaphor, simile, personification, hyperbole, alliteration, pun, and idiom.

An important detail to consider for non-specialist articles utilizing figurative language is the location of its application. Where is the figurative language being used most often in a text? Where it is absent or nearly absent? For example, in a January 2005 article from *Popular Science*, there is no figurative language in the paragraph discussing an experiment published in *Science* and about which the article is based. Yet the author of this article uses figurative language multiple times elsewhere in the article, especially in the introduction and the conclusion. Alred et. al argue that scientific or "technical writers sometimes use figures of speech to clarify the unfamiliar by relating a new and difficult concept to one with which their readers are familiar" (231).

In just two cases from two articles out of 32 articles analyzed, I found the use of a pun. Although the use of pun was rare, when it was used it was striking, and particularly amusing amidst the scientific discourse. In a December 1890 issue of *Popular Science*, in an article about light and electricity, the author chose to transition to a new topic by writing "without endeavoring at present to explain the contradiction that presents itself here, we pass to electricity; it may throw some light on the problem" (2). Did the author intend to be humorous?

Alred et. at. describe personification as "a figure of speech that attributes human characteristics to nonhuman things or abstract ideas" (233). There was no use of personification in any 21st century specialist articles, but personification was utilized in several different ways in the other three categories. For example, a January 1890 *Popular Science* article gives specific bodies of water maternal qualities: "the Lakes of the North have given birth to gigantic commercial marts" (1). In a July 1880 *Science* article, the author, in discussing applying electricity to railroads, describes "the gentle fluid, which has so quietly, for many years been the swift messenger of man, is now showing that it is also able to be a strong and lusty servant, and carry any load that it may be asked to take" (5). In a December 2015 *Scientific American* article, the author begins his article with personification: "modern medicine can grow kidneys from scratch" (14). With this use of figurative language, the author writes as if "modern medicine" is directly responsible for creating organs in the laboratory. What he literally means is that by using the latest advances in modern medicine, scientists - people - can create human organs in the lab.

I would like to highlight another example of personification. In a December 1890 *Popular Science* article, the author writes of Nature - with a capital "N." Traditionally, only proper nouns - names of people and places - are capitalized, so the author's use of Nature with a capital "N" gives nature a human quality, as if nature were a living being: "But Nature furnishes us another resource"; "there are many friends of Nature interested in the problem of light" (5, 6). Later in the same article, the author repeats this concept by referring to the Unknown with a capital "U": "the nature of electricity is another of these great Unknowns" (8). Bazerman (1988) offers an explanation for this phenomenon: "In those early years, argumentative persuasion could be used for the ignorant artisan, but for those actively pursuing nature, nature was portrayed as speaking for herself" (77).

Alred et. al. explain that metaphor is a "figure of speech that points out similarities between two things by treating them as if they were the same thing" (233). Using metaphors to explain certain concepts or to make an article more entertaining for the reader was common practice in 21st century non-specialist articles and 19th century articles from both genres. For example, in a December 1890 *Popular Science* article, the author described a series of essays discussing currents and magnets as forming an "exceptional system and a seductive whole, a magic circle, which one could not leave after having once entered it. The road was one that could not lead to the truth. It required a fresh mind to resist the current, one that could enter upon, the study of the phenomena without preconceived opinions, and was capable of starting from what it observed, and not from what it had heard, read, or learned" (2). In a January 2015 *Popular Science* article, the author described stealth, as in the stealth of autonomous drones, as "a game of give and take" (3). In a 2005 January *Popular Science* article, the author described a type of drug called selective serotonin reuptake inhibitors (SSRIs) as having a "chemical sibling" (1). And in a December 1890 article from *Popular Science* the author wrote "all the parts be seen to lend one another a mutual support, like the stones of a vault, and the whole resembled a gigantic arch thrown across the unknown and uniting two known truths" (4).

In rare occasions, 21st century specialist articles used metaphors, not necessarily to entertain the reader but as a discrete way to explain the significance of their findings. The metaphors identified in 21st century specialist articles were exclusively present in the introduction or discussion sections, as opposed to more technical sections like the results and methods. For example, near the end of a January 2015 *Nature* article, the authors describe their findings as "providing a versatile toolbox for controlling the ultimate expression of transcripts" (37). And in a December 2005 *Nature* article, the author describes the alternation between deep-water formulation in the Northern and Southern hemispheres as a "bipolar seesaw" (1469).

Alred et. al. define simile as a "direct comparison of two essentially unlike things, linking them with the word *like* or *as*" (233). Although the use of simile was overall less common, the usage trend was similar to that of the metaphor, with the 21st century non-specialist and 19th articles from both genres utilizing simile much more often that 21st century specialist articles. In a December 1880 article in *Popular Science*, the author describes a man's jumping reflex as "almost as quick as the explosion of a pistol" (4). In *Nature*, June 1890, the author utilizes a simple and straightforward simile to describe the taste of a fish: "the taste was pleasant, and distinctly like that of an oyster" (202).

Alred et. al. define idiom as a "group of words that has a special meaning apart from its literal meaning" (275). Analyzing the use of idiom across all four categories was particularly interesting because of how ingrained many idiomatic expressions are in the English language. Many other rhetorical figures like metaphor and simile were almost exclusively used in all categories other than 21st century specialist articles. While idiom was still used least in 21st century specialist articles compared to the other three categories, it was used more often in this context than other rhetorical figures. However, the idioms identified in 21st century specialist articles were more difficult to find because of how often they are used in common language. They are used so frequently, one forgets that their literal meaning means something different than its intended meaning. I argue that it is for this reason that idioms are more common in 21st century specialist articles than other rhetorical figures like metaphor and simile.

For example, in a December 2015 article in *Nature*, the authors describe how their study will make future studies on similar topics easier to conduct: "these experiments pave the way for using entanglement to characterize quantum phases" (77). The author means that the experiments are preparing a situation for future progress. In a January 1890 article in *Science*, the author describes looking quickly at the whole of the horizon:

"running my eye along its unbroken outline from north to south" (2). Instead of writing "we have not found any sternums in fish" an author in *Nature* from December 1890 decided to write "nothing answering to a sternum has hitherto been found in fishes" (142). Lastly, in a *Popular Science* article from January 2005, the author wrote that "it's a big leap" to go from mice to people, meaning that there is large difference between the two species and that the findings from the current study done in mice may not apply to the human condition.

Alred et. al define hyperbole as a "gross exaggeration used to achieve an effect or emphasis" (233). Examples of hyperbole in the four categories of science writing that I analyzed were few and far between. Out of 32 articles, I identified just five cases of hyperbole: four in 21st century non-specialist writing and one in 19th century non-specialist writing. And, the examples I did identify exist on the edge of the true definition of hyperbole. The example that best fits hyperbole was from a December 2015 *Popular Science* article: "anyone with an undergraduate biology degree could start an underground dope lab" (1). The author does not literally mean that all it takes is an undergraduate biology degree to start an underground dope lab, he is simply emphasizing how easy the process of making opiate drugs at home is compared to how it has been in the past.

Science writers across all genres and time periods of articles I analyzed made use of quotation marks to set off words or phrases, often indicating that the authors recognize that their diction should not be taken literally or that a word was being used in a special sense. For example, the author of a *Popular Science* article from January 2015 wrote that "autonomy in aircraft is actually the 'easiest' version of robotic self control" (1).

“Easiest” is in quotes because the author actually means something along the lines of autonomy in aircraft is the “least insanely difficult” form of robotic self-control. And in *Popular Science* January 1880, the author wrote “all vaccinations not considered perfect, even though they had to a certain extent ‘taken,’ were either immediately revaccinated or the parents informed that the protection was not perfect” (6). By “taken” the author means that the contents of the vaccine did produce the intended effect in the body. However, instead of using more words to explain the meaning, the author decided instead to simply use the word “taken” in quotes to communicate what they were writing about the administered vaccine.

Fahnestock (2004) adds that accommodations, meaning non-specialist articles derived from a specialist source, specifically use metaphors but leave them in quotes, representing an “acknowledgement that it is coined by someone else and perhaps not quite an appropriate term” (23). For example, in *Popular Science* January 2015, the writer describes autonomous aircraft “operating as a ‘swarm’ in surveillance” (2). Describing the operation of these drones “as a swarm” is a simile, but this rhetorical figure is certainly not the only one of its kind utilized by the writer of this article. Why is this simile in quotes when there is a lot of other figurative language not in quotes? What is it about this simile that the author deems it necessary to include quotes? What intended message is the writer attempting to send? Does the reader understand the message or is the intermittent use of quotations around figurative language confusing?

Appropriateness is also a factor when quoted words and phrases are used in 21st century specialist articles, where rhetorical figures are arguably the least appropriate, based on the numerical trends. Despite the genre conventions that make rhetorical figures inappropriate in 21st century specialist writing, authors do sometimes use them, perhaps to explain a concept that the author is having difficulty explaining with technical terms alone. Twice in a *Nature* January 2015 article the authors use the term "'right angle' asymmetric bulge" to describe a specific RNA domain structure (34). The bulge did not literally form a right angle, but the authors seem to believe that describing the bulge as a "right angle" is the best way for them and their readers to visualize its structure.

Words and phrases in quotes - and occasionally words and phrases in italics - also indicate emphasis. The same sentence in *Science* December 1880 lists both "phlegm" and "an inflammable spirit" in quotes: "he therefore distilled coal, and obtained first "phlegm," afterwards a black oil, and then "an inflammable spirit," which he collected in bladders" (275). In this case, the words in quotes likely emphasize terms that the writer has either coined or borrowed from other scientists that may not be of popular use yet. Listing the words in quotes emphasizes their differences from the other words of the sentence. Later in the article, the author writes "it was true that the inflammability of coal gas had been long known, but that no one *had purified gas*, and thus made it fit for general illuminating purposes" (275). In this particular case of emphasis via italics, the writer is emphasizing the fact that one scientist was uniquely able to purify gas as opposed to simply recording the inflammability of coal gas, which at the time had become an ability held by multiple scientists. It is important for this unique ability to be expressed because the scientist is defending a patent from which he suspects other scientists have taken knowledge.

Lastly, words and phrases in quotes can also mean that a writer acknowledges that a certain term is jargon, a technical word that the author knows that the reader might not understand. From January 2005 in *Scientific American*, the author utilizes quotes to indicate jargon several times, including “acute flaccid paralysis” (2). However, an indication that the words or phrases are jargon, at least in this case, is not always followed with an explanation of the jargon. If the author wants to call attention to the fact that a certain term is jargon, and that a reader might not understand, why not follow that emphasis with an explanation? Does the author assume that the reader will use context clues to achieve an understanding of what the term in quotes means? Even in peer reviewed contemporary science writing, problematic expressions like this persist.

3.9.12 Narratives and Cultural References

Beginning an article or a section of an article with a narrative was most common in 19th century writing, although not uncommon in 21st century non-specialist writing and not completely absent in 21st century specialist writing. Alred et. al. describes “narrative” as “the presentation of a series of events in a prescribed (usually chronological) sequence” (395). Specifically, inclusion of a narrative gave an article the essence of a story with a plot, setting, and characters, rather than a report of scientific findings. In 19th century writing, authors often began articles with a narrative to set the scene for their readers, potentially because readers were accustomed to reading stories and not scientific writing: “In the autumn of 1874… the number of cases of small-pox increased ... rapidly” (*Popular Science* 1880 p. 2). In another 19th century *Popular Science* article, the author began with a historical narrative discussing the progress of the nineteenth century in innovation and politics. In *Scientific American* January 1890, the first three paragraphs introduce the topic as a “controversy now in progress” between two “rivals” both developing systems of incandescent lighting (2). The author uses this narrative introduction, it seems, to set the precedent for the account to follow: "it is the purpose of this article to examine these" (2). An article in *Science* January 1890 begins with a narrative, written like a diary entry. In the same article, the author writes about his writing habits: "I cannot command the time to write such a letter on this subject I would wish" (2).

In the 21st century, the trends were similar, with the writer utilizing a narrative to put the article into a certain context. In *Popular Science* January 2015, the author includes a specific date, May 2, 2011, a particular setting, a residential compound in Abbottabad, Pakistan, and a character (of sorts), an unmanned aerial vehicle. The chronological narrative continues to develop throughout the article, when the author wishes to change the context of his writing: "in July 2013, the Navy's X-47B approached," then, "on its first flight, the Taranis lifted off from the runway, flopped onto its back, and crashed…" (2-3). The single example of narrative in a 21st century specialist article appeared in *Science* January 2015: "Since the discovery over a century ago by Ronald Ross and Giovanni Battista Grassi that human malaria is transmitted by a narrow range of blood-feeding female mosquitoes, the biological basis of malarial vectorial capacity has been a matter of intense interest" (49). This small use of narrative occurs at the beginning of the article's conclusion section. As discussed previously, rhetorical figures like the metaphor in 21st century specialist writing were more likely to appear in the introduction or discussion instead of the methods or results, and the trend appears to be the same for use of a narrative. The use of narrative in this unique context provides a brief historical background of the subject matter discussed in the article: the genomes of mosquitoes that transmit malaria. This background puts the article's discussion section into perspective, as the authors continue by writing about the findings of the present study and their significance in the science of malaria and its transmission via mosquitoes.

Although the other 21st century articles did not use what I considered to be narratives, Bazerman (1988) describes that "experimental reports tell a special kind of story, of an event created so that it might be told. The story creates pictures of the immediate laboratory world in which the experiment takes place, of the happenings of the experiment, and of the larger, structured world of which the experimental events are exemplary. The story must wend its way through the existing knowledge and critical attitude of its readers in order to say something new and persuasive yet can excite imaginations to see new possibilities in the smaller world of the laboratory and the larger world of nature. And these stories are avidly sought by every research scientist who must constantly keep up with the literature" (59). In this way, Bazerman provides a new approach to looking at specialist authors' purposes for writing.

Slightly different from the use of narrative to put an article in the context of something else is the incorporation of specific times, places, and pop culture references that inadvertently date an article. This is something that is particularly obvious to someone analyzing the articles written in the past, however short or long ago "the past" is. For example, in *Science* December 1890, the writer mentions "consumption" in reference to the infectious disease that contemporary readers would know as "tuberculosis." However, the author makes use of the terms "consumption" and "tuberculosis" interchangeably, indicating that the article was written in a time where the transition to the modern term "tuberculosis" was underway. The same article also referred to “quicksilver,” a chemical element that modern readers would refer to as “mercury” (60).

Writers, particularly from the 19th century, also included references to the specific time and place from which they were writing. In *Popular Science* December 1890, the author wrote “when in this century the reciprocal action of currents and magnets was discovered” and in *Science* December 1890 another writer referred to the location of the research as in “our own country” (2, 3). These inclusions led the contemporary reader to ask the questions “What century?” and “What country?” This vagueness could confuse readers, 19th century or modern, if they were reading at another time or from another locality other than where the journal was published. However, it is likely that authors of these 19th century articles assumed that most of their readers would be local and immediate, and so they felt it was appropriate to speak to their audience in a familiar way.

In *Popular Science* January 2015, the author wrote “suffice it to say, when bin Laden was house hunting, ‘sheltered under an umbrella of radar protection’ likely sat high on his wish list” (1). In this article about autonomous drones, the story of how such drones helped soldiers find bin Laden via radar is interesting and timely for many people who remember bin Laden’s discovery. In a *Popular Science* December 2015 article about home-made drugs, the writer suggested that the reader “picture Breaking Bad but with yeast” (1). If the reader had never seen or heard of the television show “Breaking Bad,” this explanation would make no sense. But the author is assuming that most people will at least be familiar with the premise of the program - a high school chemistry teacher who makes and sells meth in a mobile home. For the cultural time in which the piece was first published, the reference is relevant and useful. If in one hundred years scholars are continuing to analyze science writing from past centuries and compare it to the modern style and genre, they may make a point that such a popular culture reference from the early 21st century means nothing after the generation of people who knew of the show come and go. In one hundred years, the meaning of the phrase "picture Breaking Bad but with yeast" will have been forgotten almost completely.

3.9.13 Subjective and vague diction

Alred et. al. define diction as "the choice of words used in writing and speech" (162). Merriam-Webster describes subjectivity as "a characteristic of or belonging to reality as perceived rather than as independent of mind." This is in direct contrast with objectivity, which Merriam-Webster defines as "of, relating to, or being an object, phenomenon, or condition in the realm of sensible experience independent of individual thought and perceptible by all observers: having reality independent of the mind." Francis Bacon argued that without a constant meaning for a word, the reader can become confused and the message can get lost in translation. Instead, Bacon and other 17th century natural philosophers wanted scientific prose to contain qualities such as "immediacy, precision, rational organization" (Vickers 1989, 22).

Across both genres and time periods, nearly all writers used subjective diction at least once to describe a phenomenon, an experiment, or a scientific finding. I argue that the presence of subjective diction is evidence of the author's or authors' opinions permeating into a description or an analysis. For specialist articles, statements of opinion are particularly inappropriate, as the genre is arguably governed by facts and objectivity. However, several times in the 21st century specialist articles authors describe findings as “interesting.” Overall, 21st century specialist articles used subjection diction 21 percent less often than 21st century non-specialist articles, 66 percent less than 19th century specialist articles, and 85 percent less than 19th century non-specialist articles. To phrase this positively, 19th century non-specialist articles reflected 1.4 percent average use of subjective diction, compared to 0.87 percent in 19th century specialist articles, 0.85 percent in 21st century non-specialist articles, and 0.15 percent in 21st century specialist articles.

I also argue that subjective diction is utilized, primarily by 21st century non-specialist writers as well as by 19th century authors from both specialist and non-specialist genres, to make the writing more entertaining, more like an exciting story than an account of a scientific finding. This journalistic use of language for the purpose of making writing more appealing, taking the focus away from the facts, was exactly what Sprat and others of the 17th century scientific revolution were trying to move away from. In a way, they were successful, because the scientific writing for specialists genre did diverge from that of non-specialists. Subjective diction for the purpose of making writing more interesting occurred less frequently in 21st century non-specialist writing than subjective diction for the purpose of expressing opinions, however discrete. For example, in *Popular Science* December 2005, the author includes several subjective verbs and nouns to make the article more engaging and exciting: “zap,” “scrapped,” battle,” “monster,” “clings,” “wither,” “tinkering.” Diction in a 21st century specialist article is more likely to be literal, with the words the author chooses being very unlikely to have more than one specific meaning. Words like “zap” on the other hand could mean several things: Was someone shocked with electricity? Did someone shoot someone with a laser beam? Is being "zapped" a good thing or a bad thing? In a *Popular Science* article from January 1880, the author described someone as "reckoned as vaccinated," with "reckoned" being a subjective more or less meaning "calculated or concluded" (5).

Another component of subjective diction use is more difficult to describe. The best way to do so is through a comparison between 19th century non-specialist writing and 21st century specialist writing. In *Scientific American* January 1890, the author wrote about the "case of the employe of the Manhattan Electric Light Company who got his death shock while carrying a portable incandescent light" (2). The author could have easily replaced "who got his death shock" with "who died" or "who was shocked to death." But the author did not choose the simpler option, instead choosing a phrase that strikes the reader as more intense, perhaps another example of an appeal for pathos. Later in the same article, the author describes electricity as something that "would not destroy life," instead of writing that it "would not kill a person" (2). And again in the same article: "the charge is made against the Edison system that it is subject to leakage, which at times leads to fire. But it does not and cannot take life" (3). The latter example can also be thought of as an example of personification, giving the system the potential ability to "take life." The way this 19th century science writer talks about life and death is more poetic and thought-provoking than anything a 21st century specialist writer would write. For example, in *Science* December 2015, the authors describe the state of their animal models during the experiment: "mice were viable and exhibited not obvious phenotypes, but heterozygous intercrosses did not yield viable null offspring" (1). The two examples are comparing humans and mice, but the diction used to describe the life and death of mice in the 21st century specialist article, compared to the treatment of the health risk to humans in the 19th century non-specialist article, is still striking. Mice from the experiment are either “viable” or “not viable,” not “alive” or “dead.” Humans involved with electricity “received a death shock,” they did not simply “die.” As much as the 21st century specialist article focuses on the scientific side of life and death, the 19th century non-specialist article incorporates a poetic rhetorical treatment of life and death. This example functions as a telling comparison between both 21st century and 19th century writing as well as between specialist and non-specialist writing.

Lastly, a particularly phenomenon of diction occurred almost exclusively in 19th century writing. Writers sometimes seemed to “take the long way around” explaining a concept when a clearer, more concise option appeared to be more appropriate. For example, in *Scientific American* January 1890, the author wrote “the voltage of which bears the same ratio to that of the primary current as the number of convolutions in the primary bears to the secondary coil of the converter” instead of saying “the voltage of which is the same ratio to the primary current as the number of convolutions in the primary is to the secondary coil of the converter” (1).

An interesting finding was the inclusion of vague values across both time periods and both genres within those time periods. In a December 1890 article in *Popular Science* the author mentions something being “a little distance off,” not bothering to include even an estimation of how far away the item was. Similarly, in a December 2005 article in *Nature*, the author used the vague value “a sizeable accumulation.” Although one would expect a specialist article from the 21st century to be precise in all measurements made, it seems that even this genre is prone to using vague values in a situation where the author or authors believe that precision is not necessary or worthwhile. The vagueness continues in many examples from all four categories: “several districts,” “only a very few such cases,” “upward of three hundred members,” “a number of birds,” “over 60 of them,” “after a time,” “few missing genes.” The inclusion of vagueness when making measurements, particularly in specialist articles, suggests that the author or authors are picking and choosing when precise measurements are necessary and worthwhile, which indicates that authors prioritize their findings and appreciate precision in specific cases. Vague values in non-specialist writing reflects a focus on details other than precision in many cases, unless a specific number or statistic is particularly exciting or significant. In general, non-specialist articles are less invested in the numbers and more focused on the story, a focus that reflects the audience they are writing for, who do not need specific numbers and values to associate with certain findings.

Imagery

Overall, imagery was not a commonly used rhetorical figure in any of the four categories. I defined imagery as connotations of artistic description that a writer uses to give their work more depth. It was most frequently used in 19th century writing, equally between non-specialist and specialist genres. For example, in *Popular Science* December 1890, the author discusses light as an electrical phenomenon, “whether it be the light of the sun, of a candle, or of a glow-worm” (1). These three examples of light and warmth imagery are easy for readers to call forth in their memory - except for maybe “glow-worm” for a modern reader. In *Nature* June 1890, while the writer is describing different species of fish, he writes about one fish as “amongst the red seaweeds it lives on, by its large branched cerata and red-brown colours” (203). The imagery produced by this sentence is of an underwater scene, of a colorful fish and its nautical surroundings.

No examples of imagery were found in 21st century specialist writing, and it was used only a few times in 21st century non-specialist writing. For example, in *Popular Science* December 2005 the writer describes “swirling rain bands” and “water full of bubbles” (1). The artful description of rain and water easily triggers the memory recall of rainfall and water splashes in puddles. In *Popular Science* January 2015, the author writes: “the gangly, heavily faceted, pitch-black aircraft appeared to abandon sound aerodynamics” (2). Here, the reader imagines a dark, slender, and sleek airplane or drone flying silently through the air.

3.9.14 Parenthetical clarifications

21st century articles also made nearly exclusive use of parenthetical clarifications, a tool slightly different from instances, across all genres where authors offered an explanation for jargon that was used. Alred et. al. define parenthesis as being used to “enclose explanatory or digressive words, phrases, or sentences” (442). Although the use of parenthetical clarification such as “we localized the minimum fragment for RPL38-dependent IRES activity to nucleotides (nt) 944-1,266 (which we term the *Hoxa9* IRES element)” was to provide additional information on a concept or term, the clarification would do nothing to help a non-specialist reader understand the ideas. This is similar to the above examples where specialist authors used terms like “for example” and “such as” (*Nature* 2015, 33). The parenthetical clarification in 21st century specialist articles was purely to provide more information for specialist readers. Except for one 21st century *Popular Science* article and three 19th century *Nature* articles, 21st century specialist articles were the only category to make use of parenthetical clarifications.

Table 6: Style Features

Category	% Subjective Language Use	Figurative Language	Imagery	Parenthetical Clarifications
21st Century PopSci	1.2	38	3	8
21st Century SciAm	0.35	28	0	0
19th Century PopSci	1.75	43	5	0
19th Century SciAm	1.07	12	1	0
21st Century Nature	0.28	5	0	34
21st Century Science	0.05	9	0	17
19th Century Nature	1.49	3	1	8
19th Century Science	0.75	18	5	0

3.9.15 Text comprehension and readability

The most significant difference in text comprehension and readability is the increased number of passive sentences used in 19th century writing from both specialist and non-specialist sources. Passive voice is a key characteristic of the selections of 19th century science writing that I analyzed that, especially when compared to modern writing, often results in this remark of a someone studying those texts: “no one talks like that anymore.” Alred et. al. write that “because they are wordy and indirect, passive-voice sentences often are more difficult for readers to understand” (665). 19th century writing contained the most passive language use, followed by 21st century specialist and 21st century non-specialist (See Table 7).

Three other tests I conducted measured the readability of the texts but used different metrics other than passive-voice sentences. Instead, the Gunning Fog Index, Flesch Reading Ease test, and Flesch-Kincaid Grade Level test all used different formulas but focused on the same components: word length, sentence length, and complex word density (defined by the Gunning Fog Index as a word with three or more syllables). Interestingly, 21st century specialist writing and 19th century writing from both genres scored about the same on the Flesch-Kincaid Grade Level test (averages of 13.19 and 13.75 respectively). 21st century non-specialist writing scored the lowest on this test, with an average score of 9.49 percent. All four categories scored very similarly on the Gunning Fog Index, although it also estimates the years of formal education a person needs to understand the text on the first reading, similarly to the Flesch-Kincaid Grade Level test. Also, the scores on the Gunning Fog Index are higher than those on the Flesch-Kincaid Grade Level test. 21st century specialist writing scored the lowest (average of 29.1) on the Flesch Reading Ease test, followed by 19th century writing (average of 41.95) and 21st century non-specialist writing (average of 46.39; See Table 7).

Table 7: Text Comprehension and Readability

Category	**Average Gunning Fog Index**	**Average Flesch Reading Ease**	**Average Flesch-Kincaid Reading Level**	**Average % Passive Language Use**
21st Century PopSci	14.65	52.5	8.7	12.6

21st Century SciAm	15.72	40.275	10.2875	4.2
19th Century PopSci	14.6825	45.65	12.95	36.95
19th Century SciAm	15.7875	37.525	15.575	55.05
21st Century Nature	15.0525	39.025	9.4	9
21st Century Science	14.6525	19.175	16.975	14.5
19th Century Nature	14.6598	43.4	14.625	43.375
19th Century Science	15.705	45.75	15.075	42.25

CHAPTER 4: DISCUSSION OF KEY FEATURES AND TRENDS

The data analysis in Chapter 3 of genre and style features from 19th and 21st century science writing illustrates the relationship between the genres of non-specialist and specialist science writing and changes across time. The similarities and differences among many genre features from the 19th and 21st centuries reveal trends, more so than a study of any individual rhetorical feature. For example, just looking at the use of metaphor in 21st century non-specialist writing would not be enough to represent the core of this genre and its style. Pathos and diction, the logos of images and tables, indexes of reading comprehension, and other features must also be taken into account in order to describe 21st century non-specialist writing as a genre separate from 21st century specialist or 19th century non-specialist writing. This chapter is separated into three main sections that correspond with three major findings coming out of my data analysis: 1) similarities in specialist writing over time, 2) the unique genre features of 21st century specialist writing, and 3) the thin distinction between specialist and non-specialist writing in the 19th century.

4.1 Foundational similarities in 19th and 21st century specialist writing

21st century specialist and 19th century specialist writing included in this analysis used different methods to achieve the same goal: establish credibility as the authoritative source on the latest scientific findings and goings-on in the scientific community. On one level, scientists are establishing their own credibility as producers of research findings that are reliable and significant. On a higher level, science as a whole is establishing its role as a “provider of truth,” as an institution built on truth. The process of scientific journal publication that has developed since the 19th century and the authors who participate together provide a foundation and a functional basis for this establishment to continue building its ethos as an institution built on scientific truth. While these two time periods of specialist science writing differed in many ways, rhetorical features focused upon credibility and truth link them, and as Fahnestock (2004) points out, it is " worthwhile to ask what stays the same" (9).

In the 19th century, writers referred to specific people in their articles, but often only by their last names, or sometimes last names with a title ("Drs. Salmon and Smith" from *Science* December 1890). From the writer's perspective, this implies an expectation that the audience be familiar with the work of important scientists in the community. Consequently, the author does not need to spend any time providing an explanation. This expectation strongly implies that authors of 19th century specialist articles assumed their readers would be at or near their own level of scientific understanding and expertise.

In other instances, 19th century authors are directly addressing their expectations of the reader by assuming they know the "well-known land of Karagwe south of this river" or by writing "the reader with a knowledge of recent events can easily compare them with the facts here recorded…." Authors writing these lines do not consider the idea that a reader of their article could not know the land of Karagwe or that a reader does not have a knowledge of recent events. In the author's eyes, at least subconsciously, a reader without this knowledge should not be reading the article in the first place. The author does not address the reader who is not knowledgeable enough to understand the author's references. Only the knowledgeable reader is addressed.

What is the effect on readers when an author made assumptions like this? Scientists/knowledgeable readers would feel validated. They would continue reading that journal, potentially even contribute with articles they wrote themselves. They would feel like the intended readers, the audience invoked; they would feel a sense of community, and they would feel a connection to the author and others mentioned in the journal. The non-scientists or not knowledgeable readers would feel like outsiders, like they were participating in a community that was not their own. These readers would be made to believe that the article was not meant for them to read. They would look elsewhere for scientific information, or perhaps would be discouraged enough to stop seeking information about this kind of science altogether. However, if they did look elsewhere, they might turn to the non-specialist publications like *Popular Science* and *Scientific American* that were becoming popular at the time. They would not feel a sense of community, they would not feel like they belonged, and they would feel excluded from the scientific community implied by the author's assumptions.

How did making these assumptions benefit writers of the 19th century specialist journals? These authors were developing a population of readers knowledgeable about the journal's content, and these are readers who continue to purchase and read the journal. This population of readers could speak to the journal's credibility and share the journal with other reputable colleagues. Additionally, the journal is receiving potential new contributions for publication. And the more contributions the journal's editors receive, the more selective they can be about which articles make it into the final published edition. Overall, the journal is able to improve its reputation as a reliable source of news and scientific findings by ensuring its audience is a population of well-educated and well-informed individuals. Those who succeed in publication therefore gain in prestige.

In the 21st century, establishing credibility and authority seems to be more about implicit assumptions made through certain genre and style features that set it apart as a scientific research article as opposed to another, less reputable source of primary information like a popular magazine article or textbook chapter. For example, the 21st century specialist article has several unique characteristics, including an abstract, long citation list, complicated figures and tables, and a list of author affiliations. Regardless, the authors are still reaching for the same goal as the authors from the 19th century: build and maintain a reputation of credibility and authority with the appropriate audience. Doing so may help to create or continue a funding stream for research also. Professional recognition and academic promotion are also supported by publication in specialized periodicals.

Four of the 19th century specialist articles included citations, but all of the 21st century articles included citations (an average of 42 citations, whereas the average citations from the 19th century was just 2.25). This is a finding similar to what Gross, Harmon, and Reidy found in their 2001 study of 20th century science writing compared to past generations (170). In addition to being a sign of a “communal process centered on publication in socially recognized forums,” including citations is also a form of persuasion through ethos (Bazerman 1988, 139). According to Bazerman (1988), including citations is a rhetorical strategy used by scientists to convince the reader (in the 21st century, usually other scientists or a peer review board) that they have done the math and followed the rules, and their subsequent findings are credible as a statement of truth.

In addition to including citations, 21st century specialist authors make references to multiple tables, charts, and graphs to persuade the reader of their credibility. These figures are a mathematical representation of their data, figures with which their specialist readers are likely familiar. Lastly, 21st century specialist writing contained a significantly higher number of authors listed on each article. And with each other comes their affiliation which usually lists their associated institution and the department within that institution where they work. The list of authors and affiliations appears at the beginning of each article, so the reader knows from the beginning which scientists and which institutions were involved in the research. This is a way for those involved in the research to "show off" the products of their laboratories and the list of important people they had working on a project. Again, the list of authors and affiliations is another way to show the reader how dependable and credible the research findings are.

Drastic differences in 21st century specialist articles

In many key ways, 19th century articles I analyzed from both specialist and non-specialist writing and 21st century non-specialist writing resembled each other more than they did 21st century specialist writing. This contrast shows how 21st century specialist writing has changed the most drastically since the 19th century when science writing split into specialist and non-specialist genres.

21st century specialist writing contained more figures, citations, authors listed, use of Latin, abbreviations and acronyms, and parenthetical clarifications than those combined in 21st century non-specialist writing and 19th century writing from both genres.

There are more people with PhDs in scientific fields in the world than ever before, certainly more than there were in the 19th century when the research university was first developing. And with more PhDs comes more post-doctoral students, graduate students, and undergraduate students participating in laboratory research and the writing and publication of scientific papers. As the conducting of research, writing of reports, and publication of papers grows, the competition grows for publication of specialized findings and publication in the best journals. This growth is partly responsible for the extent to which 21st century science writing is so densely laden with parenthetical clarifications, abbreviations and acronyms, uses of Latin, authors listed, citations, and figures. The better scientists can rhetorically make a credible claim, the more likely they are to succeed in publishing papers. And publishing papers is a scientist’s primary product, along with generating grant proposals.

To achieve a paper published in journals like *Nature and Science,* periodicals that do not limit submissions to one particular field of science, scientists must ensure that they make effective rhetorical moves, making their paper the best it could be to maximize their chances of getting their paper published in the journal. A paper published in a high-impact journal like *Nature* or *Science* makes a scientist/research team look especially good to their university or other scientific institution, to their colleagues, and to potential research funding sources. Universities and other institutions that might look favorably on scientists for publishing papers in high-impact journals might improve a person’s chances of getting a raise in salary, getting approved for tenure, or getting chosen for a promotion over another scientist who perhaps did not have as good of a publishing profile. Publishing in a high-impact journal is advantageous in a scientist’s relationships with his colleagues because his colleagues might be more likely to cite that paper or express interest in collaborating on a project. As Halloran argues, the culture of the scientific profession emphasizes "winning the agreement of other scientists; the worth of an intricate methodology is largely a matter of whether it has the confidence of a scientific community" (82). And showing potential funders one's ability to meet the standards of high-impact journals increases a scientist's chances of receiving grant money for conducting important, meaningful research that people care about and procuring more money for staff, post-doctoral researchers, and graduate students to get more work done, allowing for the possibility of conducting multiple projects simultaneously. The more projects that are being done in one scientist's lab, the more chances the author has to continue publishing papers in high-impact journals, reaping the rewards of doing so all over again.

There is also more lab equipment and analytical tests than existed a decade ago, let alone a century or two centuries before. And there are terms, explanations, and acronyms to go along with these new technologies. At this point, U.S. science has had nearly 200 years since the beginning of the academic revolution to specialize, and the more specialist scientists and specialist journals there are, the more technical, specialized language there will be.

The small difference between 19th century specialist and non-specialist genres

Similarly, to what Harmon, Gross, and Reidy found in 2001, my study shows that 19th century writing from both specialist and non-specialist publications was not drastically different, especially when compared to the significant differences between specialist and non-specialist writing from the 21st century. Harmon, Gross, and Reidy explain in their 2001 study that “despite the growing separation between amateur and professional in many disciplines, the scientific article of this century refuses to look like its late 20th-century counterpart” (137).

Both specialist and non-specialist writing from the 19th century used similar amounts of figurative language, showed similar readability scores and passive language, and exhibited virtually the same amounts and types of genre features, such as figures, citations, headings, bylines, authors, and use of personal pronouns.

Why were the two genres so similar, if their purposes were different (one to reach expert audiences, the other to reach lay audiences)? In theory they were directed toward different audiences, but that audience distinction was not as clear in the late 19th century as it is in the 21st century. One explanation is that the academic revolution was only beginning to produce individuals with a PhD. In 1861, Yale University became the first American institution of higher education to award a PhD, conferring it upon three male recipients. Without numbers of scientists with PhDs to produce the conventional genre features, 19th century specialist writing would struggle to differentiate itself from non-specialist writing until the academic revolution gained more momentum.

At the time of the U.S. academic revolution, incentives to publish research were also very weak, too weak to be reflected in the literature of the article. With research universities only in their infancies, scientists were not as motivated by the factors that 21st century scientists are, namely career and salary advancement, social standing, and funding from sources, especially government sources, that would be impressed by publishing a scientific paper in the most prestigious journal. Additionally, the non-specialist science writing occupation was not born overnight. It would take the writers of science a while to catch up with the new purposes assigned to specialist and non-specialist publications.

What forces caused the two genres to become different for specialist and non-specialist science readers? The increased specialization of science over time was itself the primary cause. The more complicated that science research became, the more necessary it was for the non-specialist publications to provide a clearer understanding of findings for their non-scientist readers. More popular magazines were founded and distributed at lower costs more widely. With more competition for readers' interest, writers of non-specialist articles needed to argue more clearly and produce more interesting stories to capture the attention of their readers. The size of the audience also changed over time. In a way, the audience got larger as technology improved and editors could release and sell editions of their publication to more people in more locations, connected by faster transportation networks. As non-specialist publications developed, there also developed non-specialist publications for the lay reader within a specific field of science, like *Popular Mechanics* (1902) and *Sky & Telescope* (1941).

CHAPTER 5: CONCLUSION

In order to understand why modern scientist-authors and science writers make certain rhetorical choices in their writing, one has to have an understanding of where science writing started and how it has changed during important times in its history, such as during the academic revolution in the 19th century. This thesis aimed to do just that, comparing genre and style features in science writing between two key periods of time, the 19th and 21st centuries, and across two major genres of science writing, specialist and non-specialist. I found that specialist and non-specialist science writing in the 19th century differed little, especially when compared to the major stylistic and genre differences between the two genres in the 21st century. I also found that writers of 19th and 21st century specialist articles use different methods to achieve the same goal: impress upon their audience a sense of credibility and authority for claims of scientific truth. And lastly, I found that 21st century specialist writing changed the most drastically between the 19th century and the 21st century, as I saw that 19th century specialist and non-specialist writing were more similar to 21st century non-specialist writing than either of those genres were to 21st century specialist writing.

The shift in media from print to electronic format publications, complete with embedded links and colorful graphics, has been monumental for science writing as a medium, both specialist and non-specialist. With embedded links, an article that would be only a few pages in print can provide many additional pages of resources: supplementary material, author affiliations, related studies, and access to raw data. As technology has evolved, the ability of scientists to graphically display their data has also grown exponentially. This growth increased the complexity of graphics, allowing them to specialize right alongside the specialty of the scientist creating them. But the net effect may be that 21st century specialist science articles are inaccessible to the majority of the public which funds the research through government programs.

Narrow specialization also provides unique niches for scientists to fill, enhancing their ability to find funding for their research. For in theory, they are the only ones who are experts in their small subfield of science, which allows them to solve unique, specific problems. The peer review process has also changed as a result of narrow specialization. When an author is going through the conventions of publishing a paper, the work is reviewed by a group of peers from the same specialty. These peers are familiar with the intricacies of the specialization and will not make the same challenges someone from outside the specialty might. While there is strong competition for publication in peer reviewed journals, there is little if any editorial expectation that the information and arguments be accessible to non-specialist readers.

The journal editor also plays a role in the publication process. The editor of a 21st century specialist journal has a different role than the 17th century's Henry Oldenburg, who acted more like a correspondent than a gatekeeper. The contemporary journal editor maintains the qualifications authors must meet in order for their research to be considered for publication and supervises the peer review process. The parameters differ from editor to editor, journal to journal, but one genre feature that is virtually required for all scientific papers is the abstract. The abstract is a conventional genre feature I found to be unique to the 21st century specialist category. Why did scientists and editors decide it was necessary? Perhaps it is because the rate of scientific publication grew so large that scientists struggled to keep up with all of the research coming out, and they only had time to read a short summary of each new paper. The abstract is thus a useful tool for the busy scientist, but could a similar feature be applied for the non-scientist or non-specialist? The key terms of the abstract also now provide a vital function for the academic research databases and web-based search services. Potentially a parallel summary feature that condenses the findings and arguments in an accessible form would increase the effectiveness of popular science writing.

Depending on the audience and purpose, stylistic elements may help or hinder a reader's understanding of the text. The genre of specialist science writing in the 21st century is one that non-specialist audiences shy away from, relying instead on secondary sources to retrieve information. While this is an acceptable form of learning, key claims often get lost in translation. Scientific articles are a key product of science as a profession. Writing and publishing articles generates credibility, career advancement, and social status for scientists, that is if they publish an article in a high-impact, peer-reviewed journal. The system of scientific publishing has developed peer-reviewed journals as the highly valued publications of members of academic culture. And journals like *Nature* and *Science* are held in especially high regard because of their low acceptance rate; if you get an article published in *Nature* or *Science*, your research must be particularly significant for the advancement of science. Popular articles do not carry the same weight, yet they are often the vessel by which non-experts or non-scientists retrieve their scientific information.

Going forward, potentially the most important question to answer would be if the divide between specialist and non-specialist science communication has grown too wide for the health of the body politic. If the divide is too great, what can be done, if anything, to amend it? Will a third genre evolve that bridges the divergent audiences and purposes? Or is it plausible to think that scientist-authors in general could learn to write and communicate their findings more clearly so that non-specialists could read and comprehend their work? Or could non-specialists learn to understand scientific writing at the level of the scientist-author, comprehending scientific concepts as laid out in specialist journals without the help of metaphors or explanations? I argue that neither of these scenarios are likely for at least the foreseeable future. Both specialist and non-specialist authors play an important role in the advancement of science, but each role is geared toward a specific audience with certain expectations. And it may also be that even non-specialist writing like in *Popular Science* or *Scientific American* is not accessible enough for everyone. Although information sharing through the internet and social media has raised issues for distinguishing between truth and myth, those devoted to the dissemination of scientific information to people from all walks of life can use the technology of the internet to their advantage. The website provides a unique medium for hosting a variety of resources that could tell one scientific story in many different ways depending on the particular visitor's reading abilities and background knowledge. The internet will help to make science accessible to an ever-wider segment of the population.

We are only in the beginning of the 21st century. How will science writing continue to change during the next 100 years? The next 300 years? What style and genre changes will occur that will continue to define specialist and non-specialist writing? What new paradigms will initiate scientific revolutions that change the way we see the world? How will science and science writing evolve as a socially structured action? Whatever the answers to these questions may be, what unfolds as time passes will be a rhetorical reflection of the culture of science. Science writing will continue to evolve to be a reflection of how society understands the world, just as it did in the 17th century, just as it did in the 19th century, and just as it does now.

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APPENDIX A: LIST OF ALL PRIMARY ARTICLES ANALYZED

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APPENDIX B: REPRESENTATIVE PRIMARY SOURCES FROM EACH CATEGORY

POPULAR SCIENCE

WANT MORE?

HEALTH

Brewing A Better Painkiller

How synthetic biology could transform opiates

By Matt Giles November 17, 2015

© Science Photo Library/Alamy Stock Photo

This past August, Stanford bioengineer Christina Smolke announced a first: Her team used brewer's yeast—the stuff in beer—to produce a precursor to oxycodone and the active ingredient in Vicodin, two of the world's most popular painkillers. By splicing 23 genes from plants, animals, and microbes into yeast DNA, she says, "We created a chemical assembly line."

Predictably, the achievement caused a stir. On the one hand, it was a significant breakthrough. Opiates are useful and highly sought-after painkillers. Yet their manufacture still begins with physically scraping sap from the seedpods of opium poppies. That makes them expensive and limited. Smolke's method breaks that process open in a big way.

"The way we produce these chemicals is so outdated. Synthetic biology is dragging the field into the future."

—Christina Smolke, Stanford bioengineer

On the other hand, democratizing drug manufacture sounds scary. "People are trying to figure out potential abuses of this powerful technology," says Kenneth Oye, a political scientist at MIT. "It is hard to put stuff back in bottles after the fact." In theory, once Smolke refines the process, anyone with an undergraduate biology degree could start an underground dope lab. Picture *Breaking Bad* but with yeast. Drug agencies, Oye says, are not remotely prepared to handle a flood of synthetic opiates.

The truth is, they don't have to worry for some time. In its current form, Smolke's yeast is still proof-of-principle. The yield is so low that you'd need 4,400 gallons of it to make a single Vicodin pill. That said, the process will become more efficient, as every process does, and when that happens some regulation needs to be in place. "We don't want to get caught flat-footed and suffer a moratorium on exciting research," says John Dueber, a synthetic biologist at the University of California at Berkeley.

5.5: Number of people worldwide, in billions, without access to painkillers, according to a United Nations report

In the meantime, scientists will continue to coax painkillers and other drugs from yeast. Synthetic biologists already have a target list of thousands. They will also try to improve and customize the drugs we have. By modifying yeast, scientists could in theory use it to produce less-addictive painkillers, resistance-proof antibiotics, and even drugs to combat cancer. "Plants have never made the ideal medicine; humans just adapted them," Smolke says. "Now we can go beyond that to build better medicines."

This article was originally published in the December 2015 issue of Popular Science, *under the title, "How To Brew A Better Painkiller".*

news SCAN

PUBLIC HEALTH

Polio Postponed

POLITICS SLOW POLIO'S ERADICATION—AND CAUSE IT TO SPREAD **BY CHRISTINE SOARES**

The celebration started January 15, 2004, when health ministers of the last six countries where the poliovirus still circulated—Afghanistan, India, Pakistan, Egypt, Nigeria and Niger—gathered in Geneva to commence a very public countdown. After 15 years and some $3 billion, the Global Polio Eradication Initiative was going to halt all transmission of the "wild" virus by the end of the year and thereafter consign polio to the same fate as smallpox, declared officially banished in 1980.

MOBILE IMMUNIZATION TEAM in northern Nigeria carries insulated boxes of oral polio vaccine during a mass-vaccination campaign in early October.

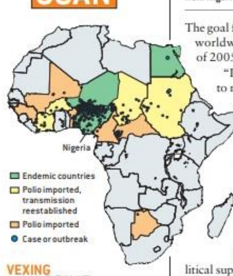
UNICEF/HQ04-0733/MUDIYAHAYA

Unfortunately, polio has proved to be a much trickier disease, and the world is a different place than it was in the 1970s. Rather than having been eliminated, polio is now present in 10 countries. The polio program has succeeded in many difficult areas, says University of Pittsburgh professor D. A. Henderson, who led the smallpox eradication program and guided polio eradication in the Americas. "But at this time they're running into some very heavy weather," he warns.

Polio's perfect storm started in the summer of 2003 in northern Nigeria. In the Kano state, politicians and clerics claimed that the polio vaccine was a "Western" ploy, tainted with HIV or with hormones meant to render Muslim women infertile. The resulting resistance to the eradication program led to immunizations being suspended for 11 months. By the summer of 2004, outbreaks in Nigeria had spread to 10 surrounding nations that had been polio-free for years, leaving nearly 700 children paralyzed and reestablishing polio in four countries.

A massive mop-up campaign began in October, involving one million volunteers in 23 African countries attempting to vaccinate 80 million children by year's end. The unexpected setback cost the cash-strapped eradication program an additional $100 million.

news SCAN



WILD POLIO was exported to 10 polio-free countries from Nigeria in 2004.

VEXING VACCINE

Wild poliovirus is present in India, Pakistan, Afghanistan, Nigeria, Niger, Egypt, Ivory Coast, Burkina Faso, Chad and Sudan. These nations hope to eliminate the disease by the end of 2005. The World Health Organization will wait three years before certifying that wild virus is no longer circulating in the world. Then the agency faces another hurdle: banning further use of the oral polio vaccine (OPV) and destroying any remaining stockpiles. The live virus in OPV can mutate back into pathogenic form, and at least four polio outbreaks have been attributed to the vaccine itself. The Global Polio Eradication Initiative does not want to eradicate polio only to combat vaccine-derived outbreaks.

The goal for ending wild-virus transmission worldwide has now slipped to the end of 2005.

"It's certainly biologically feasible" to meet the new target date, says David L. Heymann of the World Health Organization. Since Heymann took over the polio program in mid-2003, the veteran epidemiologist has observed that political will is the real wild card [see "A Strategy of Containment," by Christine Soares; SCIENTIFIC AMERICAN, March 2004]. So he has spent much of his tenure traveling to drum up political support for polio eradication.

One of Heymann's first big accomplishments was gaining an endorsement from the Organization of the Islamic Conference (OIC), a confederation of 56 Muslim nations. Polio has hit the group hard: five of the six original endemic countries and two where wild virus was reestablished are members. Malaysia and the United Arab Emirates, both in the OIC, each made $1-million contributions to the eradication program last year. The organization's support also softened opposition in Nigeria. By last spring, Kano officials agreed to resume vaccinations but made a show of purchasing the vaccine from Muslim Indonesia, and sending it to India to be safety-tested. (Ironically, India, where polio is still endemic, has yet to resolve two past incidents of locally manufactured vaccine being contaminated—either accidentally or intentionally—by a virulent wild strain of the poliovirus.)

Meeting an end-of-2005 target in Africa will require a "heroic effort," according to Henderson. The 13 African countries where outbreaks occurred last year cover an area bigger than the 48 contiguous states and have a population of some 300 million people. Because polio only causes a detectable "acute flaccid paralysis" in one of every 200 victims, it is much harder to ferret out than smallpox, Henderson adds, and 800 documented cases in Africa mean that 160,000 people were probably infected.

India, Pakistan and Afghanistan are in far better shape. By early November, India had detected only 81 cases. According to Heymann, all three Asian countries should "finish up" efforts to halt wild-virus transmission early in 2005. Doing the same in Africa by the end of the year is essential, he says: "If countries don't do it now, it won't happen. This is the best chance we'll ever have."

The polio program's tribulations may already have dampened enthusiasm for the concept of total disease eradication. Measles was supposed to be next, but measles fighters are only "talking about mortality reduction and catch-up" these days, Heymann remarks.

"There's been an undue emphasis on the idea that we're going to eradicate things," Henderson says, despite his own successes against smallpox and polio. Noting tremendous progress in controlling childhood diseases, such as neonatal tetanus and rubella, Henderson thinks that if nothing else, "the polio program has served to show countries what could be done with large-scale immunization, when you mobilize a whole community to act."

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THE WORLD'S FAIR OF 1892.

As our readers are aware, it is proposed to hold an international exhibition of the science and industries of all nations in 1892. The United States will be the scene of the exhibition, which is in commemoration of the discovery of America by Columbus in 1492. The city for the exhibition remains yet to be chosen. It must be determined by the action of Congress. The federal legislature will designate the locality, and in so doing will pledge the assistance and co-operation of the central government for the enterprise. Several prominent cities are making strenuous efforts to be selected, feeling that the fair will be a great benefit to the metropolis in which it will be held. These efforts have taken the form of conditional subscriptions, appointments of committees to forward congressional action, and have, in New York particularly, led to the definite selection of grounds, and the formation of a fund of five millions of dollars.

All Americans should have at heart the success of the exhibition as viewed from the national standpoint. The interests of a particular city are entirely a side issue. The fair is to be even more than national. The world of civilized nations is interested, and Congress should take this aspect of the case in evolving special legislation.

The impartial investigator would be guided in making a choice by considerations affecting the size of the assemblages, facility of transportation and of accommodation, and would regard the finances of the fair as practically assured. The city of New York would be pre-eminent in these respects. It represents a center of population, and literally a national metropolis, of over three millions of inhabitants.

It may be considered in this sense as second in size to London only of all the cities of the globe. Within the limits traced by a ten mile radius, the above population is included. But this is not all. Distance may be expressed in time. Within eight hours of New York by fast trains a number of great cities are situated. Rochester on the west and Boston on the east, come well within the above limit. Between them lies a number of centers of population, all of considerable importance. Going south, the cities of Philadelphia, Baltimore, and Washington would be contributors within the eight hour line. On this basis, it has been calculated that a home population of ten millions of people will be within eight hours of New York.

The foreign visitors will be most admirably provided for. It is but a few weeks since we illustrated examples of several new and magnificent ocean steamers, the property of as many transatlantic lines, all running to New York. If the exhibition is held here, fifty ships of equally fine character could be employed, and the present New York and European fleet, unequaled, and never to be equaled, will be the all-important factor in bringing visitors from abroad. Wherever the fair is held, the visitors must pass through the gates of the national metropolis. After the sea voyage they should find themselves at their goal, not a thousand miles or more distant.

As regards facility of transportation, the particular site selected is peculiarly good. It occupies a central position as referred to distances north and south. The approaches will radiate to northeast and south from its gates, and from each direction approximately equal numbers will come. This distribution will do much to prevent overcrowding. The site faces with a high bluff for three and a half miles upon the Hudson River. This frontage can be utilized to great effect. Wharves and anchorage facilities can be provided all along this stretch. Steamers from all parts of the Atlantic coast can bring their passengers directly to the fair grounds. They can lie at the foot of the grounds for a number of days and be used as hotels by their passengers, who thus can visit the fair with the maximum of comfort and convenience. Numerous elevators will be in operation from the wharves to the grounds. The world has never yet offered a site which presented the possibility of carrying out such an arrangement. There is no doubt if the fair is held on the grounds in question follow aquatic races and marine contests of every description.

The subject of money to carry out adequately the ends of the fair, and to enable America to present a greater exhibition than the world has yet seen, need hardly be considered. The wealth of New York, the character of the subscribers to the guarantee fund, and their ability to double or treble the subscriptions, are beyond all question. No city can offer a more satisfactory financial basis than that already guaranteed by New York.

THE INCANDESCENT LIGHT CONTROVERSY.

The controversy now in progress between the promoters of the rival systems of incandescent lighting, though some will think of doubtful expediency, so far as the companies are concerned, admirably serves to acquaint a public now grown timorous, with the detail of operation and with the nature of the precautions which, if employed, would render both systems entirely safe, at least to the user.

With perceptions sharpened by constant investigation, the rival champions have each in turn pointed out the defects of the other's system of lighting—defects which, because of the reticence of the companies, have, till now, only been surmised by the public.

It is the purpose of this article to examine these, as they have been pointed out; inquiring as to the mischief that might come, and describing the steps which the studies of practical electricians show to be necessary for their correction.

The alternating current system, the attack on which led to the present controversy, is used very generally on both sides of the water for incandescent as well as for arc lighting; its chief recommendation, the power it possesses to light extensive districts from a single station. In an arc light circuit the current reaches the lamps directly from the conductors, the voltage varying, according to requirement, from 1,200 to 2,000. In the incandescent system this high voltage is maintained in the street circuit, but, by the interposition of converters or transformers, located in or near each building, a secondary current of scarcely more than fifty volts is produced. This is suitable for operating a number of lamps, each equal to a full working five-foot gas burner of 16 candle power. The transformer is made up of two separately wound and insulated coils, one of thin wire connected to the street mains and the other of thick wire connected to the wires of the building to be lighted; currents sent through the coil of thin wire induce in the near-by coil of thick wire currents, the voltage of which bears the same ratio to that of the primary current as the number of convolutions in the primary bears to the secondary coil of the converter. For example, if the electromotive force of the primary or street current is 500 volts, and the electromotive force of the secondary current is required to be 50 volts, the primary coil will require ten times as many convolutions as the secondary. The promoters of this system say that it is an easy matter to make the insulation between the two already separated coils effective and to prevent the current in the primary wire from penetrating it. On the other hand, their rivals say that no system of incandescence which has a high tension current behind it can be rendered absolutely safe, that breaks or leakages will come, because the mechanisms of man, however ingenious, are never perfect, and human watchfulness and foresight not to be depended upon. They instance the case of the employe of the Manhattan Electric Light Company who got his death shock while carrying a portable incandescent light in the engine room of the station, a lamp, be it said, supposed to be protected from the main current by a converter. There would seem to have been a break in the insulation of the wire, which his hand must have rubbed against, his face perhaps touching a steam pipe, thus forming a ground. The station men say that only 120 volts were on the circuit, but as this would not destroy life, it is evident that the high-pressure alternating current must have reached the wire, and, passing

RESEARCH ARTICLE

HEART MITOCHONDRIA

Imbalanced OPA1 processing and mitochondrial fragmentation cause heart failure in mice

Timothy Wai,[1,2]* Jaime García-Prieto,[3]* Michael J. Baker,[1] Carsten Merkwirth,[1] Paule Benit,[4,5] Pierre Rustin,[4,5] Francisco Javier Rupérez,[6] Coral Barbas,[6] Borja Ibañez,[3,7]† Thomas Langer[1,2,8,9]†

Mitochondrial morphology is shaped by fusion and division of their membranes. Here, we found that adult myocardial function depends on balanced mitochondrial fusion and fission, maintained by processing of the dynamin-like guanosine triphosphatase OPA1 by the mitochondrial peptidases YME1L and OMA1. Cardiac-specific ablation of *Yme1l* in mice activated OMA1 and accelerated OPA1 proteolysis, which triggered mitochondrial fragmentation and altered cardiac metabolism. This caused dilated cardiomyopathy and heart failure. Cardiac function and mitochondrial morphology were rescued by *Oma1* deletion, which prevented OPA1 cleavage. Feeding mice a high-fat diet or ablating *Yme1l* in skeletal muscle restored cardiac metabolism and preserved heart function without suppressing mitochondrial fragmentation. Thus, unprocessed OPA1 is sufficient to maintain heart function, OMA1 is a critical regulator of cardiomyocyte survival, and mitochondrial morphology and cardiac metabolism are intimately linked.

The dynamic behavior of mitochondria preserves mitochondrial integrity and distribution and allows mitochondrial shape and function to be adapted to altered physiological demands (*1*, *2*). Disturbed mitochondrial dynamics is associated with a number of neurodegenerative disorders and cardiac hypertrophy in mice (*3*, *4*). Dynamin-like guanosine triphosphatases (GTPases) mediate the fusion and fission of mitochondrial membranes. Mitofusins 1 and 2 (MFN1 and MFN2) orchestrate outer mitochondrial membrane fusion, whereas OPA1 is required for inner mitochondrial membrane fusion. Fission, on the other hand, is executed by dynamin-related protein 1 (DRP1), a cytosolic protein that is recruited to the mitochondrial surface in response to various physiological cues. This complex machinery, including DRP1-specific receptor proteins and cytoskeletal components, assembles at contact sites between the mitochondria and the endoplasmic reticulum, which mark mitochondrial division sites (*5*, *6*).

Fusion and fission of mitochondrial membranes occur in a coordinated manner. Balanced cycles of fusion and fission determine the shape, size, and number of mitochondria, which leads to a large variability in the morphology of mitochondria in different cell types. Although mitochondria form interconnected, tubular networks in cultured fibroblasts, they appear as distinct entities in tissues, such as heart and skeletal muscle, that are characterized by low fusion and fission rates (*7*). Moreover, coordinated mitochondrial dynamics is critical for the bioenergetic function of mitochondria and is closely linked to metabolism. Changes in mitochondrial ultrastructure and dynamics occur in response to altered metabolic demands (*8*–*11*), and components involved in mitochondrial fusion are central regulators of cellular metabolism (*12*). Coordinated fusion and fission events are crucial for mitochondrial quality-control. Fusion contributes to mitochondrial maintenance, whereas excessive fission causes mitochondrial fragmentation, which allows removal of irreversibly damaged mitochondria by mitophagy and is associated with cell death (*13*, *14*). Fragmentation of the mitochondrial network is observed in a wide variety of diseases.

The dynamin-like GTPase OPA1 mediates mitochondrial fusion and orchestrates mitochondrial cristae morphogenesis and resistance to apoptosis in response to physiological demands (*15*–*17*). The processing of OPA1 is emerging as a central regulatory step coordinating fusion and fission of mitochondria (*18*, *19*). Two peptidases in the inner membrane, OMA1 and the *i*-AAA protease YME1L, convert long OPA1 forms (L-OPA1) into short forms (S-OPA1) (*20*–*23*). The balanced accumulation of both forms maintains normal mitochondrial morphology: Fusion depends on L-OPA1 only, whereas S-OPA1 is associated with mitochondrial fission (Fig. 1A) (*24*–*26*). Cellular stress, mitochondrial dysfunction, or genetic interventions (such as deletion of *Yme1l*) can activate OMA1, which results in the increased conversion of L-OPA1 into S-OPA1 and mitochondrial fragmentation (*25*, *27*–*30*). Loss of *Yme1l* in cultured fibroblasts does not impair fusion but triggers mitochondrial fragmentation (*22*, *25*, *31*), which can be suppressed by deletion of *Oma1* (*22*, *25*, *31*). Thus, although OPA1 processing is dispensable for mitochondrial fusion per se, an increased oxidative phosphorylation promotes cleavage of OPA1 by YME1L (*10*). It thus appears that different stimuli modulate OPA1 processing by YME1L or OMA1, which allows the coordination of mitochondrial fusion and division under various physiological conditions.

In agreement with its role for stress-induced OPA1 processing, ablation of *Oma1* in mice causes impaired thermogenesis and diet-induced obesity and protects against ischemic kidney injury (*29*, *32*). Here, we generated tissue-specific mouse models for the OPA1-processing peptidases YME1L and OMA1 and examined the role of OPA1 processing in myocardial function.

Results

YME1L is essential for embryonic development

To study the importance of balanced mitochondrial dynamics (Fig. 1A), we generated conditional mouse models of the OPA1-processing peptidases *Yme1l* and *Oma1* (fig. S1, A to D, and table S1). We used a mouse line expressing Cre recombinase under the control of the β-actin promoter to delete *Yme1l* or *Oma1* by Cre/loxP-mediated recombination in all tissues. As expected (*29*), $Oma1^{-/-}$ mice were born at the expected Mendelian ratio (fig. S1E). $Yme1l^{+/-}$ mice were viable and exhibited no obvious phenotypes, but heterozygous intercrosses did not yield viable null offspring (Fig. 1B). We observed a generalized developmental delay in $Yme1l^{-/-}$ embryos isolated from embryonic day 8.5 (E8.5) to E12.5 (Fig. 1C). Hearts from $Yme1l^{-/-}$ embryos isolated at E9.5 and E10.5 failed to beat properly, and we did not recover any null embryos after E13.5. Thus, YME1L is essential for embryogenesis.

Cardiomyocyte-specific deletion of Yme1l causes dilated cardiomyopathy

We next examined the requirement of YME1L for the function of the heart, a metabolically demanding organ sensitive to disruption of mitochondrial shape (*7*, *33*). We crossed $Yme1l^{LoxP/LoxP}$ mice to mice expressing Cre recombinase specifically in cardiomyocytes (Myh6-Cre; cYKO) (*34*). cYKO mice were viable but had a significantly shortened life span (median life span: 46 weeks) (Fig. 1, D and E) punctuated by weight loss before their demise (Fig. 1F), which suggested that YME1L is required for normal heart function.

[1]Institute for Genetics, University of Cologne, 50674 Cologne, Germany. [2]Max-Planck-Institute for Biology of Aging, Cologne, Germany. [3]Myocardial Pathophysiology Area, Centro Nacional de Investigaciones Cardiovasculares Carlos III (CNIC), Madrid, Spain. [4]INSERM UMR 1141, Hôpital Robert Debré, Paris, France. [5]Université Paris 7, Faculté de Médecine Denis Diderot, Paris, France. [6]Centre for Metabolomics and Bioanalysis (CEMBIO), Faculty of Pharmacy, Universidad San Pablo CEU, Campus Montepríncipe, Boadilla del Monte, 28668 Madrid, Spain. [7]Department of Cardiology, Instituto de Investigación Sanitaria (IIS), Fundación Jiménez Díaz Hospital, Madrid, Spain. [8]Cologne Excellence Cluster on Cellular Stress Responses in Aging-Associated Diseases (CECAD), University of Cologne, Cologne, Germany. [9]Center for Molecular Medicine (CMMC), University of Cologne, Cologne, Germany.
*These authors contributed equally to this work.
†Corresponding author. E-mail: thomas.langer@uni-koeln.de (T.L.); bibanez@cnic.es (B.I.)

ELECTRICITY AS POWER.

BY FRANCIS R. UPTON, ESQ.

In the early history of electrical science, many forms of engines were made, by which the power of electricity could be shown. Each was as wonderful as the other to the unthinking observer; for, without apparent combustion of fuel, work was done. We find, among the largest of these engines, one used in St. Petersburg, to drive a small boat, and one in this country to propel a train.

The United States Congress voted a sum of money to Prof. Page to carry on his experiments and he built a very efficient motor. After many experiments, though it was found that any amount of power could be obtained, yet the expense was so great as to make it of no practical value. In a small machine, the consumption of zinc might not be noticed, while in a large machine it would be found to burn exactly as the work was taken. Now that the doctrine of energy is clearly understood, the folly of the attempt can easily be seen. In a battery the fires are fed with an expensive metal. The energy developed by the zinc, thus used, was given to it artificially when it was reduced from the ore. In order to obtain a convenient fuel, both the coal and zinc ore must be mined, and the latter reduced, absorbing in the reduction a very small per cent. of the energy of the coal used in the process. Thus batteries for furnishing power consume a fuel at least fifty times more expensive than coal.

Besides the cost of fuel, the atmosphere, so to speak, in which the zinc burns, must be furnished to it artificially in the shape of acids or solutions. Though this has nothing to do with the theoretical cost, yet in practice, it is found to be the largest item of expense. It resembles furnishing a boiler with air made by a chemical process, so far as the economy of combustion is concerned. Yet the convenience and reliability of a battery to burn zinc has, where very small amounts of power are required, allowed of its use commercially, since steam is extremely difficult to manage in fractions of a horse power.

To-day the practice has been entirely reversed from what the first experimenters expected to realize. For electricity is now entirely made by means of steam engines to drive large motors. The last few years have brought the means of generating and using electrical currents to such a high state of perfection that power may be with economy transferred by them.

The loss in transferring is double; if a machine converts fifty per cent. of the power it receives from a staem engine, only fifty per cent. of that can be utilized, that is, twenty-five per cent of the original; thus wasting seventy-five parts out of each hundred of energy. A sixty per cent. machine can render effective thirty-six per cent.; an eighty per cent. machine can turn into useful work sixty-four per cent., and so on. This wasting of power in the transmission is more than counterbalanced in a great many cases by its delivery at the point where needed; for example, from a waterfall to a field for ploughing and threshing, as has been done in France; or from the shore to the water for the purpose of driving a torpedo boat, as has been done in this country.

Lately experiments have been made to show the application of electricity to railroads. Mr. Siemens, in Berlin, and Mr. Edison, at Menlo Park, are experimenting with electrical railroads. Mr. Edison uses the rails as conductors of electricity, the current going in one and returning in the other. The wheels are insulated, so that, by means of brushes on them, the electricity may be brought to the moter, which is on a carriage. The moter is simply one of Mr. Edison's generating machines, laid on its side, and connected by suitable mechanism to the axle of the driving wheels. On an experimental track of one-half mile length, a speed of twenty to thirty miles an hour has easily been reached, in spite of heavy grades and sharp curves.

For elevated and underground railroads, this method has many advantages; it does away with all the smoke and noise from the puffing of the locomotive, and substitutes for the many locomotives a few stationary engines scattered along the route. Mr. Edison feels very confident of success, since his troubles so far have all been in transferring the power from the armature to the driving wheels. He thinks that if the armature is only reliable, experiment will lead to proper mechanical devices for transferring the power from the quick-running armature to the slower driving wheels.

The road will be very useful in mountainous regions, since the engine is quite light and can be carried by trestle work and light earth work, over any country. The engine and boilers are not in this case put on wheels and required to push themselves over grades and around curves, but are placed in the valley below. Perhaps in many cases they may be done away with and water used to drive the generators.

For beach roads, in grand exhibitions, as feeders to main lines, and in many ways it is easy to see that use may be made of a properly constructed road. The gentle fluid, which has so quietly, for many years been the swift messenger of man, is now showing that it is also able to be a strong and lusty servant, and carry any load that it may be asked to take.

ELECTRICAL INSECTS.—It is not generally known that there are insects which possess the peculiar electrical properties of the Raia Torpedo and Gymnotus Electricus. Kirby and Spence, in their entomology, describe the *Reduvius Serratus*, commonly known in the West Indies by the name of the *wheel bug*, as an insect which can communicate an electric shock to the person whose flesh it touches. The late Major-General Davis of the Royal Artillery, well-known as a most accurate observer of nature, and an indefatigable collector of her treasures, as well as a most admirable painter of them, once informed me, that, when abroad, having taken up this animal and placed it upon his hand, it gave him a considerable shock, with its legs, as if from an electric jar, which he felt as high as his shoulder, and dropping the creature, he observed six marks upon his hand where the six feet had stood. Two similar instances of effects upon the human system resembling electric shocks, produced by insects, have been communicated to the Entomological Society by Mr. Yarrell; one mentioned in a letter from Lady de Grey, of Groby, in which the shock was caused by a beetle, one of the common *Elateridae*, and extended from the hand to the elbow on suddenly touching the insect; the other caused by a large hairy lepidopterous caterpiller, picked up in South America by Capt. Blakeney, R. N., who felt on touching it a sensation extending up his arm, similar to an electric shock, of such force that he lost the use of his arm for a time, and his life was even considered in danger by his medical attendant.

Neon isotopes constrain convection and volatile origin in the Earth's mantle

Chris J. Ballentine[1], Bernard Marty[2,3], Barbara Sherwood Lollar[4] & Martin Cassidy[5]

[1]*Department of Earth Sciences, University of Manchester, Oxford Road, Manchester M13 9LP, UK*
[2]*Centre de Recherches Pétrographiques et Géochimiques, 15 Rue Notre Dame des Pauvres, BP 20, and* [3]*Ecole Nationale Supérieure de Géologie, Rue du Doyen Roubault, 54501 Vandoeuvre lès Nancy Cedex, France*
[4]*Department of Geology, University of Toronto, 22 Russell Street, Toronto, Ontario M5S 3B1, Canada*
[5]*Department of Geosciences, University of Houston, Houston, Texas 77204-5503, USA*

Identifying the origin of primordial volatiles in the Earth's mantle provides a critical test between models that advocate magma-ocean equilibration with an early massive solar-nebula atmosphere and those that require subduction of volatiles implanted in late accreting material. Here we show that neon isotopes in the convecting mantle, resolved in magmatic CO_2 well gases, are consistent with a volatile source related to solar corpuscular irradiation of accreting material. This contrasts with recent results that indicated a solar-nebula origin for neon in mantle plume material, which is thought to be sampling the deep mantle. Neon isotope heterogeneity in different mantle sources suggests that models in which the plume source supplies the convecting mantle with its volatile inventory require revision. Although higher than accepted noble gas concentrations in the convecting mantle may reduce the need for a deep mantle volatile flux, any such flux must be dominated by the neon (and helium) isotopic signature of late accreting material.

The difference between the noble gas isotopic compositions of convecting mantle and deep mantle, sampled by mid-ocean-ridge volcanism and ocean island volcanism, respectively, has been a cornerstone of the 'layered mantle' model that has dominated our conceptual understanding of the terrestrial mantle for the past 25 years[1,2]. The difference in the $^3He/^4He$ ratio between the values for plume-source basalts and the more uniform (but mostly lower) $^3He/^4He$ from mid-ocean-ridge basalts (MORB) was explained by a steady-state transfer of material from a primitive, volatile-rich 'lower' mantle into an 'upper' mantle, separated by the phase change at 670 km depth[3]. Further support for a layered mantle included the K-derived ^{40}Ar mass balance between the atmosphere and solid Earth, which pointed to a hidden reservoir with a ^{40}Ar concentration significantly higher than that in the upper mantle[4]. Similarly, the imbalance between heat and helium fluxes from the Earth was consistent with a mantle boundary layer (670 km) capable of separating these co-products of U and Th decay[5].

Geoid and dynamic topography, seismic tomographic imaging and fluid dynamical studies, taken together, show that chemical layering is not achieved by the 670-km phase change[6–8]. The existence of still deeper convectively isolated volatile-rich layers or regions to provide the volatile flux to the convecting mantle has been advocated[9,10]. The compositional density contrast proposed to stabilize these regions should be observed seismically. Significantly, however, it has not been imaged[11]. Other recent conceptual models include a water-rich melt layer within the mantle that preserves a volatile-rich deep reservoir while allowing whole-mantle convection[12]. These, and the original steady-state models, source all primitive volatiles in the convecting mantle from a deep, volatile-rich reservoir.

Mantle-derived samples contain $^{20}Ne/^{22}Ne$ ratios higher than the atmospheric value (9.8), and are interpreted as evidence for trapped solar neon in the mantle[2]. Indeed, the $^{20}Ne/^{22}Ne$ ratio of the Sun and the solar nebula is thought to be >13.4, derived from analysis of solar wind trapped in the lunar regolith (13.4–13.8), solar wind in Al foil (13.7 ± 0.3) and observation of the solar corona (13.8 ± 0.7)[13,14]. These values are in distinct contrast to a mixture of SEP (solar energetic particle) Ne and solar-wind Ne found in meteoritic material irradiated by solar atoms and ions[15], called Ne-B[15]. The mixture of these two components is found in relatively uniform proportions to give a Ne-B value of $^{20}Ne/^{22}Ne = 12.5 \pm 0.04$ (ref. 16). Work reported in refs 16 and 17 has highlighted the importance of identifying the source of the Ne isotopes in different mantle reservoirs, as this information provides a critical evaluation of the mechanisms proposed to incorporate volatiles into the silicate Earth and, shown here, the extent of interaction between different mantle reservoirs. To date, however, interpretation has been compromised by ubiquitous air contamination found in MORB and ocean island basalt (OIB) samples[18]. We show in this work that magmatic natural gases can be used to obtain an unambiguous Ne isotopic value for the convecting mantle that is consistent with an irradiated meteorite origin (Ne-B). When compared to the highest reliable values found in deep mantle plume material (>13.0 ± 0.2)[19], which are closer to solar nebula values, our result rules out the possibility that this OIB volatile source provides the noble gases found in the convecting mantle.

Magmatic CO_2 in New Mexico and noble gas results

Since the first identification of magmatic ^3He in continental fluids, there has been an increasing awareness that magmatic CO_2 can dominate some crustal fluid systems[20,21]. The Bravo dome natural gas CO_2 field (Fig. 1) was discovered in 1916 in Harding County, New Mexico[22] (it was originally known as the Bueyeros field). Today this field is producing from over 250 wells. The gas is 98.6–99.8% CO_2 with trace amounts of N_2, CH_4 and noble gases. Earlier noble gas isotopic studies of one well in the old Bueyeros section[23–25] show the CO_2 to be mantle-derived[23]. Here, 15 samples were collected from producing wells across the field. Between 10 and 30 cm^3 STP of sample gas was analysed[26]. The ^4He, ^{20}Ne, ^{40}Ar and ^{84}Kr abundances, and $^3He/^4He$, $^{20,21}Ne/^{22}Ne$ and $^{40}Ar/^{36}Ar$ isotope ratios, were determined for each sample (Table 1). Xe isotopes, $^{38}Ar/^{36}Ar$ and stable isotope results will be presented in future publications.

$^3He/^4He$ shows a coherent variation from $0.76R_a$ to $4.23R_a$ (R_a is the atmospheric $^3He/^4He = 1.4 \times 10^{-6}$) across the field (Fig. 1). $^{20}Ne/^{22}Ne$ and $^{40}Ar/^{36}Ar$ show the same coherent spatial variation, and have some of the highest values measured in a free crustal fluid, up to 11.88 and 22,600, respectively. The samples define a plane in three-dimensional plots of $I/^{22}Ne$ versus $^{21}Ne/^{22}Ne$ versus

FERTILITY OF HYBRIDS FROM THE COMMON AND CHINESE GOOSE

IN the "Origin of Species" I have given the case, on the excellent authority of Mr. Eyton, of hybrids from the common and Chinese goose (*Anser cygnoides*) being quite fertile *inter se;* and this is the most remarkable fact as yet recorded with respect to the fertility of hybrids, for many persons feel sceptical about the hare and the rabbit. I was therefore glad to have the opportunity of repeating the trial, through the kindness of the Rev. Dr. Goodacre, who gave me a brother and sister hybrid from the same hatch. A union between these birds was therefore a shade closer than that made by Mr. Eyton, who coupled a brother and sister from different hatches. As there were tame geese at a neighbouring farm-house, and as my birds were apt to wander, they were confined in a large cage; but we found out after a time that a daily visit to a pond (during which time they were watched) was indispensable for the fertilisation of the eggs. The result was that three birds were hatched from the first set of eggs; two others were fully formed, but did not succeed in breaking through the shell; and the remaining first-laid eggs were unfertilised. From a second lot of eggs two birds were hatched. I should have thought that this small number of only five birds reared alive indicated some degree of infertility in the parents, had not Mr. Eyton reared eight hybrids from one set of eggs. My small success may perhaps be attributed in part to the confinement of the parents and their very close relationship. The five hybrids, grandchildren of the pure parents, were extremely fine birds, and resembled in every detail their hybrid parents. It appeared superfluous to test the fertility of these hybrids with either pure species, as this had been done by Dr. Goodacre; and every possible gradation between them may be commonly seen, according to Mr. Blyth and Capt. Hutton in India, and occasionally in England.

The fact of these two species of geese breeding so freely together is remarkable from their distinctness, which has led some ornithologists to place them in separate genera or sub-genera. The Chinese goose differs conspicuously from the common goose in the knob at the base of the beak, which affects the shape of the skull; in the very long neck with a stripe of dark feathers running down it; in the number of the sacral vertebræ; in the proportions of the sternum;[1] markedly in the voice or "resonant trumpeting," and, according to Mr. Dixon,[2] in the period of incubation, though this has been denied by others. In the wild state the two species inhabit different regions.[3] I am aware that Dr. Goodacre is inclined to believe that *Anser cygnoides* is only a variety of the common goose raised under domestication. He shows that in all the above indicated characters, parallel or almost parallel variations have arisen with other animals under domestication. But it would, I believe, be quite impossible to find so many *concurrent and constant* points of difference as the above, between any two domesticated varieties of the same species. If these two species are classed as varieties, so might the horse and ass, or the hare and rabbit.

The fertility of the hybrids in the present case probably depends to a limited degree (1) on the reproductive power of all the Anatidæ being very little affected by changed conditions, and (2) on both species having been long domesticated. For the view propounded by Pallas, that domestication tends to eliminate the almost universal sterility of species when intercrossed, becomes the more probable the more we learn about the history and multiple origin of most of our domesticated animals. This view, in so far as it can be trusted, removes a difficulty in the acceptance of the descent-theory, for it shows that mutual sterility is no safe and immutable criterion of specific difference. We have, however, much better evidence on this head, in the fact of two individuals of the same form of heterostyled plants, which belong to the same species as certainly as do two individuals of any species, yielding when crossed fewer seeds than the normal number, and the plants raised from such seeds being, in the case of *Lythrum salicaria*, as sterile as are the most sterile hybrids.

Down, December 15 CHARLES DARWIN

[1] Charlesworth's "Mag. of Nat. Hist.," vol. iv., new series, 1840, p. 90. T. C. Eyton, "Remarks on the Skeletons of the Common and Chinese Goose."

[2] "Ornamental and Domestic Poultry," 1848, p. 85.

[3] Dr. L. v. Schrenck's "Reisen und Forschungen im Amur-Land,' B. i. p. 457.

CLOUD CLASSIFICATION[1]

THE work of a meteorologist who has devoted himself with great diligence for many years to the study of the structure, forms, and movements of the clouds, possesses a strong claim on the attention of all who are interested in this difficult branch of science. Independently of the importance of the challenge which Prof. Poëy offers to an existing system of nomenclature, his book contains numerous facts and suggestions of very considerable scientific value. In the present enlarged and revised edition the author has endeavoured to satisfy the requirements of our advancing knowledge on the subject of which he treats; a task which ought, unfortunately, to be one of no great difficulty, owing to the small amount of progress which has been made in this, as compared with other departments of meteorology, since the appearance of the second edition.

The history of cloud-nomenclature has been to a great extent a record of wrecks and casualties, because classification has, by an unfortunate necessity, preceded the knowledge of the physical structure of the objects classified. Prof. Poëy was one of the first to appreciate the importance of the fact that the terminology of the clouds must, ultimately, be based not simply upon the varieties of the forms of clouds, but upon those physical conditions to which these varieties are related. But our knowledge of the physical conditions which determine the development of the modifications of cloud is at the present time so limited that no classification founded thereon can as yet be unreservedly adopted. A great deal of questionable hypothesis necessarily enters into the construction of Prof. Poëy's scheme, as he would, we believe, with the candour which distinguishes him, be the first to admit. There is of course a strong *prima facie* desirability that cloud observers should possess some definite system of nomenclature; and at present nearly all of them, not of the lazy class, complain that cloud-classification is still in a state of chaos. Yet it may be doubted whether, for some years to come, a Meteorological Congress will be able to establish an absolutely fixed system of classification which will be universally accepted. Of the ground on which such a system should be built science has hitherto explored but a small portion; and even where we have the materials for observational and experimental research in this direction, very inadequate use has been made of these materials. The immediately practical problem which is raised by the study of this book is this:—In the provisional adaptation of our cloud classification to the status of our knowledge, is it desirable that Prof. Poëy's terminology be adopted in lieu of that of Howard, or should the still prevailing nomenclature be retained, with such modifications as the observations of Poëy and of other students of the subject have as yet shown to be necessary? To this problem we shall venture in the present article to suggest an answer.

As might be expected from the condition of the subject the critical portion of Prof. Poëy's treatise is more successful than the constructive. Several of Howard's terms have had from the first an ill-fated career. To

[1] "Comment on observe les Nuages pour prévoir le Temps." Par André Poëy. Third Edition. (Paris: Gauthier-Villars, 1879.)