How to Write Your First Scientific Paper

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***Abstract*—this paper presents a method to instruct students on how to write their first scientific paper. The method adopts a holistic approach that discusses several different aspects of paper writing. Covered issues include the choice of the paper subject, hypothesis formulation and the design of experiments to test it, the collection and analysis of data, and the planning and writing of the final text. The method has been successfully used to teach graduate and undergraduate students to write their first articles.**

Keywords—writing; paper writing; scientific method

I. INTRODUCTION

Engineers normally do not receive formal training in writing skills, at least not extensively. This is possibly the reason why the second chapter of Carl Selinger's book (*Stuff You Don't Learn in Engineering School* [1]) is about writing. It is true that communication skills, especially written communication skills, may affect the professional success of engineers.

Scientific paper writing is more complex than just writing. This complexity arises from the fact that paper writing involves reporting scientific advances. The process involves several aspects, such as formulating a hypothesis, proposing an experiment to test it, executing the experiment, collecting data and analyzing the data to judge the hypothesis and finally writing a report about the whole process. The final report has also to consider the writing tradition of a given community.

Due to the multiple aspects involved in scientific paper writing, material devoted to teach this skill normally focus more on a single aspect, or they are too extensive. This paper proposes a short introduction to paper writing, contemplating a broad variety of associated topics and skills, yet in a concise and practical way.

This paper is organized as follows. Section II presents describes the concept of new knowledge and how it is produced. Advice for conducting the process of investigation of hypotheses is given in section III. The writing of the report is discussed in Section IV; while Section V provides advice to deal with scientific communities. Finally, conclusions are presented in section VI.

II. UNDERSTANDING AND MANAGING THE PROCESS

Writing a scientific paper is a process that need some time for maturing the contents of the paper. Understanding the process helps to produce better papers. This section provides insights on how new knowledge is produced.

A. *Dealing with New Knowledge*

Article writing is about new knowledge, as a paper is supposed to advance the scientific knowledge. This means that imagination plays an important role in scientific discovery. The ability to imagine new things relies on divergent thinking [2], which implies in being able to associate ideas that normally would not be associated. This is difficult to admit for people starting in science, as normally students are educated in such a way that they study a book chapter; and then they are tested to check if they have learnt the contents of the chapter. This is done normally with a set of exercises that test if the student understood what was taught and if (s)he is able to use the knowledge from the chapter, which is a well established knowledge. This kind of thinking is called convergent thinking [2]. Fig. 1 illustrates the concept that new knowledge has to be imagined outside the sum of all human knowledge; this is the case of new idea *ni2*, in Fig. 1. Notice that in the more frequent cases, a person imagines something that is new for the person, but it is not new to humankind; this is the case of new idea *ni1* in Fig. 1.

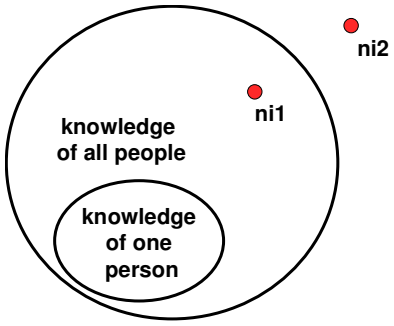

Figure 1. New knowledge has to be imagined first

B. *Knowing the Frontier of Knowledge*

Imagination, or divergent thinking, is an important part of research. However, it is not the only important part. In fact to decide if a product of our imagination is new to us or for a field of knowledge it is necessary to know the field. For this, it is necessary to read and compare. Reading is necessary, in order to: (1) understand which is new in each paper, (2) to establish what the contribution of the paper is, (3) to be able to compare

the approaches in each paper, (4) to gain perspective of the historic evolution of the knowledge in the field. Notice that the border between the known and the unknown is formed by a sequence of recent papers that forms what is frequently referred as the *state of the art*. The state of the art is dynamic and changes over time, due to new contributions. Fig. 2 illustrates the concept of the state of the art dynamically changing with the publication of new papers. At each year, a different set of papers may describe the state of the art (Fig. 2 is an exaggeration, as some papers stay in the state of the art for years).

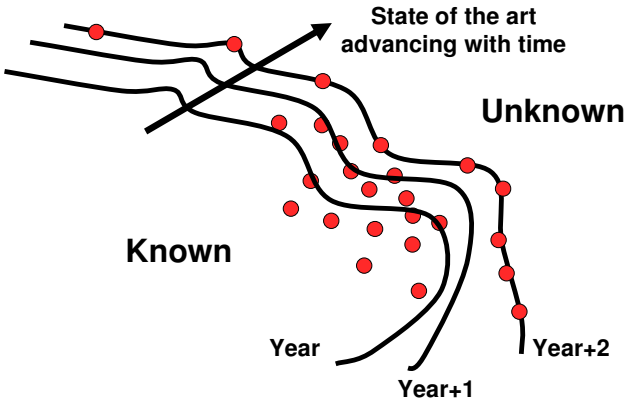

Figure 2. State of the art evolving during the years

C. *Managing the Process Over Time*

The process of imagining something new, and working out the status of the idea from imagined to known, requires several validation steps. These steps require time, and in the beginning the work will be more centered on divergent thinking, in order to produce a new approach. Over the time, the ideas will start to become clearer and the work will be more centered on convergent thinking. The process involves several aspects, such as (1) formulating a hypothesis, (2) proposing an experiment to test it, (3) executing the experiment, (4) collecting data, (5) analyzing the data to judge the hypothesis and (6) writing a report about the whole process. Normally, people writing their first paper will do that under the guidance of an advisor. Part of the success of paper writing comes from establishing a good communication with the advisor. This communication will occur in meetings which have to be managed. Every meeting has to have an agenda with the last item being next steps and action items. The agenda and the meeting notes have to be stored to keep track of the evolution of the research over time; this will also help to gain perspective and self-criticality. Communication skills [3] and meeting management skills [1] can make this process much easier to manage over time.

III. EXECUTING THE PROCESS

The success of the process of research depends significantly on a good start point. The initial steps determine the start point, and these steps rely more on divergent thinking. This section discusses how to manage these early steps that tend to be more chaotic.

A. *Selecting and Reading Bibliography*

Once the general field is chosen, it is necessary to select and read papers about the area. The first question is where to start searching. A good start point is to ask your advisor, or someone experienced in the area, what are the main conferences, journals, research groups and scientific societies in the field. Another way is to search for keywords in the internet. Google scholar, for instance, is an excellent resource to do academic searches. In fact, even by getting a ready list from your advisor, this list should be seen as a start point to be checked and extended by search in academic search engines like Google scholar, ACM digital library, IEEE Xplore, Elsevier Scopus, etc. Additionally, each paper cites or is cited by other papers; which have to be investigated as well.

Once a list of relevant papers in the chosen field is available, it is necessary to read the papers. In an initial stage read, it is more important to have a global picture of the complete set of papers than to understand all the details of every paper. Beginners will tend to try to understand all the details of each paper due to traditional education before starting a scientific education. They will follow the model where they study a paper as if it is book chapter for which they will be tested to see if they have learnt the contents. They will prepare themselves to understand all paper details to solve a set of exercises that test if the student understood and is able to use the knowledge from the paper as a well established and limited packet of knowledge. As a consequence, it is frequent for beginners to understand all the technical details of paper P1 and all the technical details of paper P2. However, they would have trouble to discuss the differences between paper P1 and paper P2. In fact, the most important thing in reading a comprehensive set of papers representative of a given field is to classify the papers. In simple terms this can be seen as dividing a huge pile of papers into smaller piles of related papers. Papers that fall in the same sub-piles will have common attributes. The attributes discovered in this process represent a new understanding of the field. Part of this process of understanding is to be able to list the discovered attributes and the set of possible classifications according each attribute. This idea is illustrated in Table I, in a simplified way. Notice that this is done by most of us (explicitly or implicitly) when taking decisions that are important in our life, like buying a car or a house, for instance.

TABLE I. ATTRIBUTES AND CLASSIFICATIONS ACCORDING THE ATTRIBUTE

Attribute	Sets of Possible Classifications
A1	{A, B, C}
A2	{J, K}
A3	{W, X, Y, Z}

The attributes that are discovered by grouping similar papers allow explaining the differences among papers being

read. This idea is explained in Table II, which lists different attributes for four different papers. This is the kind of comparative understanding that is necessary before choosing the topic for a new paper. This comparative view, combined with an historic perspective, allows understanding the (current) state-of-the-art and how to advance it.

TABLE II. FOUR PAPERS CLASSIFIED ACCORDING ATTRIBUTES IN TABLE I

Paper	Attribute A1	Attribute A2	Attribute A3
P1	A	J	W
P2	A	K	X
P3	B	K	Y
P4	C	J	Z

B. *Choosing a Paper Topic*

As explained in Section *II.A*, papers are about new knowledge. This means that when proposing a new paper, the author should be concerned in producing something that is different from what has been proposed before (in existing papers). This can be done by creating new combination of attributes (as shown in Table III) with respect to already existing combinations (as shown in Table II). Notice that the number of possible combinations for attributes with 2, 3 and 4 possibilities is 2x3x4=24. Table II and III combined present 8 out of the 24 possible combinations. From the possible new combinations, it is possible to choose the most promising ones to be tried out as new research topics that will lead to new papers after the research is conducted. Notice that selecting a given combination as promising implies in having an intuition that the new combination will be useful to solve a specific problem. Notice that the choice of the topic can also start from a list of future work in the papers that have been read or simply by attacking a new unsolved problem. However, in any case it will be necessary to read about previous approaches and classify them in a way similar to Table III so that innovation can be justified for the new approach.

TABLE III. POSSIBLE NEW PAPERS OBTAINED BY NEW COMBINATIONS OF ATTRIBUTES IN TABLE I

New Paper	Attribute A1	Attribute A2	Attribute A3
NP1	A	K	W
NP2	B	J	Y
NP3	B	J	X
NP4	C	K	W

C. *Planning an Experiment*

When a novel set of attributes has been selected to be investigated as a research project, the investigators should have in mind that the novelty has to be argued as promising. This means the novelty should be seen as an improvement over existing techniques. Additionally, this improvement must be of such an order that it can be justified by words (i.e.: the author should be able to justify the initial intuition) or even better by some quick calculations.

Once the motivation and expectations are clear, the experiments have to be designed to check and measure the novel approach. As an example consider the new paper NP1 in Table III. Paper NP1 differs from P1 and P2 in Table I by just one attribute. This way, comparative experiments have to focus on showing the difference between NP1 and P1 regarding attribute A2. Similarly, comparisons between NP1 and P2 have to focus on attribute A3. Comparative experiments between NP1 and P3 (P4) have to be designed more carefully, as they differ by two (three) attributes. When the difference between papers is given by more than one attribute experiments have to be designed to evaluate the attributes individually; also the experiments may be affected by dominances among different attribute values.

The general rule for experiment planning is to understand what is being tested, what the results will prove or disprove, what are the expected results, how the results relate to the initial hypothesis, how the results relate to the novelty of the paper. Notice that this has to be clear for each experiment being made. Remember that the IEEE code of ethics encourages: “to be honest and realistic in stating claims or estimates based on available data”.

IV. WRITING THE REPORT

When the advice given in the prior two sections is followed, the writing of the derived paper is an easy process. This section provides specific guidance for the writing task.

A. *Types of Papers*

A paper can follow different models. In order to facilitate further discussions we enumerate four types of article models. Most papers present a new approach alternative to existing ones. Some articles present a new theoretical analysis or a new theory. Survey papers present a comprehensive overview of a given field of study. There are also articles that enunciate a new problem. It is important for beginners to know which model your article will follow.

B. *General Planning*

General planning of an article deals with planning the use of the available space. Another important decision is to set the contribution of the paper, meaning that a large research project may have several point contributions, and researchers can decide to publish them in separate papers. This way, general planning also involves deciding the specific content of each article. The use of available space will be impacted by the number of figures, tables, different sections and etc. It is wise to create an empty draft of the paper to decide the elements the paper will have and how much space they will consume. This should be done before start to write; this way text for each section will be generated with an adequate size. As illustrated in Fig. 3, people plan houses before building them. It is wise to do the same thing with articles.

Figure 3. Houses are planned before construction, articles should be as well

C. How to Write the Title

Titles should provide a brief description of the contents of the paper. The title should inform the field of the paper and what is the main contribution of the paper. This information has to be presented briefly, preferentially in a single line of text. Titles should focus on words that are related with what is novel on the paper. Notice that generic words like "a study about…" do not add much about the content of the paper. The same is true about funny titles; many times the joke adds words that are not useful to determine the content of the paper.

D. How to Write the Abstract

The abstract serves to convince someone to read the paper. Abstracts can be organized in three sections. The first section is composed of phrase informs what the paper is about (e.g.: this paper presents…). Optionally, a second phrase describes the importance of the topic. The second section details the novel aspects introduced by the paper. The third section details what has been done to use/validate the contents. Notice that there is no division between these sections, simply they be imagined to organize the abstract. Other organizations can also be used, but this one is the more straightforward.

E. How to write the Introduction Section

The introductions are normally made of four distinct movements. The first movement talks about the importance of the area. The second movement discusses the approaches that existed before and why they were not satisfactory. The third movement presents a new approach that improves the previously existing ones. This is normally seen as the contribution of the paper, and all the paper has to be centered on this contribution. The fourth movement is the description of the organization of the paper.

F. Paper Body

After the introduction the body of the paper starts. There is not a ready formula for the paper body, which can be used for all papers. The best advice is to try to imitate papers that have already been published in the same journal or paper. The choice of which sections to include must be directed to demonstrate the contribution of the paper. So a good paper structure has to be a seamless sequence of sections that are focused in explaining and demonstrating the contribution of the paper. This idea of a seamless sequence of points is illustrated in Fig. 4.

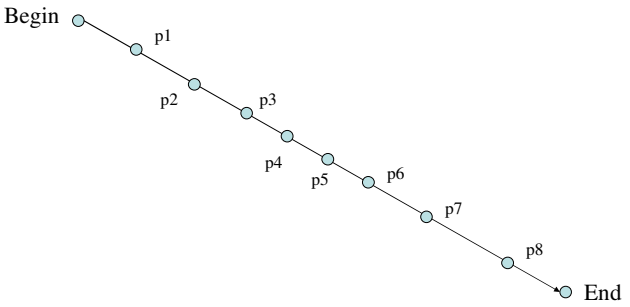

Figure 4. Reading an article should be a seamless experience from begin to end

In contrast to well written articles, a badly written paper will pass the impression of points that are not linked in a continuous flow. This is illustrated by Fig. 5.

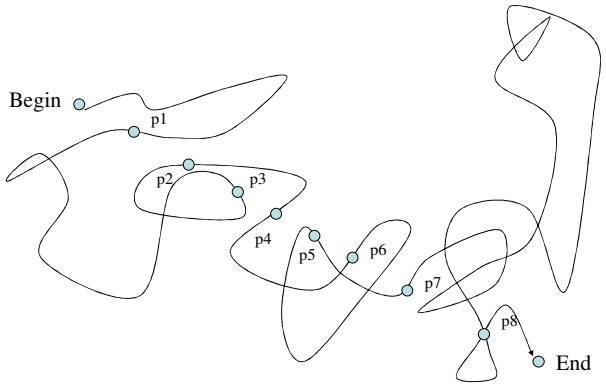

Figure 5. Reading badly written papers feels like a long and winding road

G. Results Section

Results are used to provide support for the contributions of the paper. Before presenting the results, it is necessary to explain the purpose of each experiment; as well as the experimental setup. Then results have to be presented for the proposed contribution and compared to some reference. Finally, the conclusions have to be derived from the comparisons.

Remember that results serve to demonstrate the contributions of the paper. This way, results should not be inserted in the article just because data was gathered. Presented data has to be useful to demonstrate the contribution of the paper.

H. Critical Thinking and Phrasing

A scientific publication is made by deriving conclusions from established premises. This derivation of logic conclusions from facts is discussed in critical thinking books [4]. This kind of logical analysis is made with statements, defined as sentences that are either true or false. The main advice for making phrases in a paper is to use statements; i.e. to ensure that every phrase in your text can easily be assumed true or

false. If a phrase cannot be assumed as true or false it is probably confuse or carry more than one idea, making the text difficult to read. Using statements will keep the text more formal, simple and agreeable to read.

I. Bibliography and How to Cite

Notice that much of the bibliography is already available from Tables I and II. These tables contain all the information to discuss what existed before, in the second movement of the introduction. Similarly, the investigation made in Table III describes what the contribution of the paper is, and what are the differences, innovations and improvements over previous approaches. As discussed in section IV.E, this discussion has to be done in the third movement of the introduction. Besides that, survey papers and papers that enunciate new problems are desirable to justify the importance of the area in the first movement of the introduction. It is necessary to be careful to assess the relative importance of different conferences and journals, to avoid citing papers of bad quality. Finally, the number of references in the bibliography should be compatible with the normal practice in the target conference or journal.

V. DEALING WITH YOUR COMMUNITY

Writing a paper also involves interactions with a community of researchers. This community defines what the publication tradition for the field is. It is easier to publish if you follow the publication tradition of the community where you want to publish.

A. Selecting a Conference or Journal

When selecting a conference or journal, a student should know that journals and conferences have different thresholds of quality to accept an article. Regional conferences may accept papers with a lower threshold of quality, as the goal of the conference is to gather the regional community. Student forums or workshops also tend to accept works with a lower threshold of quality, as the goal is to bring students to discuss early or intermediate results. The main advice to select a target conference or journal to publish is to have a similar contribution in terms of results and quality compared to articles published in the conference. The publication life of a subject under development can start with early stage submissions to regional conferences of focused workshops. Then the work can be further developed and submitted to good conferences. Finally, once the work is well matured and well revised contributions could be submitted to top ranked conferences. Finally the work can be extended and submitted to a journal. The general rule is that the extension to journal should include at least 30% of new material.

When you are sure that you have an excellent contribution and that you paper is well matured and revised, send it to a top conference. When your paper is just preliminary work, send it to a workshop or for a good conference. You can also decide to send it to a top conference, if you want to get the technical reviews. But to succeed in getting good technical reviews, the article must be clearly and well written.

B. Reviewers and Reviews

Reviewers have two main tasks [5]. The first task is to guarantee that the best submitted papers are selected to be presented and published. The second task is to give advice for authors of rejected papers on how to improve their work for future submissions. Reviewers have no obligation to give extensive advice on how to rewrite the paper if it is not well written. When writing a first paper, students should understand that the most clear and well written is the paper, the best would be the technical feedback that they will receive from specialists in the area. If the submitted paper is not clear and well written, the content of the provided reviews will focus on advising to write it better next time and the authors will loose the opportunity to get precious technical feedback.

C. Presentations

Presentations are not intended to explain every detail of the paper. A successful presentation will focus in explaining what the contribution of the paper is, instead of explaining all implementation details. Start by presenting the area and the motivation for the addressed problem, follow by explaining what existed before and how it can be improved, then present your contribution as something that does this improvement. Use examples to do so, rather than explaining details of the method.

Avoid too much text in a single slide. Use large fonts (18 or more) so that it can be read easily from far away in the back of the room. Avoid complicated color schemes as colors can be viewed differently according the hardware and software available as well as the people watching. Use animations to illustrate examples and results. A simple way of using animations is to use arrows and boxes to point to specific things you want to discuss. And above all, practice to be able to respect the allocated time to your presentation. Avoid jokes (sense of humor varies a lot among different cultures) and always be kind to people asking questions after, before and during the presentation. Do not forget to smile and show enthusiasm. Try to spend some time reading each paper from other authors in your section and understand how their work relates to yours. Prepare one or two questions to ask to other authors in your section if nobody else asks questions during the session. If you are not sure about the quality of your questions, ask your advisor to confirm that the questions are good enough to be asked aloud (this will avoid asking naïve or badly formulated questions). If too many people ask questions during the session, you can use the questions to talk to other authors from yours session during the coffee breaks. Try to introduce yourself to other authors and to the session chairs before (or even after) your session.

VI. RELATED WORKS

The book by *Booth, Williams and Colomb* [6] presents a very good text to help beginners or experienced people in the craft of research. Besides writing papers, researchers can be involved with writing patents [7, 8, 9].

VII. CONCLUSIONS

This paper has presented a comprehensive approach to give advice for students on how to write their first article. The paper presented a varied range of topics that help students to understand better what a scientific paper is. Provided advice helps students to reach maturity earlier, by introducing them to standpoints that have to be considered in a holistic way to produce good scientific papers. The method presented herein is being successfully used to teach graduate and undergraduate students how to write their first scientific article.

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