How to Write a Scientific Article

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ABSTRACT

Writing a scientific article can appear intimidating, but need not be. The various parts of a scientific article are examined and guidelines given. With time and patience, almost anyone can write a scientific article.

INTRODUCTION

So you have a fossil in your collection that you want to tell the world about? You may ask, "How do I write a scientific article?" Contrary to what many think, you do not need a Ph.D. to write a scientific article. For example, until he died in 1995, the world's foremost expert on fossil eggs, Karl Hirsch, only had a high school degree. Karl became interested in fossil eggs when he found one on a fossil hunting trip in the early 1970s. He showed the egg to several professional vertebrate paleontologists, but none could tell him with certainty what animal laid the egg. Most paleontologists said that fossil eggs were just rare curiosities and of little scientific value. Dissatisfied with the answers, Karl delved further into the subject discovering that, in fact, fossil eggs were much more common than realized and that there was much information that could be gleaned from fossil eggs and eggshells. Karl eventually published over 28 scientific articles on the subject and in the process pioneered many of the techniques and terminology used today. As for the egg that started it all, Karl eventually described it as a turtle egg (Hirsch 1983). If Karl can do it, so can you. Let's begin.

The steps toward publication can be summarized like this:

- Do research
- Write manuscript
- Submit
- Editor sends to review
- Returned manuscript with reviews
- Revise
- Published

We will concentrate on the first two points, which will get you started to finally showing off your article to family and friends.

PART I. DOING THE RESEARCH

In order to describe your fossil, you are going to have to do some research. Research basically seeks to answer a question: Why are the bones in this quarry laid out the way they are? How do the parts move? or What organism is this fossil?

As you gather data during your research, you should record it in a notebook (or on your computer). Never trust your memory because as you gather more and more data, and as more and more time passes, the chances of forgetting some crucial point will increase. Ideally, you should make sketches in your notebook to help you later interpret photographs taken. For example, you photographed a skeleton you have partially

uncovered in the field. A quick sketch with parts labeled may make it easier for you to interpret the photograph at a later date because not all the bones will be completely exposed, or they may be broken and incomplete.

Fossil sites need to be recorded to give the fossil context (see Walter Stein's article in this issue). Why bother you ask. Let me give you an example. In 1975, Peter Dodson wrote a now classic article in which he concluded that many of the different species of crested hadrosaurs were in fact males and females of two species. Then a few years ago, David Evans and his colleagues revisited the quarries where the specimens were collected in the 1910s and 1920s in what is now Dinosaur Provincial Park, Alberta. By plotting the quarries (hence the specimens) stratigraphically, they discovered that the supposed males and females did not occur in the same beds, but rather in different stratigraphic levels (Evans and others, 2006). Therefore, the diversity of crested hadrosaur species in the Dinosaur Park Formation was greater than Dodson realized - a conclusion only made possible by the records of locality data. This example illustrates one reason why it would be good to archive your notes at the JPS website.

What should that data include? The most obvious data to record is, of course, GPS coordinates. You should also describe the local terrain: Is the fossil site at the base of a cliff, bottom of a gully, or at the top of a ridge? What formation do the fossils come from and if known, what member? (Some formations have been formally subdivided into members, such as the Brushy Basin Member of the Morrison Formation). Are the beds tilted, and if so, how much? Give a description of the rocks the fossils are from, including the rock type. Ideally, this description should include rock type, color, grain size and shape, hardness, and cement. Unfortunately, few people have enough geology background to record these data, so saving a small sample with the fossil is one solution. Finally, photograph the site from a distance at different angles to aid in relocating the spot at a later date.

You will also need to do some library research, which today also includes the internet. Be careful what you read, however, not everything there may be true. As you will see in the next section, this phase of research gives your scientific article some context, and it will help you to justify your statements. Almost everyone who collects fossils has also amassed a small library of books and articles. These are a good starting point, but don't be surprised if you have to go to a bigger library. The library of a university with a geology department is ideal because then you would probably find suitable journals and books there. If you don't live near enough to use such a library, start with your public library. Often it is possible to order scholarly articles through interlibrary loan at the reference desk. However, some small libraries have no experience in that, so you may need to work with them in getting what you need. Sometimes you can get a photocopy of an article for free or at low cost.

How do you find these scholarly articles? Many Portable Document Format files (a.k.a. PDF) of articles can be downloaded from the internet. For example, using Google (probably the best search engine for this sort of thing), a search for "trilobite" produced 802,000 sites. Most of these sites are not useful for our needs, so I narrowed the results with "trilobite PDF." That reduced the sites to 109,000 sites, some of which included PDFs of scientific articles. Suppose you made a large collection of a trilobite at different growth stages and you need information on the changes that take place in trilobites as they grow. A search of "trilobite growth PDF" produced 23,400 sites, including free PDF scientific articles, such as "Development of the caudal exoskeleton of the pliomerid trilobite *Hintzeia plicamarginis* new species" and "Growth, Visual Field, and Resolution in the Juvenile *Limulus* Lateral Eye." A related search engine that I often use is Google Scholar (http://scholar.google.com), although that often processes sites with restricted access, such as various scientific journals. Usually, though, you can read the abstracts (more on that in the next section) and at least get a feel for the article. You can sometimes make a one time purchase of the entire article (don't forget to print it or save it!). You may also be able to get the article through interlibrary loan (give the librarian the entire article reference: authors, date, article title, journal title, volume number, and pages).

Reading scientific articles can be difficult for a variety of reasons, including unfamiliarity with the topic, poor writing and too much jargon. It may be necessary to read an article several times to understand it. You should at least strive to understand the sections called the Abstract (more on that below), the Introduction and the Conclusion, as well as the captions for any illustrations. If you can understand those sections, you can generally understand the most important parts of the article. You should definitely look up unfamiliar words

because they can be the heart of the article. Google is a good tool to use. Be sure to include the word "define" in the search, such as "define prezygopophysis" in order to narrow the results.

PART II. DOING THE WRITING

Why write a scientific article in the first place? Writing is a way of disseminating or sharing the results of research; it allows you to share your discovery with the rest of the world. The process of writing does not need to be tedious, but what is written needs to be honed through repeated "tweaks." If writing feels tedious, then perhaps you are trying too hard to write the "perfect" manuscript. Accept that you will need to refine your manuscript several times, so it is best just to get the ideas down first. It is also possible that you are not sure what it is you want to write. In that case, making an outline can help. An easy way is to start with the major parts of a scientific paper as given below and then organize your information and thoughts into each of the sections.

In honing your manuscript by reading and rereading, remember to keep to the subject. If writing about a dragonfly fossil from the Green River Shale, don't get side tracked into writing about other insects. It is OK in this example (and indeed preferred, as you will see below) to mention other dragonfly fossils, especially those from the Green River Shale in a historical context. If you suggest an idea (called a hypothesis), be sure to back it up. In other words, give your reasons for your belief, even if it requires reference to some other article. For example, if I write "*Triceratops* males used their horns as weapons in fighting," you might ask, "Why does he think that? Does he have a time machine?" As written, the statement is presented as fact. Because I am speculating it is better to write, *"Triceratops* males may have used their horns as weapons in fighting each other much like Jackson's chameleons during territorial disputes (Carpenter and Ferguson, 1977)" or "Farke (2004) has suggested that *Triceratops* used its horns in fighting much like the Jackson's chameleon." Note that in the first example I gave a reference to where I found the information that the Jackson's chameleon uses its horns as weapons. If I had left the reference out you could rightly ask how I knew this to be a fact.

Let's now look at the structure of a scientific article. The layout is fairly consistent. The biggest difference is in how the references are formatted. For the Journal of Paleontological Sciences (this journal), you will set up your manuscript as it will appear on the internet. Be sure to follow the guidelines or risk not having your manuscript accepted. For most journals, however, what is submitted will look different from what is eventually published. For these journals don't try to set up your manuscript as you think it will appear in published form. In other words, don't "desk-top publish" your manuscript. Because the requirement for each journal is different, you must carefully read the submission guidelines for each, or risk having your manuscript rejected. Now let's look at the parts of a scientific article. The arrangement is fairly standard and serves to organize the contents of the manuscript:

Title
Author name(s) and address(es)
Abstract
Introduction
Main body of manuscript
Conclusion/Summary
Acknowledgments
References Cited
Illustrations and Figure captions
Tables

Title

The title is the first thing that the reader will see and this will often determine whether they will read further. You naturally want to capture their attention, so the title needs to succinctly encapsulate the subject of

the article. The best way to do that is to use key words. Contrast this bad example, "Flying reptile of the Jurassic" for an article about a *Rhamphorynchus* specimen from Solnhofen, Germany. The key words really should have been "*Rhamphorhynchus*" and 'Solnhofen." Try to also make your title interesting. Contrast these two titles: "A plesiosaur skull" vs. "A complete plesiosaur skull from the Niobrara Formation of Kansas." Which article would you most likely look at? How about, "Butterfly Fossils from Colorado" vs. "A Butterfly Fossil Showing Color Patterns." The more specific the information you give in the title, the more likely someone will read your article. On the other hand, avoid long titles that are too ponderous to read: "A new ammonite specimen showing iridescent color from the Trail City Member of the Fox Hills Formation, Corson County, northern South Dakota, USA." Why not: "Iridescent Ammonite Shell from the Fox Hills of South Dakota"?

Abstract

Having read your wonderful title, the reader will next want to know a little more information without having to wade through a long article to get the "meat." That is the purpose of an abstract. It briefly (150-350 words) conveys the essential information of your article, including its purpose, the results and conclusion. The purpose may be to describe a *Eusmilus* skull with lower jaw or to report on a new dinosaur quarry). The results may be that the *Eusmilus* skull can be referred to the species *E. sicarius*, or that the new quarry has a juvenile *Stegosaurus* skeleton. The conclusion may be that this specimen is only the second *Eusmilus* skull from Niobrara County, Wyoming, or that the juvenile *Stegosaurus* skeleton is the most complete found to date. Although the abstract occurs near the front of the article, it is actually written last. Why? Because you need to select and summarize from the text of your article once it is written. Abstracts seldom contain references to other articles. Above all, they need to be concise and clear.

Here is a poorly written abstract:

> "My restudy of the short-necked plesiosaurs *Alphasaurus* and *Betasaurus* is presented. I have found a new, magnificent, little crushed skull I refer to *Alphasaurus*, which I illustrate and discuss. *Alphasaurus* and *Betasaurus* were originally described by J.M. Smith (1933) based on partial skulls collected in the Thermopolis Shale of eastern Wyoming. The specimen is complete and allows me to correct mistakes made by Smith, namely, that *Betasaurus* is a juvenile *Alphasaurus*. Therefore, *Betasaurus* is not a valid name."

Compare that with this version:

> "A complete skull of a pliosaur from the Thermopolis Shale is described. It is referred to *Alphasaurus* on the basis of the unique premaxillary-maxillary notch. The skull also shares with *Betasaurus* the pineal opening at the frontal-parietal suture. Therefore, *Betasaurus* is considered a junior synonym."

Why is the second version better? Because it gets to the point, has more information and give the justification for considering the skull to *Alphasaurus* and for why *Betasaurus* is the same as *Alphasaurus.*

Introduction

The Introduction "introduces" the reader to your topic or subject (why are you writing this article?). Consequently, you need to arrange the information from general to more specific. It is also important to give your reader a historical context so that they can understand the significance of your article. The best way is to refer to previous publications. The following is taken from an actual article:

> "The armor-plated stegosaurs were first named by O.C. Marsh in 1877 for elements collected from the Morrison Formation near Morrison, Colorado… One genus, *Stegosaurus*, and three species, *S. armatus*

> *(sensu stricto), S. ungulatus,* and *S. stenops*, are recognized by Carpenter and Galton (2001) from the Upper Jurassic of North America. The obscure *Hypsirophus discurus*, named by Cope (1878), differs enough from *Stegosaurus* to warrant recognition (Carpenter 1998). Yet another specimen of stegosaurid has recently been found that differs from all known genera (Carpenter and Miles 1997), indicating that the diversity of stegosaurids was greater in North America than previously realized" (Carpenter et al. 2001, p. 55-56).

In reading this, you know immediately that the topic of the article must have something to do with stegosaurs. You want to avoid leaving your reader guessing what you are writing about, so don't string them out too long. The historical context is given by reference to various previous publications about stegosaurs. Finally, the new stegosaur is referred to, which was implied by the title: "New primitive stegosaur from the Morrison Formation, Wyoming." The progression then of the information is general (stegosaurs) to more specific (diversity of stegosaurs in the Morrison Formation) to very specific (a new stegosaur).

Main Body of Text

This is the "meat" of your article. It does not really have a title because it will depend on what you are writing about (don't write **Main Body of Text**). If you are describing a eurypterid, you might simply title this section **Description**, or if you are elaborating about an idea on feeding behavior in trilobites you might call this section **Trilobite Feeding Behavior**. You may actually have several section that make up the may body of your article. Each of these may have different titles, such as **Evidence for Trilobite Feeding Behavior** and **Trilobite Mouth Parts**. Remember though, to keep to the point. Don't wander from the theme of each section, or you will loose your reader. You may find that you have to create new sections in order to accommodate different subjects.

Sometimes in scientific papers you will find headings such as **Materials and Methods**, which lists specimens used in the study and what methods or procedures were applied to them (CAT-scan, enhancement of digital images in PhotoShop, measurements with a digital caliper, statistical tests, etc.). This allows others to replicate the study, and hopefully to get the same results. The information is given as a narrative, rather than step-by-step instructions. There may be a section called **Results** where you literally give the results of the analysis, but you don't interpret them. That occurs either in the next section, **Discussion**.

The **Discussion** explains the meaning of the results (such as a Chi-square statistical test applied to a group of brachiopods), or why the results differ from what others have previously reported. For example, Smith may have reported that the average length-width ratio for the cephalon (head portion) of the trilobite *Elrathia kingii* from the Wheeler Formation of Utah as 0.44, whereas your result is 0.40 (given in the **Results** section). In the **Discussion** you would explain why your results differ, perhaps because you used twice as many specimens (called the sample size), for example.

Not every manuscript will have **Materials**, **Methods**, **Results**, or **Discussion** sections, especially if your article is descriptive of a single specimen. Regardless of how many sections you have, you need some sort of title so that the reader knows that they are no longer reading the **Introduction**.

Conclusion/Summary

This is where you wrap-up your article by either summarizing the main points (**Summary**) or by interpreting the significance of your article (**Conclusion**). If either of these is short (one or two sentences), then you can just add it to the end of the **Main Body** rather than make it a distinct section. The **Conclusion** is a good place to set your results in a bigger picture, which might help the reader understand the significance of your article. For example, if your article describes small theropod teeth from a single site in the Hell Creek Formation, you might discuss how the diversity compares with other sites or even how the diversity is representative of small theropods from the Hell Creek. The **Conclusion** is also a good place to recommend future research, perhaps in the form of a hypothesis. For example, the abundance of large dinosaur eggshell

fragments at a site might suggest the possibility that a nesting site was once nearby. Regardless of what you include in the **Conclusion**, the last sentence should convey closure so that the reader recognizes "The End" without you having to write those words.

Acknowledgments

You might have had some assistants toiling at the excavation. This is where you thank them for their hard work. Perhaps someone allowed you to describe a specimen they owned,. Again this is where you thank them. Did you have someone make your illustrations, type the manuscript, or read it for you? Thank them all. Be careful, however, not to get carried away with flowery language. Rather than write "I would like to thank…", just do it: "I thank…"

References Cited

This is where you list alphabetically by author's last name(s) any article that you referred to (such as in the example above under Introduction). You do not list any articles or books you read for background if you did not cite them. Let's suppose you read Fenton and Fenton's, "The Fossil Book", to get some background about brachiopods for yourself, but don't refer to it when you finally get around to describing a wonderful pyritized brachiopod from Illinois. In this case, you would not list Fenton and Fenton in the References Cited section. How references are organized is perhaps the one area that different journals vary. I have no idea why they are fussy, but they are. For example, the Journal of Vertebrate Paleontology has the references thus: Sues, H.-D., E. Frey, D. M. Martill, and D. M. Scott. 2002. *Irritator challengeri*, a spinosaurid (Dinosauria: Theropoda) from the Lower Cretaceous of Brazil. Journal of Vertebrate Paleontology 22:535–547. In contrast, the Journal of Palaeontology wants references like this: BENESKI, J. T., Jr and LARSEN, J. H., Jr 1989. Interspecific, ontogenetic, and life history variation in the tooth morphology of mole salamanders (Amphibia, Urodela, Ambystomatidae). *Journal of Paleontology*, **199**, 53-69. Before submitting an article, be sure that you have the references in the correct format. You can find this information at each journal's website. Also be sure to check the references against the citation in the text of the manuscript so none are overlooked. That is one of the most common mistakes professional paleontologists make.

Illustrations and Figure Captions

Because "a picture is worth a thousand words", you should plan to illustrate your article with maps, images of the specimen(s), etc. Typically when you submit your article, these do not go within the manuscript, but are each on separate pages (or separate files if electronic). However, for the *Journal of Paleontological Sciences* you will insert the images within the manuscript and add a caption (i.e., a narrative to the illustration) so your reader will know what they are looking at. Any image is called a figure and each is given a separate figure number. Be sure to refer to each figure in the text, so your reader will know what image you are referring to. Be sure to include both a north arrow and scale for any map, and a scale for any image of a fossil. In addition, give any abbreviations used in the image (such as for various parts of a fossil) either in the caption, or compile all of them (if many) as an Appendix. For the *Journal of Paleontological Sciences* the images within the manuscript should be of low resolution, or it will take too long to download your article. Higher resolution images can (and probably should) be archived at the Journal's Website.

Tables

Tables allow you to present a great deal of information in a non-narrative format, i.e., tables are lists. The list can be of measurements, specimens you examined, etc. However, a table should not repeat all the information given in text. For example, rather than give measurements for all the bones in the skeleton in the text, compile them all in a table. This makes it easier to read. Each table should have a caption to explain what

the list is about. As with Figures, Tables numerical and should be referred to in the text: “Measurements of the specimens used in this study are given in Table 1.” A table should be created using the Table menu, not using the tab or space bar. To create a table in Microsoft Word, find it in the menu: ‘Table > Insert > Table’, then set the rows and columns to the numbers you need.
Here is an example:

Table 1. Measurements (in cm) of Stegosaurus *femora*

element	Greatest length	Greatest proximal width	Greatest distal width
Femur (L) DMNH 243	128	24.5	22
Femur (L) YPM 1987	~130.25	26.3	-
Femur (R) YPM 1991	120.2	19	15

WRITING STYLE

Remember that it isn’t enough to simply have a good idea. You must be able to communicate it clearly.

> ‘Twas the nocturnal segment of the diurnal period preceding the annual Yuletide celebration and throughout our place of residence, kinetic activity was not in evidence among possessors of this potential, including that species of domestic rodent known as *Mus musculus*. (Author unknown, http://www.textfiles.com/holiday/night.hum).

One of the biggest mistakes made by first time writers is trying to sound scientific. Don’t bother. You will only confuse your reader. Be careful about jargon because you will come across as pompous and your article will not be read (remember that the point of your work is to entice someone to read it). Some scientific terminology is unavoidable such as “caudal vertebrae” for vertebrae in the tail or “jugal” because it refers to a specific bone in the skull. The example above is full of technically correct words, but it is difficult to understand. You can find a great deal of basic invertebrate terminology in Boardman and others (1987), as well as at numerous web sites. One particularly good site for vertebrate anatomical terminology is found at the Dinosauria site: http://www.dinosauria.com/dml/dmlf.htm .

Long sentences are also difficult to read, so cut them into two or more:

> “On the tops of crinoids is a circle of plates called radials, which in some primitive crinoids is further divided into a lower inferradial and an upper superradial, and below the radials is a circlet of plates called basals.”

can be simply written:

> “On the tops of crinoids is a circle of plates called radials. In some primitive crinoids these radials are divided into lower inferradials and upper superradials. Below the radials is a circlet of plates called basals.”

The first sentence contains 39 words, whereas the revision is composed of 3 sentences with an average of 13 words each. Shorter sentences are easier to read. Sentences should rarely exceed 25 words, and then only if you are presenting a list. For example, “The skeleton contains a nearly complete skull, 6 vertebrae, a left

femur and parts of the right, 12 ribs, two left metacarpals, five right, twelve phalanges, and numerous unidentifiable fragments."

Finally, there are common mistakes that even professional paleontologists make, but which you should avoid:

- Scientific names are never pluralized: "Three specimens of *Tyrannosaurus* were found" not "Three *Tyrannosauruses* were found".
- Scientific names of the genus and species are by convention given in italics, with species always given in lower case: *Aeger tipularius* (a shrimp from Solnhofen).
- 'Upper' and 'Lower' refer to the age of rocks, such as "the Upper Cretaceous Pierre Shale", whereas 'Late' and 'Early' refer to time: "*Macginitiea wyomingensis* is a common Early Cenozoic leaf." An easy way to remember all this is "Early Cretaceous dinosaurs are found in Lower Cretaceous rocks."
- Be careful about using words that imply motion when the object is stationary: "In the gastropod *Murex*, the spines extend or project outwards to a point" not "In the gastropod *Murex*, the spines run outwards to a point". These spines have no legs, so they can't run.
- If you know something to be true, then say so. Don't be wishy-washy: "The teeth of *Allosaurus* appear to be sharp." Is there doubt? "The teeth of *Allosaurus* are sharp." There are many similar words you should avoid, such as: 'suggests,' 'appears,' 'probably,' 'may be.' Better words to use are 'indicates,' 'implies,' 'shows,' 'illustrates,' etc.
- Avoid implying time when none is meant. "Because the teeth were broken we restored them" rather than "Since the teeth are broken, we restored them." Other words to be careful of using include: 'while' and 'frequently'. Use 'whereas' or 'many'.
- Redundancy can sometimes slip by: "The leaf is triangular-shaped." Triangular is a shape, so to write it is redundant. It is better to write "The leaf is triangular."
- 'As' implies a comparison, whereas 'because' implies the result of some action: "The legs of this specimen are unknown as they are missing" should be "The legs of this specimen are unknown because they are missing."
- Something that is not alive cannot possess, therefore write: "the premaxilla of the skull…", not "the skull's premaxilla…"
- Be careful about writing something in the past tense if it still exists. For example, rather than "three teeth were found in the jaw," write "the jaw has three teeth." Your reader will have an easier time if you write in the here and now, rather than in the past.

CONCLUSION

Having gotten this far, I hope you are not discouraged in your attempt to write a scientific article. I should warn you, however, that once you submit your article, it isn't done. Articles are given to someone to review (i.e., evaluate). Hopefully it is someone who is knowledgeable in the topic of your article. The purpose of the reviewer is to ensure that the science in the paper is sound and that they can follow your train of thought. Often negative reviews occur because the reviewer can't follow how you got from "A" to "C". They can't get into your mind. To limit that have a friend or colleague read your article before you submit it. Tell them you want an honest appraisal, but don't lash out if they don't sing praises. Better they give you constructive comments now, than getting harsh ones later from the journal reviewer. The whole review process is emotionally traumatic. This is one reason why some professional paleontologists publish few articles during their career. Even after 30 years of publishing scientific articles (about 200 thus far), it is still an emotional blow to me to get negative comments (and yes, I have manuscripts that were rejected and never published). When that happens to you, it is best to set the manuscript aside for a week or more in order to get some emotional distance. Then go back through the review comments and tweak your manuscript to improve it according to the comments. Your manuscript will be better for it.

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