The Art of Scientific Writing

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Can popular science texts be used in the L2 classroom to teach scientific academic writing? This paper will examine how different audience concerns on the part of these two genres have constructed different core language features. This will initially be achieved by examining the sociology of science, and comparing the two communities of practice within which the two genres exist. Finally, a comparison of the core linguistic features at the level of both genre and register will highlight key differences in the construction of the two distinct types of text. The paper concludes with an acknowledgement of the usefulness of popular science for familiarizing teachers with the content of science texts but cautions against using popular science as models for scientific writing itself.

第二言語の授業において科学技術系アカデミックライティングを指導する際、ポピュラーサイエンス・テキスト（一般向け科学書）を使用することは適切であろうか？本論では、この2つのジャンルにおいて、それぞれの読者を想定してなされる考慮により、異なった中核的言語特性が構築される仕組みについて研究する。この研究はまず、科学社会学についての検討、およびこの2つのジャンルを含む2つの実践共同体（community of practice）の比較により行われる。最終的に、両方のジャンルおよび言語使用域のレベルにおいて中核的言語特性を比較することにより、この2種類のテキストの構成における主要な相違が明確に示される。本論は、教師が科学技術関連のテキストの内容に精通することに関して、ポピュラーサイエンス・テキストが有益であることを認めると同時に、科学技術系アカデミックライティング自体のモデルとしてポピュラーサイエンス・テキストを使用することには、慎重さが求められるという結論に至っている。

Science majors in the L2 writing classroom may benefit from consulting existing texts in the genres of both popular science and academic science. Both these genres are well established and therefore represent a considerable wealth of knowledge upon which to draw. Yet, if a science major is studying English for the purpose of writing academic papers then the relevance of both genres to this purpose needs to be considered. Whilst popular science is far more accessible, has this accessibility been brought about by sacrificing the defining features of academic science? Does the use of popular science represent a wise investment of classroom time if the goal is to equip students with the ability to write academic science? In order to answer this question a brief examination of the sociology of science and knowledge (SSK) will yield insights into the academic atmosphere within which academic science is produced. Then an examination of the two different genres (popular science and academic science) from the perspective of communities of practice will highlight some of the differences that exist in audience considerations. Finally, some of the core features of the two written genres will be examined and compared, which will highlight some significant differences between the two text types.

Terminology

There are three points of terminology that must be defined before this question can be answered: What is science? What is meant by popular and academic science? What is meant by a text? Definitions of science will often vary only in terms of what academic disciplines are included in the definition. This paper will include only math, physics, chemistry and biology within the category of science. This is not to suggest that no other topic could be described as scientific but rather because these are the four disciplines least likely to be called controversial choices. The next definitions are more contentious: What is popular science and what is academic science? Academic science will be described as science textbooks and scientific journals designed for the education of scientists, while popular science will be used as a term for books written about science but designed for the entertainment mass market. The final piece of terminology that requires a definition is what constitutes a text. This paper will use the term *text* only to refer to written texts.

Understanding Science: The Sociology of Science and Knowledge

What can the sociology of science tell us about how academic science is written? "Recent work in the sociology of knowledge suggests that the set of ideas one holds to be true is largely a function of the group of people one interacts with and references to authorities recognized by the group" (Moody, 2004, p. 213). These ideas, with relationship to academic scientific writing, would include scientific knowledge on how the universe functions and on methodological considerations. Yet, if we accept that ideas are a function of group membership, so too would be the language used to express those ideas. Commonality of ideas will take place through the medium of a co-constructed, shared language. Therefore, learning about the manner in which the group functions will, almost certainly, provide insight into the manner in which the ideas of that group are expressed. Furthermore, how a writer constructs a text is a consequence of the writer's perception of the audience. Exactly what that perception is for writers in the field of academic science can be inferred by examining what SSK has to say about the group that is academic scientists. Hence an examination of SSK is of value.

The Paradigm of the Sociology of Science and Knowledge

Gieryn (2010) suggests seven antinomies to serve as a paradigm for SSK.

1. Science is social and cognitive.
2. Science is cooperative and competitive.
3. Science is institutionalized and emergent.
4. Scientific objects in the world are real and constructed.
5. Science is autonomous and embedded.
6. Science is universal and local.
7. Scientific knowledge is cumulative and … not.

The first claim suggests SSK studies both the life of scientists (social) and the life of scientific facts (cognitive). The life of scientists is a major consideration for those who believe science is constructed by scientists working in institutions and basing that knowledge on the research that has gone before (i.e., cumulative). The life of a fact is a major consideration for those who believe science is a discovery of real facts that have universal applicability. The competitive nature of science means that academic scientific writers write for an audience that includes their competitors, therefore adding to the knowledge owned by their competitors, thus, in effect, writing for their competitors and collaborating with their competitors. The strength of Guerin's paradigm is that it is paradoxical; the paradoxical nature is both inclusive and reflective, and yet, is not contradictory. That such opposing views *continue to exist* in SSK is suggestive of the turmoil that exists within the field of science itself; a paradoxical paradigm in SSK is the consequence of studying a paradoxical field of knowledge. When we consider the manner in which science choses to express itself, it would be a mistake not to consider this internal flux for these are the conditions within which the academic scientists function. When considering how science is expressed it is a common mistake to see it as the objective discovery of universal truths that have but one interpretation. Guerin's paradigm for SSK warns us against such a dangerous simplification.

A Paradigm for Popular Science

In order to discuss the paradigm of popular science it will first be necessary to create one. As such, the paradigm created for this paper, to stand in contrast to that of the paradigm of SSK, has been compiled from the introductions to popular science books and a chapter written about popular science. It has attempted to identify the purposes and themes that the authors claim to have motivated them to write their books in the first place. However, it should be recognized that this paradigm is a first-generation paradigm. It is unlikely that its current form will survive refinement. But, in the absence of a well-established paradigm (like that for SSK) a functional starting point for contrast is required.

1. Popular science seeks to demystify key scientific concepts for non-expert readers.
2. Popular science expresses these concepts without using the lexically dense language of academic science.
3. Popular science is written so as to be accessible to non-experts.
4. Popular science shows the everyday applications of the concepts addressed.
5. Popular science portrays the scientists as everyday people.
6. Popular science does not attempt to prepare its readers to continue to study the concepts.

This paradigm of popular science attempts to establish the purposes behind the writing of popular science. It attempts to show the key considerations for the audience that must remain at the forefront of the writers' minds when they put pen to paper. The main difference between this paradigm and the paradigm of SSK is the ultimate target of the philosophy. The SSK paradigm suggests that scientists function within a dynamic process. This incompleteness drives scientific enquiry. However, popular science is more concerned with the relationship it has with its reader than it is with its topic. Concern for reader-wellbeing is central to the paradigm of popular science. And this should not be so surprising, popular science is both entertainment and knowledge. Successful popular science sells books. Successful books are both entertaining and enlightening. The enlightenment aspect is taken from the domain of academic science. The entertainment aspect must come from a different domain to the knowledge. The language is the language from the humanities domain.

Communities of Practice

Seeking to describe the differences in the language of academic science and popular science also benefits from the exploration of communities of practice. Wenger (1998) describes a community of practice as "a kind of community created over time by the sustained pursuit of a shared enterprise" (p. 45). From this description we can identify three key components in a community of practice relevant to this discussion: a sustained interest in the topic, a shared interest, and pursuit of a target. As such, membership of a community of practice is not instantaneous, but rather, it is something that occurs over a period of time, as potential members seek to utilize the knowledge of practice already shared by the community. The purpose is to participate in the communities attempt to achieve a goal.

Let us examine what this means for the community of practice of academic scientists. Firstly, the fact that it is a sustained interest tells us that the progression from peripheral membership to core membership is a gradual progression, gradual by necessity, as the depth of knowledge required in order to become a core member cannot be achieved with ease. Instead it takes a sustained period of involved study, starting with the knowledge contained in textbooks, and moving to the knowledge presented in academic journals and presentations. Initially, students will begin in secondary education learning the facts that are represented in their textbooks, proceed through university using textbooks and eventually, as researchers, be involved in writing academic journals. There is a gatekeeping aspect to the community of practice that scientists are involved in. Those wishing to become core members of the community must qualify for each progressive stage of membership. These stages are not designed to allow entry to any willing participant but designed to exclude the incapable. This represents the considerable amount of time taken by students of science as they move from legitimate peripheral participation through to core members of the community of practice, but always moving towards the shared goal of enhancing the field of knowledge.

Having examined the community of practice for academic scientists, it would seem balanced to compare it with the community of practice of popular science. Unfortunately, it seems unlikely that one actually exists. The sustained nature of membership of the community of practice could be translated into popular science as a sustained interest in reading books on popular science for a number of years. However, it completely lacks any progression towards a shared goal, for there can be no common goal between the producer of entertainment and the consumer of entertainment that is long-term for no goal that can survive the final consumption of the product.

Tellingly, there is no competitive aspect to the consumption of popular science. Writers of academic science are aware that their competitors, sometimes their most ardent critics, will be reading the work once it is published. This competitive nature of academic writing forces the writer of academic science into using expressions that need not be immediately accessible but must be compacted so as to function within publication word limits while remaining meaningful. These expressions must contain large amounts of information packed into the tightest orthographical packaging (see nominalization below). Different constraints exist for the writer of popular science. They must operate without the use of the language of academic science. Indeed, "popular science authors point to the problems of relating the complexity of the ideational (or referential) content of science in texts that should display none of the characteristically forbidding forms of academic science, such as high degrees of nominalization, embedded causality, technical lexis and mathematical equations" (Fuller, 1998, p. 35).

Linguistic Features of Popular Science and Academic Science

Popular science contains a number of features that are not to be found in academic features. Likewise, academic science contains a number of features that are not to be found in popular science. Although the explanation of these features that follows is brief, it should serve to highlight the differences between the two genres.

Popular Science Features

There are two common features existing in popular scientific writing that are missing from academic scientific writing; an extended use of metaphor and an attempt by the author to motivate the reader to continue reading.

Extended Use of Metaphor

The introduction to the bestselling popular science book, *The Elegant Universe* (Greene, 2000) offers reading advice. One of the comments the author makes is to note how he has "tried to stay close to the science while giving the reader an intuitive understanding--often through analogy and metaphor--of how scientists have reached the current conception of the cosmos" (Greene. 2000, p. xi). This use of metaphor and analogy is a common tool in the popular science writer's kit; it is also very apparent in a number of other popular science books. Atkins (1995) uses geographical metaphors throughout his book on the periodic table. Analogies to journeys are to be found in books about evolution. These analogies and metaphors are useful in helping the non-scientist gain insight into scientific concepts. But they do not exist in academic scientific writing for they are not needed. The readers/participants of academic science do not need to draw upon knowledge from another domain with which they are more familiar; science is their domain.

Motivating the Reader to Continue Reading

Many popular science books include a chapter, often as a preface or at the beginning of the book, which explains how the science to be discussed has implications for all of us and, therefore, why it is of interest. For example, The Language of Life (Collins. 2010), a popular science book dealing with genetics, opens with a chapter dealing with a family bereavement. Typically, the language used is dramatic and emotional. This may represent an attempt by the writer to build a relationship with the reader and justify the readers continued investment of time in reading the book. Needless to say, such acts do not exist in the discourse of written academic science.

Three Core Features of Academic Writing

Writers of popular science and academic science, by considering their target audience, have found themselves moving towards a standardization of approach in their respective genres. The functionality of language is a driving force behind standardization. Much of the discourse of the sciences is based on the need to provide a functional description of abstractions, which may in turn have contributed to the multimedia aspect of scientific discourse (see below). As writers, such as Newton and Priestley, struggled to describe their findings in the English Language, they were forced to rely upon older languages. Halliday (1998) has shown the influence of ancient Greek on the creation of modern scientific discourse and Banks (2005) has shown the influence of Latin. Halliday and Martin (1993) discuss the emergence of a new discourse register:

> A newly evolving register is always functional in its context (whether the context itself is one of consensus or conflict); the language may become ritualized, but it cannot start that way, because to become ritualized a feature must first acquire value, and it can acquire value only by being functional. (p. 68)

Many of the features of academic science writing are not to be found in popular science writing. Three of these features are discussed in detail below; nominalization, the multi-media nature of academic science writing, and lexical density.

Nominalization

Nominalization is when a process is represented as a noun, e.g., *declare* (verb) would be represented as *declaration* (noun). The sentence, *When the minister declared war on tax avoidance it was met with applause* would become *The minister's declaration of war on tax avoidance was met with applause.* How nominalization is used in scientific writing can be seen in the sentence *They have clearly demonstrated that Bosnic-stimulated emission is important in the process.* (Lamb, Schleich, Scully, & Townes, 1999, p. 272**)**. This sentence, if unpacked, would be an immeasurably unwieldy construction, and yet this process, having been packed into its current form can now conveniently be described as "it" without causing the reader any trouble, as has just done. Writers would also find nominalization useful when attempting to conform to word limits set by publications.

This is more than a mere grammatical formality; it has been a core feature of scientific writing since Newton (see Banks 2005 for the historical origins of nominalization), and, of critical importance, nominalization has achieved its status in scientific discourse through functionality. Halliday describes two benefits of nominalization (Halliday 1998):

> [w]hen a figure … is reworded … in a nominalized form; a considerable amount of energy is released, in terms of the two semantic potentials; the potential for referring, and the potential for expanding. That is, for transforming the flux of experience into configurations of semiotic categories, and for building up such configurations into sequences of reasoned argument. (p.197)

This unlimited potential for categorization or taxonomic organization through nominalization allowed the early writers of modern science to succinctly and accurately describe experimental results. The functionality of this feature led to its becoming ritualized.

In order to compare the use of nominalization in popular science and academic science a total of the instances of nominalization was drawn from four books, two popular science and two undergraduate textbooks. The textbooks chosen were chosen to match as closely as possible the topic of the popular science books. The results can be seen in Table 1.

Table 1. Instances of Nominalization per 2000 words in Popular and Academic Science Texts

Book and Author	Nominalization per 2000 words	Topic
The Language of life –Francis Collins	49	Popular science Biology - genetics
The Molecular Biology of the Gene –Watson, Hopkins, Roberts, Steitz, and Weiner	114	Academic science Biology - genetics
The Elegant Universe – Brian Greene	51	Popular science. Physics – string theory
String Theory and M-Theory –Becker, and Schwarz	90	Academic science Physics – string theory

It is clear that the use of nominalization is considerably greater in academic science than it is in popular science. Its relatively sparse appearance in popular science suggests that popular science is not a useful model for students seeking to learn academic scientific writing.

A Multimedia Genre

The process of scientific writing includes another core ingredient that differentiates it from the Humanities; it is a multimedia genre. This last claim probably needs some support. The written word is a medium for communication as are graphs, tables, and mathematic equations. Scientific writing employs all of these communicative resources, and is thus a multimedia genre. What may surprise some people is the manner in which these multimedia resources are employed and how it differs from the Humanities. Lemke (2009) conducted an analysis of what he describes as "multiple semiotics" within scientific texts across a number of scientific disciplines and he found that, unlike Humanities, there is very little redundancy between what is described graphically and what is described textually. Whereas Humanities graphs and tables often require an in-depth description, scientific writing tends to use graphs, tables and equations instead of text. There is no accompanying description (apart from that included in the graphic itself) that explains the information to the reader. Lemke (2009) suggests that with scientific graphs, tables and equations, there *should not* be any need to describe the graphic as, if it is possible, then the graphic was unnecessary.

The multiple semiotic nature of scientific writing is "jointly co-constructed" (Lemke 2009, p. 110) through graphics and the written word. Therefore, for the initiate scientific writer, care needs to be taken not to create pointless graphics that do not service the reader beyond what the text offers. Scientific discourse is, in part, constructed through the co-deployment of non-redundant, graphical/textual information.

The difference between the centrality of graphics in academic science and popular science is shown in Table 2.

Table 2. Average Graphics per 15 Pages in Popular and Academic Science Texts

Book and Author	Average graphics per 15 pages	Topic
The Language of life – Francis Collins	1	Popular science Biology - genetics
The Molecular Biology of the Gene –Watson, Hopkins, Roberts, Steitz, and Weiner	19	Academic science Biology - genetics
The Elegant Universe – Brian Greene	5	Popular science. Physics – string theory
String Theory and M-Theory –Becker, and Schwarz	50	Academic science Physics – string theory

Indeed, the contrast between the need for graphics in academic science and the aversion to certain graphics (i.e., equations) in popular science has been described thusly, "Someone told me that each equation I included would halve the sales. I therefore resolved not to have any equations at all" (Hawking 1988, p. ix). A student who is attempting to learn how to write for academic science publications would need to learn how to utilize graphics, and doing so through popular science texts will not enable the student to observe how central certain graphics are and how to use them in academic science. This disparity suggests popular science would not be the best choice to use as a model for students seeking to acquire proficiency in academic science writing.

Lexical Density

One of the most apparent features of scientific writing is the abundance of technical terms. Such technical terms can be divided into three categories:

1. Interlocking definitions.
2. Technical taxonomies.
3. Nominalization.

Nominalization has been dealt with above, however, interlocking definitions and technical taxonomies will require a brief description. The very nature of the sciences means that there will be a great deal of abstraction. These types of abstraction often require further abstract concepts to define them. Halliday (1989) uses the example of the definition of a circle from an unnamed primary school textbook:

> A circle is a plane curve with the special property that every point on it is at the same distance from a particular point called the *centre*. This distance is called the *radius* of the circle. The length of the circle is called its *circumference*. (p. 163)

Understanding is reliant on the reader being able to understand a number of concepts simultaneously. The second category of technical terms; the technical taxonomies, can be further subdivided into two categories; superordination and composition. Superordination is described as a *is a kind of* x, for example *tropical is a kind of climate*. Composition is described as b *is a part of* y, for example, *temperature is a part of climate*.

The lexical density of two popular science texts was compared with two undergraduate textbooks. Lexical density is described by the formula:

Number of lexical words/total number of words*100.

These findings are shown in Table 3.

Table 3. Lexical Density in Popular and Academic Science Texts

Book and Author	Lexical density as a percentage	Topic
The Language of Life –Francis Collins	52.6	Popular science Biology - genetics
The Molecular Biology of the Gene –Watson, Hopkins, Roberts, Steitz, and Weiner	71.7	Academic science Biology - genetics
The Elegant Universe –Brian Greene	54.0 (not adjusted) 54.8 (adjusted)	Popular science. Physics – string theory
String Theory and M-Theory –Becker, and Schwarz	56.5 (not adjusted) 76.8 (adjusted)	Academic science Physics – string theory

One interesting finding was related to the physics texts. When calculating lexical density, traditionally, numbers are included as function words and not as content words. In the numerically rich text of the academic physics paper this had a massive impact. When a second calculation was made which was adjusted to include numbers as content words, not as function words, there was a dramatic change in the lexical density as seen in Table 3. The comparison of academic science and popular science shows a very different approach to the nature of the lexical composition of the texts. Again, this suggests popular science does not reflect the linguistic nature of academic science and should not be used as a model for teaching writing for academic science.

Conclusion

The language of popular science and the language of academic science are different. The reason they are different is because each of the genres serve different purposes. Academic science services a community of practice of experts and neophytes who have invested or are willing to invest a considerable amount of time learning about their topic. Popular science services a different audience, and represents information as entertainment, but not information as part of a sustained process towards a shared goal. The different purposes to which each genre must attend have led to different expressive mechanisms becoming woven into the fabric of the texts. Audience concerns have been the defining force for both genres, and these forces have not been moving in the same direction. Teachers who have no scientific background but are being asked to teach science majors how to write academic science will find popular science texts useful for familiarizing themselves with the concepts, but care needs to be taken to ensure that the linguistic boundaries between popular science and academic science do not become blurred in the classroom.

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