INTRODUCTION

WRITING SCIENCE FOR NEW READERS, WITH NEW TECHNOLOGIES, IN NEW GENRES

Science must have clear, persuasive voices. At no time in history has it been both more important and more possible for scientists to be able to influence public policy locally, nationally, and around the world to earn trust with those who are impacted by science. At the same time, science must remain true to its time-honored mission to seek the truth and to resist any temptation to come to easy conclusions at the expense of the careful, often tedious, unglamorous collection of data and open-minded analysis.

Meanwhile, advances in information and communications technology have provided science communicators with an astonishing range of styles, languages, and tools for carrying out the work of science and for sharing that work worldwide.

This introduction will lay out the rhetorical focus of this book: its recurring emphasis on the scientist-writer's obligation to fit the content of writing (the what) to the needs of a great range of readers (the who). Today's readers of science, technology, engineering, and math (STEM) possess great differences in knowledge, but they want to understand scientific breakthroughs and processes—and to use them for practical purposes toward ensuring human and environmental survival and success. Increasingly, "Arts" is added to STEM (for STEAM) and this book can also help those in the social sciences and humanities become science communicators.

This introduction will also explain how twenty-first-century technologies have both broadened the audiences for science and brought about new genres for science writing not before possible. Among these recent advances is the effective redefinition of writing as no longer limited to the conventions of alphabetic and mathematical language, but now able to better use visual, aural, and kinetic capabilities for showing and explaining phenomena to communicate about science.

This book is for you, if

- You are a *practicing scientist* who needs to write one or more of the following documents: grant applications; project reports for supervisors or agencies; articles in research journals; laboratory or field research reports; summaries or reviews for non-specialist readers; posters and oral-visual presentations for meetings or conferences; blog posts or other online writings; create multimodal communications including videos, infographics, or other visual elements; opinion or descriptive pieces for more popular venues such as newspapers, magazines, and broadcast media; advocacy articles for legislatures or government committees.
- You are a *teacher of a STEM subject* who wants to help students deepen their knowledge or wants to help students read, write, and communicate better about their STEM topics or a communication teacher looking to teach students about communication in the sciences.
- You are a *graduate student* who is part of a team or lab that needs to write any of the above documents, or who teaches or assists undergraduate STEAM courses.
- You are a *science writer, technical writer, or non-fiction writer* with an interest in science topics and in writing about science in blogs, newspapers, magazines, books, and other non-specialist venues.
- You are an *undergraduate college* or *high school student* with a serious interest in a STEM subject and who wants to communicate well in school and with other people as interested as you are.
- You are anyone who loves science-relevant topics and who wants to communicate your interests, discoveries, and ideas to others—but may lack confidence in your writing and communication.

Writing Science in the Twenty-First Century presents 13 concise chapters (plus this introduction) that offer guidance and examples to help you succeed in a broad range of writing tasks and purposes, all pertinent to the work of science and other STEM fields. We emphasize the *twenty-first century* because writing about STEM topics is much more varied now than

in the past and reaches perhaps a billion more people because of Internet and broadcast technologies.

Many of our chapters will also address how genAI can both help and hinder writers' growth as rhetorically smart and effective communicators.

A FOCUS ON SCIENCE, BUT RELEVANT TO ALL STEM

This book will take most of its examples and lessons from scientific fields, such as the life sciences, chemistry, physics, and geology, but some examples will be taken from mathematics and engineering, so those in all STEM fields should find the book relevant to them. The "Writing in Science" classes that our colleagues and we have taught over years have included students from a very wide range of STEM majors, including engineering disciplines, agricultural and environmental sciences, computer science, and mathematics, as well as fields such as chemistry, biology, and physics, not to mention the many majors that have developed as combinations of sciences and technologies.

Students also come from such majors as anthropology and psychology, which rely on methods, materials, and genres that have much in common with all other STEM majors. The principles, processes, and techniques this book describes have been useful to these students, and we hope you will find them useful, too, and perhaps even inspiring. Thus, when we refer to writing in science in this book, you should understand it in terms of this more-inclusive STEAM context.

Here is an overview of what you can find in each chapter of the book:

CHAPTER ONE: WRITING TO REACH READERS

This chapter illuminates the act of writing as a person's (or team's) striving to achieve effective communication with a wide range of people who want and need to understand the writer's message. We must first dispense with the idea that "the data and facts speak for themselves." The data and facts can only be as powerful as the writers and speakers who interpret and explain them. This is the important work of knowledge building and sharing, and it requires a serious commitment from both authors and audience.

By examining contemporary examples from both peer-reviewed and more popular science writing, this chapter shows how effective science writers craft their writing to relate to the interests of their readers. Specific tools and techniques will be described—including a **systematic method** of both reading and writing with rhetorical awareness. Indeed, we must be sophisticated readers to understand the scientific literature we engage and to broaden our communicative abilities.

CHAPTER TWO: BUILDING EXPERIENCE AND CONFIDENCE IN WRITING SCIENCE

How we become capable communicators may take many forms, but underlying all of them is a confidence in our voice. Tools to be explained will include **writing to learn** in science and other powerful techniques of learning and thinking for the student. The chapter will describe typical obstacles for student writers in STEM fields and how writers, often with teachers' help, can overcome them. This chapter considers how technologies—including generative artificial intelligence (genAI)—can help us think about writing and communication and be ethically used in brainstorming and editing, but also surveys the limitations of these **technologies** as we develop as writers and communicators. Indeed, the focus of the chapter is the cultivation of one's own voice, and only secondarily how technologies can help writers develop fluency and confidence to take on greater challenges. At its core, the chapter illustrates how the important diversity of perspectives, experiences, and communicative styles make scientific communications richer and more rhetorically sophisticated.

CHAPTER THREE: "WRITING" REDEFINED MULTIMODALLY

Using examples from recent digital and print sources, including peer-reviewed journals, this chapter describes how effective science communicators have augmented conventional letters and numbers with visual language (e.g., photographs), aural language (sound files), video, animation, hyperlinks, and generative artificial intelligence tools. Online tools have become indispensable for scientists, but the range of possibilities in digital rather than print forms means one must make many rhetorical considerations when crafting a message. This chapter begins a process of showing writers easy ways to integrate some of these tools into their writing, and how to do so with rhetorical effectiveness. This process will be further elaborated in Chapters Eight through Eleven.

CHAPTER FOUR: WRITING SCIENCE ETHICALLY

While ethical conduct in the pursuit of scientific advances will be noted from time to time throughout the book, this chapter pays particular attention to ethical conduct in ways particularly pertinent to science writing and overall communication. As scientists gain greater access to broader publics through the Internet and new genres, science writers contend more and more with how to resist the urge to overclaim the importance of their work. They contend with acknowledging the limitations of their methods in the face of (1) stringent competition for scarce funding, (2) opposition

from those who have been historically harmed by, for example, scientific or medical institutions, (3) opposition from those, often hostile to science, who never hesitate to expound their points of view, with little regard for accuracy, and (4) misinformation.

Ubiquitous use of generative artificial intelligence technologies also raises ethical issues for researchers, both in their own work and in their assessment of others' work. In this chapter, we will explore these matters as well as accurate citation of sources, when and how often to cite, how fully to report methods, how to realistically measure the importance of results, and how to realistically make claims about the implications of one's research. Each of these concerns will be concisely explored in this chapter and advice given.

CHAPTER FIVE: WRITING THE RESEARCH ARTICLE, PART I—ABSTRACT, INTRODUCTION, METHODS AND MATERIALS

Because publication in peer-reviewed journals is still the gold standard for academic research scientists, two chapters consider the conventional introduction-methods-results-discussion (IMRD) research article and offer advice on making the most of the opportunities this form gives to write clearly, accurately, and persuasively. Looking at excerpts from influential articles in such journals as *Biological Conservation* and *Science*, this chapter shows how reader-oriented writing can both be persuasive and adhere to strict standards of precision. Chapter Five will focus on abstracts, introductions, and methods and materials as part of the IMRD form.

CHAPTER SIX: WRITING THE RESEARCH ARTICLE, PART II—RESULTS AND DISCUSSION

This chapter will continue the pattern established in Chapter Five, but will focus on the writing of results and discussions. It will consider new patterns in citation (e.g., links to sources) and graphic display that can make journal writing more effective in reaching readers, among other recent stylistic innovations brought about by online publication tools and capabilities. In addition, this chapter (and Chapter Five) will consider ways in which the different sections of the IMRD format can be tailored to the needs and characteristics of different types of readers.

CHAPTER SEVEN: WRITING THE RESEARCH REVIEW

For both working STEM professionals and STEM students, reviews of research are essential tools in both understanding scientific inquiry and communicating the importance of any path of research. Not only is the

review of research an essential aspect of all IMRD articles (in the Introduction of the report), but the research review is also a major form in its own right in the peer-reviewed literature.

This chapter offers advice for making the research review a purposeful, persuasive, and reader-focused work that demonstrates the writer's ability to summarize, paraphrase, and quote other researchers accurately and forcefully. It calls for an awareness of the history of science and the ability to probe how ideas change in science. In this chapter, the review of research moves way beyond the summary of key studies to become a tool to shape the significance of research and forge paths for new research.

CHAPTER EIGHT: STEM JOURNALISM—WRITING, READING, AND CONNECTING WITH BROADER AUDIENCES

This chapter describes the huge growth in popular (non-specialist) science writing in print and online magazines, newspapers, websites, and social media. Examples from a wide range of print and online sources in this chapter illustrate ways in which STEM writers can learn to communicate with broader audiences and in ways attuned to diverse audiences and today's multimodal expectations and tools.

The chapter spells out some of the implications of broader global accessibility, and what these mean for science communicators. The most profound changes have been the global broadening of the audiences for science communication and the formation of new genres and styles enabled by tools and influences from social media.

Although the peer-reviewed IMRD article and the research review are established forms in traditional print publishing, they, too, have been influenced by the emergence of new technologies and their capabilities, as well as by the global reach of the Internet. The chapter will include tips on voice, genre, and organization, as well as writing vividly to attract and maintain readers.

CHAPTER NINE: SCIENCE ONLINE—NEW READERS, NEW VOICES, NEW TOOLS

All fields require science communication online to some degree. Communication of science online has become a common way whereby new ideas—and new voices—in science have been recognized. For example, consider science blogs, which can be stand-alone sites by individuals and research teams or interactive adjunct sites to established companies, journals, and agencies. New styles, including freer use of first-person point of view and multimodal capabilities, provide many ways to communicate science. This chapter offers insights and advice for making the most of these opportunities, especially

through a consideration of audience, genre, and the affordances and constraints of the platforms used to communicate online. Challenges in these spaces, from bots and misinformation, and the difficulties of cultivating an audience in an attention-saturated environment are also discussed.

CHAPTER TEN: CREATING POSTERS AND INFOGRAPHICS

Poster presentations at academic conferences are a traditional way of displaying research in a highly visual, but condensed, format. Posters enable text, but they feature emphatic graphics, usually charts and diagrams, often colorfully. The poster's more versatile, online cousin, the *infographic,* is another genre used for communicating science that is highly visual but condensed. Whereas text is still the primary tool of the poster, the infographic emphasizes the visual, though it can still display a surprisingly large amount of text. Scientists' ability to create visual presentations is an integral part of their ability to communicate with audiences of all kinds. Creating a slide deck for conferences and meetings is common. This chapter offers advice and models not only for making the visual aspect of presentations stronger, but also to emphasize and strengthen the interactive relationship of the speaker and the audience. In this way, the chapter also explores how text, oral communication, and the interaction of different modalities can strengthen our communication of complex information.

CHAPTER ELEVEN: CREATING ORAL-VISUAL PRESENTATIONS

Scientists' ability to give oral-visual presentations is an integral part of their ability to communicate with audiences of all kinds. PowerPoint presentations are standard at conferences and meetings, as well as becoming more and more common as alternatives to straight textual presentations online. This chapter offers advice and models not only for making the visual aspect of presentations stronger, but also emphasizes and strengthens the interactive relationship of the speaker and the audience.

CHAPTER TWELVE: WRITING SCIENCE WITH STYLE AND STYLES

Although science writing is caricatured as "dry" (parched? drought-stricken?) and boring, this can rather signal a lack of care in writing and communication. Clear communication helps in clear thinking and argument, which is exactly why we cannot separate the work of science from science communication. Indeed, unclear and vague writing can cover up shoddy methods and thinking (which readers are too confused by to investigate!). Numerous examples of AI-generated text have illustrated exactly such problems, too.

This chapter digs into common stylistic problems with science prose—cluttered paragraphing, confusing organization, too much jargon, too

many irrelevant numbers—and offers simple methods to make the science researcher's prose as interesting as the work and ideas themselves. Use of many technologies can aid in the editorial process, and this chapter considers where such tools are appropriate and where they might hinder one's efforts to obtain a clear, engaging voice in their communication of science.

CHAPTER THIRTEEN: EDITING SENTENCES

While a scientist takes great care to keep a worksite clear, clean, and ready for work, sentences in science prose often can't do their work because meaning is hidden by lazy writing. This chapter puts sentences in sharp focus and offers tips for editing syntax, voice, length, tone, and word choice to make meanings stand out. *Editing* of sentences is distinguished in this chapter from the crucial work of *revision*, by which writers modify their ideas and presentation throughout the process of writing to make it more effective.

WRITING RHETORICALLY: CENTRAL TO EFFECTIVE STEM COMMUNICATION

Throughout this text, we will use the terms "rhetoric" and "rhetorical" to discuss the process whereby researchers and other writers can successfully communicate their ideas to the readers important to them. Why is rhetoric so important to science? How can it be most usefully understood?

Let's begin with a thought experiment that we call "Confronting the Rhetorical Wall."

> Think about the scientific topics that you are most interested in. Think about the work you do and the work by others that you read. Now think about the people to whom you have spoken about these interests and about what you have read. How would you characterize these people? What do they have in common? How are they different? Are some of them easier for you to talk with than others? Why?
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> Are there some people you avoid talking with about your work because (1) they have a different point of view about the subject than you do, or (2) explaining what you do and why you do it would be so hard for them to understand that you feel it's not worth the effort?
>
> Are you ever frustrated to realize that some of the people whom you **most need to convince about your work** are in one or both of those categories? Do you ever retreat back into your lab or field site to run another test or take more samples or make more observations because you don't want to think about those frustrations?

If so, then you have run up against a "rhetorical wall." Rhetoric is an ancient idea that more or less means the art and science of persuasion. The Greek philosopher Aristotle (2006) wrote about rhetoric more than 2,300 years ago, but even then the need for rhetoric was very ancient. Rhetoricians have been writing about non-violent persuasion ever since, as cultures have changed and technology has advanced.

Because rhetoric is so powerful, it is incredibly dangerous. The people who have been most successful in the world—whether for good or for evil—have tended to be good rhetoricians. But rhetoric does not require truth to be effective, merely the appearance of truth. Thus, for good reason, many who love science distrust, even hate, rhetoric for how it has been abused.

Because science normally proceeds in pursuit of truth, the idea of learning rhetoric might not seem necessary. However, most of us can readily think of examples of how difficult complex subjects can be to understand and why learning to communicate effectively is important. We can also think of cases that illustrate that science is no longer separate from society and, accordingly, science communication must address the civic sphere as well as the scientific one.

For example, almost all environmental scientists think it should be obvious that humans have caused climate change in the twentieth and twenty-first centuries, because test after test shows this to be so in numerous settings. Nevertheless, polls show that one-third of the people in the US refuse to accept the idea of human-caused climate change, and way fewer than half actually act in their daily lives as if this truth mattered.

Why is this difference between scientific truth and widespread belief and behavior so drastic? And why do scientists who wish to have some impact on public policy and public behavior need to understand this difference? In other words, why do scientists need to learn rhetoric?

WHY SCIENTISTS NEED TO LEARN RHETORIC

Part of the fear of rhetoric in the scientific community is that researchers will need to oversimplify the language of science to communicate with non-specialists. But rhetoric can help us understand how to transform our communications to address the audience's needs rather than trying to simply provide them with scientific knowledge or information for its own sake. Certainly, oversimplification is a danger when, for example, years-long processes of research and the intricacies of clinical trials are reduced by advertisers and mass media to dramatic claims of breakthroughs, such as played out with mRNA vaccines during the COVID-19 pandemic or "scare stories" about the supposed dangers of vaccines through the debunked alleged link between childhood immunizations and autism (a case that also reminds us of

the importance of non-ableist communications, which here would not frame autism as a scare nor seek to "cure" autism). Rhetoric addresses all these issues and more in a rich set of scholarly traditions we here draw upon to more effectively communicate about complex information and knowledge.

Later, Chapter Four on "Writing Science Ethically" focuses on the temptations to scientists themselves to exaggerate the value of research or its applicability in order

- to secure funding from public or private sources, or
- to draw attention within the science community.

Whatever the reason for the oversimplification of science, the problem is not oversimplifying to a less educated audience as it is misleading audiences that could—and should—be trusted to understand a more cautious, less one-sided message. That trusting audiences can work is shown by the success of systematic nutrition labeling on food products over the past thirty years, which has drastically changed consumer—and producer—behavior. Systematic labeling has demonstrated the ability of consumers—when given access to diverse products—to make choices based on more complex information.

Chapters Eight through Ten will expand on this need to reach broader, non-specialist audiences with accurate information that is presented with respect for the intelligence and knowledge of diverse groups of readers.

Learning rhetoric so that one can reach different audiences should better be thought of as

1. Working to understand why different audiences need different information, and
2. Learning how to use different *language, media, and argument strategies to meet those different needs.*

WRITING AND SPEAKING WITH RESPECT FOR DIVERSE READERS

An attitude of respect for diverse audiences is more realistic than an attitude of contempt. Recognizing that *certain audiences have greater expertise* in some crucial areas than do the researchers will go a long way toward helping scientists succeed in reaching those audiences. For example, a key purpose of government scientific research agencies is to provide evidence to legislative and executive committees as they ponder proposals to change laws on such issues as health, water, energy, parks, roads, and public safety. Indeed, it's difficult to think of an area of government where scientific thinking and study are not important.

But scientists often lack the knowledge that lawmakers and staffers have of the greatly varying concerns of different groups of voters. Scientific data collection and analysis that meets priorities of the researchers is often doomed to be thought irrelevant—if the scientists-writers are not aware of the needs and concerns of the policy makers and their constituents.

For example, publishing in-house technical reports on an agency website meant for voters and legislators will most likely confuse and bore, unless those reports are carefully introduced and summarized in a way that addresses the concerns of the readers. Moreover, if even highly relevant research is presented only in the numerical and theoretical languages of the scientists, then the relevance of the research will never be seen and surely not used. It is tempting for scientists to criticize the inability of non-scientists to read scientific discourse and theory, but if budgets are cut for scientific research because of the lack of persuasive communication with the people who fund those budgets, then blame is poor compensation. Blame may feel good, but it won't pay the bills.

EFFECTIVE TOOLS FOR STEM RHETORICIANS

Fortunately, contemporary science journalism and communication offers us many, many examples of highly effective writing that bridges the gap between the languages of the lab (and the specialty journals that speak them) and the constituent groups responsible for bringing knowledge of real concerns and human situations to policy questions. Periodicals such as *National Geographic, Catalyst,* and *Scientific American* have different missions, but each reaches a broad audience of readers, most of whom are not science researchers but all of whom have varying levels of interest and knowledge in science topics. In addition, major newspapers such as the *New York Times* and *Washington Post* publish both online and print versions that include science-relevant articles on a daily basis.

Science journalism is a profession that has burgeoned in the past three decades, and which includes not only many skilled writers, but outstanding photographers and, more recently, digital designers. Chapters Eight through Eleven will particularly study methods used by these writers, designers, and editors.

Science communication is another field of research that studies a range of ways to communicate about science and challenges to doing so, and which empirically tests approaches. In science, too, we find that peer-reviewed research journals themselves are changing in response to access by larger online audiences—and by the awareness that science communication needs to become more rhetorically effective for science to succeed—and also to challenges within the disciplines such as the "replication crisis" that can be

addressed through rhetorical means such as pre-registered studies. Chapters Five through Seven focus on this need to change and how it can happen.

In Chapter One, we will look more intensely at the process of reaching readers with your writing: scaling that rhetorical wall for audiences of different perspectives and kinds of knowledge.