Is there a science to writing (particularly science writing) and, if not, why not?

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A friend and I, a few years back, debated how to search for truth. Since my friend was an attorney, he cited jurisprudence as the optimum path. I felt this was completely wrong because, in a criminal trial, the two people who probably know the truth are the defendant and his/her attorney and they are precisely the people who aren't required to testify. The modem system of jurisprudence is designed, it seems obvious to me if not to attorneys, to attain some ideal of "fair trial." Uncovering the truth is a secondary goal. There are, of course, reasons that jurisprudence has evolved along these lines but they are outside the scope of this inquiry. The point is that determining "true" from "not true" is not the major thrust of our modem legal system.

On the other hand, discovering truth is the explicit goal of what we know as the "scientific method." This dates from about 1600 and consists of gathering experimental data; attempting to find a theory which explains (without a single inconsistency) it; communicating the results to the scientific community; consideration of other relevant data and/or theories; and iteration of the entire process (starting with more refined experiments) until consensus is reached or new knowledge/technology (e.g., the demise of alchemy in the wake of the modem theory of the elements) makes further effort pointless.

Although this brief summary sounds irrefutably logical, I contend it has a major flaw. It contains an assumption as fatal as the notorious parallel axiom of Euclid; i.e., that the results will be perfectly communicated. The eternal concern over the low readership of GEOPHYSICS and other traditional scientific journals is prima facie evidence-again, at least to somethat proponents of the scientific method cannot take communication for granted. My own position is that the scientific method should be applied to communication in order to find out what kind of communication "works."

As almost everybody who has ever written anything for formal publication knows, plenty of books and articles are available which purport to provide guidelines for improving your authorial ability. Alas, they usually offer few concrete ideas other than "use short sentences" or "stick with the active voice."

An exception is the article The *science of scientific writing* by George D. Gopen and Judith A. Swan, published in the November-December 1990 issue (volume 78) of *American Scientist.* It is encouraging, at least to me, because it indicates that some initial steps have been taken toward applying the scientific method to the communication of scientific and/or technical material.

This research has led to some concrete suggestions which Gopen and Swan demonstrate to revise some impenetrable paragraphs of typical scientific prose into something that most readers probably would consider more palatable. The key idea is that *readers interpret written material based on clues they receive from its structure.*

> Readers have relatively fixed expectations about where in the structure of prose they will encounter particular items of its substance. If writers can become consciously aware of these locations, they can better control the degrees of recognition and emphasis a reader will give to the various pieces of information being presented. Good writers are intuitively

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Some rules for writing scientific material

1. Don't put significant verbal distance between subject and verb. The opening sentence in a paragraph dissected by Gopen and Swan contains 42 words, 23 of which separate the subject from the verb. The value of the material in between subject and verb appears, to the reader, to vary inversely with the number of interposed words.

> Readers expect a grammatical subject to be followed immediately by a verb. Anything of length that intervenes be tween subject and verb is read as an interruption, and therefore as something of lesser importance.
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> The reader's expectation stems from a pressing need for syntactic resolution, fulfilled only by the arrival of the verb. Without the verb, we do not know what the subject is doing, or what the sentence is all about. As a result, the reader focuses attention on the arrival of the verb and resists recognizing anything in the interrupting material as being of primary importance. The longer the interruption lasts, the more likely it becomes that the "interruptive" material actually contains important information; but its structural location will continue to brand it as merely interruptive. Unfortunately, the reader will not discover its true value until too late-until the sentence has ended without having produced anything of much value outside of that subject-verb interruption.

2. Contrary to widespread practice in scientific writing, new information should be placed at the end-not the beginning-of a sentence. This is a revolutionary suggestion because most scientific writers are eager to reveal what they consider "new" and they naturally put it first. However, Gopen and Swan assert that readers automatically rank material at the end of the sentence as more important than that which precedes it.

> It is a linguistic commonplace that readers naturally emphasize the material that arrives at the end of a sentence. We refer to that location as a "stress position." If a writer is consciously aware of this tendency, she can arrange for the emphatic information to appear at the moment the reader is naturally exerting the greatest reading emphasis. As a result, the chances greatly increase that reader and writer will perceive the same material as being worthy of primary emphasis. The very structure of the sentence thus helps persuade the reader of the relative values of the sentence's contents.
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> The inclination to direct more energy to that which arrives last in a sentence seems to correspond to the way we work at tasks through time. We tend to take something like a "mental breath" as we begin to read each new sentence, thereby summoning the tension with which we pay attention to the unfolding of the syntax. As we recognize that the sentence is draw ing toward its conclusion, we begin to exhale that mental breath. The exhalation produces a sense of emphasis. Moreover, we delight in being rewarded at the end of a labor with something that makes the ongoing effort worthwhile. Beginning with the exciting material and ending with a lack of luster often leaves us disap pointed and destroys our sense of momenturn. We do not start with the strawberry shortcake and work our way up to the broccoli.
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> When the writer puts the emphatic material of a sentence in any place other than the stress position, one of two things can happen; both are bad. First, the reader might find the stress position occupied by material that clearly is not worthy of emphasis. In this case, the reader must discern, without any additional structural clue, what else in the sentence may be the most likely candidate for emphasis...The second possibility is even worse: The reader may find the stress position occupied by something that does appear capable of receiving emphasis, even though the writer did not intend to give it any stress. In that case, the reader is highly likely to emphasize this imposter material, and the writer will have lost an important opportunity to influence the reader's interpretive process.

3. Provide context for the reader before asking that reader to consider anything new. (The phrase topic position in the following is reading researchese for beginning.)

> Readers also expect the material occupying the topic position to provide them with linkage (looking backward) and context (looking forward). The information in the topic position prepares the reader for upcoming material by connecting it backward to the previous discussion. Although linkage and context can derive from several sources, they stem primarily from material that the reader has already encountered within this particular piece of discourse. We refer to this familiar, previously introduced material as "old information." Conversely, material making its first appearance in a discourse is "new information." When new information is important enough to receive emphasis, it functions best in the stress position.
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> When old information consistently arrives in the topic position, it helps readers to construct the logical flow of the argument: It focuses attention on one particular strand of the discussion, both harkening backward and leaning forward. In contrast, if the topic position is constantly occupied by material that fails to establish linkage and context, readers will have difficulty perceiving both the connection to the previous sentence and the projected role of the new sentence in the development of the paragraph as a whole.
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> In our experience, the misplacement of old and new information turns out to be the No. 1 problem in American professional writing today. The source of the problem is not hard to discover: Most writers produce prose linearly (from left to right) and through time. As they begin to formulate a sentence, often their primary anxiety is to capture the important new thought before it escapes. Quite naturally they rush to record that new information on paper, after which they can produce at their leisure the contextualizing material that links back to the previous discourse. Writers who do this consistently are attending more to their own need for unburdening themselves of their information than to the reader's need for receiving the material.

aware of these expectations; that is why their prose has what we call "shape."

Gopen and Swan claim the theory of "reader expectations" leads to some concrete rules for writing scientific material. The three that I found most concrete are discussed in the box on this page. The introductory paragraph (in large print) is my interpretation. The following small print is taken directly from Gopen and Swan's text.

Those rules sound reasonable and, better yet, scientific. I would add, for additional consideration, the results of some cursory research that I conducted after reading the article by

Gopen and Swan. The 15th edition of Bartlett's *Familiar Quotations* devotes more than 60 pages to Shakespeare. I picked one at random for detailed examination.

This page contained 35 quotations which were made up of 479 words. Exactly 22 of those words were longer than two syllables. One of the paragraphs of undecipherable (to me, at least) scientific prose cited by Gopen and Swan consisted of 135 words and scientific symbols; 55 were more than two syllables (one string of 24 words contained 19 of at least three syllables). My "control group" was the title page from a recent (less than 12 months old) issue of GEOPHYSICS. The titles of the articles contained 185 words. Only 38 of them were less than three syllables and 29 of those were either articles, prepositions or connectives (of, in, a, an, the, for, by, with, into, and). An abstract in that issue contained 381 words, 97 of which were more than two syllables.

I think these data support a legitimate hypothesis to which the scientific method should be applied: *Does the clarity of a piece of written text vary inversely with the average number of syllables per word?*

(Alas, affirmation of this hypothesis might have little impact upon scientific writing because it is far from certain that articles which treat leading edge science and/or technology can be written with a vocabulary dominated by words of one or two syllables. There are also related "political" problems. Would the Associate Editors of GEOPHYSICS accept such an article without changing splitting to birefringence? Or, would a university accept a dissertation with such "simple" wording from a doctoral candidate? I have insufficient evidence to speculate about the former, but I'm certain the answer to the latter question is an emphatic negative. In fact, I ran the second point by a friend who recently retired from a university faculty and he said, regretfully, that the answer was an "emphatic emphatic no!")

Finally, although I wholeheartedly endorse the current attempts to apply the scientific method to science writing, I question some of the axioms used by Gopen and Swan. It is important to remember that they are linguists. As a result, they assume that most people think verbally and that writing is the "natural" way to convey thoughts to a large audience.

Unfortunately for them (and perhaps for us), there is formidable evidence that this is not the way many minds-particularly the best scientific minds-actually work. This is tellingly discussed by the eminent mathematician/physicist Roger Penrose in *The Emperor's New Mind* (Oxford 1989) under the heading "Non-verbality of thought":

> One of the major points that (French mathematician Jacques) Hadamard makes in his study of creative thinking is an impressive refutation of the thesis, so often still expressed, that verbalization is necessary for thought. One could hardly do better than repeat a quotation from a letter he received from Albert Einstein on the matter: *The words or the language, as they are written or spoken, do not seem to play any role in my mechanism of thought. The psychical entities which seem to serve as elements of thought are certain signs and more or less clear images which can be "voluntarily" reproduced and combined.. The above mentioned elements are, in my case, of visual and some muscular type. Conventional words or other signs have to be soughtfor laboriously only in a secondstage, when the mentioned associative play is sufficiently established and can be reproduced at will.*
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> The eminent geneticist Francis Galton is . also worth quoting: *It is a serious drawback to me in writing, and still more in explaining myself that I do not think as easily in words as otherwise. It often happens that after being hard at work, and having arrived at results that are perfectly clear and satisfactory to myself when I try to express them in language I feel that Z must begin by putting myself upon quite another intellectual phone. I have to translate my thoughts into a language that does not run very evenly with them. Z therefore waste a vast &al of time in seeking appropriate words and phrases, and am conscious, when required to speak on a sudden, of being very obscure through mere verbal maladroitness, and not through want of clearness of perception. That is one of the small annoyances of my life.*
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> Also Hadamard himself writes: *I insist that words are totally absent from my mind when I really think and I shall completely align my case with Galton's in the sense that even after reading or hearing a question, every word disappears the very moment that I am beginning to think it over: and I fully agree with Schopenhauer when he writes, "thoughts die the moment they are embodied by words."*
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> I quote these examples because they very much accord with my own thought-modes. Almost all my mathematical thinking is done visually and in terms of non-verbal concepts, although the thoughts are quite often accompanied by some inane and almost useless verbal commentary, such as "that thing goes with that thing and that thing goes with that thing."... Also, the difficulties that these thinkers have had with translating their thoughts into words is something that I frequently experience myself...& a related observation, I had noticed, on occasion, that if I have been concentrating hard for some time while on mathematics and someone would engage me suddenly in conversation, then I would finmyself almost unable to speak for several seconds.
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> This is not to say that I do not sometimes think in words, it is just that I find words almost useless for mathematical thinking. Other kinds of thinking, perhaps such as philosophizing, seem to be much better suited to verbal expression. Perhaps this is why so many philosophers seem to be of the opinion that language is essential for intelligent or conscious thought! No doubt different people think in very different ways-as has certainly been my own experience, even just amongst mathematicians.

The evidence cited by Penrose convinces me that thinking about thinking is a very complex undertaking and that verbal communication of sophisticated scientific thinking is perhaps an order of magnitude more complex. My conclusion is that we should certainly encourage the application of the scientific method to communication, particularly writing, in the hope that some universal laws or easily mastered algorithms can be discovered...but my gut feeling is that it's a long shot. The first step toward improving scientific communication may have to be widespread acceptance that communication is a vital part of the scientific method-as important as the experiments, hypotheses, practical applications-but that those highly proficient in any of these areas are not necessarily skilled at any of the others and, in fact, it's unintelligent, even unscientific, to expect otherwise. LE