Revista de Sistemas de Informação da FSMA
n. 7 (2011) pp. 2-5

SISTEMAS DE INFORMAÇÃO
http://www.fsma.edu.br/si/sistemas.html

TRILHA PRINCIPAL

The Logic of Scientific Writing

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***Abstract*— In this work, I describe a logical method for scientific writing. Any decision made in this type of writing should be based on the logic of science and the rules of communication, as part of a creative discourse. I present some logical flaws (regarding journal classification, academic vs. non-academic texts, and subjective inferences) and writing mistakes (in the structure of a paper and the writing style) that can undermine publication.**

***Index Terms*—scientific writing, scientific communication, scientific publication, science, logic.**

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I. Introduction

SCIENTISTS have a historical responsibility to discover and share scientific knowledge. In this journey, they have agreed to use empirical evidence to acquire acceptable provisional knowledge. The importance of empirical evidence to scientists creates a qualitative difference between science and philosophy. Scientists do not rely on personal experience; they require objective empirical evidence that is reproducible. In order to be accepted, data from one research group must be confirmed by data from other groups. Religion contradicts science and philosophy because religious thinking searches for truth by accepting the existence of God, in both the past and future. A religious position relies on individual experiences, some of which are believed to occur through divine revelation. These religious requirements are not consistent with the manner in which science views the world. While scientists are uncertain about whether current scientific knowledge will be valid in 500 years, religion is certain that God is forever. Another way to view the natural world is through art, in which esthetics is the major underlying premise. Although science is not based on esthetics, modern science has gradually paid more attention to the creative and artistic aspects of communication. In this context, communication among scientists must adhere to a shared framework consisting of a search for general rules that build a logical discourse based on reproducible empirical evidence and that is presented in a creative, clear and concise manner.

Despite this historical background, most published scientific works still lack a strong logical basis. In this text, I provide examples of logical flaws that cause mistakes in scientific writing. I intend to demonstrate that the construction of a good scientific text requires scientists instead of technicians trained to construct papers. Scientific writing should reflect clear, logical thinking that does not contradict its philosophical and scientific bases.

The following discussion presents examples that compare illogical and logical reasoning in writing a scientific paper. The link between scientific writing and the philosophical bases of science is the main assumption underlying the logical method for scientific writing that I have developed over the past 26 years [1]. This method also considers complementary communication rules after the logical issues have been satisfactorily addressed.

II. Logical Flaws in the Publication Process

A. Scientific Publication

The classification of scientific journals is generally based on a journal's impact factor (JCR) and on other, region-specific considerations (e.g., the QUALIS system developed by CAPES in Brazil). These classifications incorporate logical flaws with respect to the main goal of empirical science (to discover general laws about natural phenomena). Such a goal requires an international discourse, an international language and an international impact of the conclusions. The impact factor fails in this respect because it simply weighs the number of citations by published papers, a measure that does not incorporate the reach of the published science. Hence, a journal with an impact factor of 2.5 might be very different from another with the same rating, depending on whether the citations originate in the same country or in several countries. An international reach is logically expected in science. Therefore, I have defined four categories of scientific journals in this logical method [1].

a) *International journals* publish papers from different countries and are cited by authors from different countries. They are divided into *impact journals* (which are read by researchers in a particular field) and *high-impact journals* (which interest researchers in different fields, even when the scope of the journal is restricted to a single field).

b) *Regional impact journals* publish papers from one region (a country or a continent) and are mostly cited by scientists from within that region. *Non-impact journals* form a subset familiar only to the editorial staff, the authors, and certain researchers from the journal's academic institution.

Note that the above classification uses a logical method. It is based on the natural method for conducting science, considering that a publication must help scientists discuss issues with other scientists either in their area of expertise or in related areas. I am not referring to the communication of science outside academia. I maintain that it is imperative for scientists to validate their conclusions in academic circles (by producing publications in high-quality international journals) before spreading these ideas to the non-scientific community. Great care must be taken before releasing medical treatments to the community, and the same holds true for theoretical knowledge.

Another mistake is to consider only scientific discourse that is based on strong scientific evidence. Despite their empirical base, scientists are human beings who are tempered by psychological events. Thus, scientific writing should consider the readers' psychological universe; otherwise, communication may be ineffective. Scientific knowledge is not based only on objective evidence (the empirical base) obtained under controlled conditions. It must also be accepted by other scientists [2], which is an important consideration. Scientific writing is thus not simply the reporting of scientific studies. It is a universe in which the author discusses with other scientists how to validate her/his conclusions (a scientific conclusion is a theoretical proposal based on facts but not restricted to them [3]). In this respect, logical communication strategies should be used, but I recommend never contradicting logic in favor of communication aspects. It is also important to creatively prepare a concise and clear text that can be found, read and accepted by the peer community.

III. Logical Flaws Underlying Writing Weaknesses

A. The Structure of a Paper

Many logical flaws are found in scientific texts published in regional journals, but they are also found in international impact journals (as defined above). Below, I list some of them.

A Report or Paper?: the Logic of a Paper

The scientific community is more concerned with the conclusions of experiments rather than the actual experiments. Thus, information that does not logically support the conclusions should be omitted when constructing a paper. Achieving this focused writing style requires that one carefully analyze the data and orally present the discourse several times until it is clear. As the conclusions are determined, write them down on a separate sheet to serve as a guide for future concerns when writing the paper. Then, select the results necessary to support these conclusions and choose the best way to present them (e.g., by emphasizing the results using a figure). Write the results section. Now write the methods section, including only the procedures used to collect the data you have mentioned (it is occasionally useful to include procedures that did not produce data but that might have affected the subject of the study—never cheat the reader). Write the discussion section; here, you should demonstrate to the readers why your conclusions are valid and how the current scientific understanding is changed by your findings. Use your data and the literature to construct these arguments. In a logical argument, do not include unnecessary premises (data or literature) or those that lack necessary support (this makes for a strong and concise text). Finally, write the introduction because you are now able to present the argument (the data, literature and argumentation to support the conclusions) that you have built.

Specificity of the Research Goal

Researchers in many areas have become so focused on the specific aspects of the data that they limit the construction of science. In natural science (studying natural phenomena from the empirical approach), this mistake is seen in a strong emphasis on the locale in which the research was carried out. This emphasis may appear in the title, in which the author states that the study was conducted in a particular locality, province/state, and country. They need only to give the postal code to completely address the objective of the research in question. This emphasis reveals a mistake about the scientific process.

I have found that all empirical research is performed somewhere. Thus, should every study emphasize the location at which the data were collected in the title? From a logical perspective, we know that in empirical science we need data, which is obviously obtained from somewhere; however, the conclusions must be more important than the data. Freud, Darwin, and Einstein achieved this goal, and as a result, we know who they are. If a paper is focused on a city, it might be published in the city newspapers. Specific and local data should be used to describe or test general phenomena if one is to reach the international scientific community. This argument is valid both for places and for states and conditions (sex, age, nationality, etc.). For example, reference [4] describes how we investigated students from a public school in a small Brazilian city and discussed the results internationally.

Introduction and Justification

Some Brazilian agencies format research proposals by stating that the introduction is separate from the justification of the proposal. Accordingly, you should write the introduction and then the justification (the reasoning for the study). However, the introduction to a paper, thesis or project

is undoubtedly the place in which you should contextualize your research in a broad scientific context, include the question you have addressed and objectively validate your objectives; that is the aim after you have introduced your readers to your research.

Introduction to Logical Claims

I have classified any kind of empirical scientific objective into three logical categories [5]. There are objectives that describe one variable; in this case, no hypothesis is necessary (descriptive studies). There are also objectives that test the association between two or more variables (here, examining associations is the main goal). Associations are necessary because one variable affects another (cause-effect studies) or because another variable affects both (association studies). For example, pollution may increase respiratory problems (pollution interferes with respiration), which is a clear cause-effect relationship. However, social problems are positively associated with the number of churches in a city not because priests are causing problems but rather because population density affects both social problems and the number of priests.

In the introduction section, the author should not write about the investigated variables but rather should explain why she/he wants to describe a particular variable or why two or more variables should be associated with each other.

Unnecessary Information

The inclusion of unnecessary information is another logical flaw. Any section in a scientific text should be as short and focused as possible. To achieve this, include only the necessary premises of your argument. For example, when you include the laboratory name in the methods section, you are maintaining that this information is necessary. If this information is necessary, the objectivity of the study is poor or nonexistent. This argument-based recommendation logically suggests what should be included and what should be removed throughout the text.

B. *Writing Style*

Voice in Discourse

Many scientists believe that the third-person voice is a characteristic of the scientific writing style. This is a logical and philosophical flaw.

The third-person voice assumes that the readers will accept the author's discourse. For example, when you write "From these data, it is concluded that $x > y$," you are suggesting that anyone will come to this conclusion from the evidence you have presented. This suggestion assumes that the empirical evidence is sufficient to warrant the conclusion. The history of science has several examples that contradict such an assumption. Data do not determine conclusions; rather, conclusions are based on data that are tempered by the psychological world (e.g., Kuhn's paradigm concept [6], which extends even to individual preconceptions). When using the first-person voice, you are stating that you have analyzed the data and have reached certain conclusions that, if accepted by other scientists, will have the sort of impact that is necessary for building scientific knowledge. Note that the use of the first-person voice in scientific writing has increased greatly since the 1990s and that it is used mostly in high-impact journals. I believe that this trend is the result of scientific style gradually evolving in the direction of the logical bases of science.

Tense for Conclusions

There are two ways to construct conclusions in empirical science. In the first, you investigate a representative sample to reach conclusions about a larger universe (the population). If you use the past tense in the conclusion in this case, you are reinforcing your sample and not your population. Therefore, you should write the conclusion in the present tense to refer to the population. In the second, you investigate evidence that explains a past event (for example, evidence about what caused the American Samoa and Tonga Tsunami on September 29th, 2009 [7]). In this case, the conclusion concerns an event in the past; thus, concluding in the past tense is logical.

Passive or Active Voice?

Many journals have encouraged texts that use the passive voice excessively. Some researchers still believe that the passive voice is necessary in scientific writing. This belief is a serious mistake that is supported by a logical flaw.

The passive voice should be used only when the focus is on the action and when who or what is performing the action is either unknown or irrelevant; these circumstances are exceptional, however. The scientific style requires the active voice [8]. One of the widespread searches in the scientific literature concerns the effect of certain variables on others. Such a cause-effect relationship is undoubtedly a necessary logical basis of science and expresses the action of an agent(s) on another element(s). Which appears first, the cause or the effect? In logical terms, first you have the cause and then you have the effect. Why should we contradict this logic when writing a scientific paper? You should employ the active voice wherever possible. Moreover, the active voice allows for shorter phrases than do passive voice, and the aim of not wasting words or the reader's time is also an element of the scientific style.

IV. Concluding Remarks

The above discussion exemplifies the use of a logical method for scientific writing. Writing decisions are based on logic and not on custom or tradition. It is also necessary to consider esthetics, but style should always be subordinated to logic. There are no rules in the writing process other than logic, esthetics, and creativity. Each text has its own style of argumentation; thus, what is appropriate for one text might not be appropriate for another one.

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