

Guidelines for writing a research paper for publication

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A primary task of a researcher is the communication of technical results to the broader scientific community. Whether in written or oral form, scientific communication is a critical step in the scientific method and is the key driver of movement within a scientific field. Therefore, the construction of a written scientific manuscript must not be taken lightly. As part of our service to the broader scientific community, we thought it may be beneficial to identify some of the common aspects of a well constructed scientific manuscript. These points are briefly discussed below.

It should be noted that manuscripts that are successfully submitted to a journal for publication have three main components: (1) the overall idea, (2) the execution of the work, and (3) the presentation of the work. While each of these is critical, the guidelines presented below primarily speak to the third component, namely the presentation of the scientific work. Thus a poor idea or a poorly designed investigation can not be saved by an excellent presentation of the work, and equally an excellent idea that is well investigated can still be doomed by a poor presentation. Hopefully the concepts described below will help to minimize the latter situation.

Structure and Approach

Scientific research must begin with a defined research question, which results in a well designed research protocol that plans the overall approach. This foundation should lead to a set of data from which the manuscript can be constructed. Manuscripts submitted to journals for consideration for publication typically have the following components.

- Title Page
- Abstract
- Introduction
- Methods
- Results
- Discussion
- Conclusions
- Acknowledgements
- References
- Tables and Table Captions
- Figure and Figure Captions

A reasonable approach to writing a scientific manuscript may be the following. First write the Methods section, largely derived from your initial research protocol, and perhaps during the experimental phase of the work itself so that all details are included. Construct all of the figures and tables that contain the data included in the work, and then write the Results section. Depending upon the type of study, there may be some iteration in the presentation of the data and writing of the text. Reconsider the scientific questions the manuscript will address, again referring to your research protocol, and then write the Introduction. Next, use the Introduction and Results to guide the writing of the Discussion. Summarize everything in an Abstract, and then condense and refocus the Abstract into a Conclusions section. Below is a brief discussion of each of the sections. These are only suggestions on how a scientific manuscript may be written. Other strategies may also be used, but clarity should be the guiding principle. *In general, the purpose of a scientific manuscript is to construct a clearly written document that describes a question and then logically presents an answer to this question that is based upon theoretical or experimental results.*

A scientific manuscript is meant to convey technical information to the reader. Therefore, it is generally designed to be a straightforward presentation and discussion. Paragraphs and sentences should be simply constructed. One point of view that supports this concept is that the scientific aspect of the manuscript may be challenging enough for the reader to comprehend, therefore the text itself should support the endeavor to convey the scientific information, rather than acting to further obscure the concepts and results.



Title Page

A title page should be included. State the title of the manuscript, which should be short and simple, as well as authors and author affiliations. Indicate the journal to which the manuscript is being submitted. Provide approximately 5 key words, as well as a short title (sometimes referred to as a running title) for the manuscript. Finally, provide complete contact information for the corresponding author.

Abstract

The abstract is typically a single paragraph. The abstract should be considered as an independent document, so that the abstract does not rely upon any material in the body of the report and, similarly, the body of the report does not rely upon any material in the abstract. The first sentence should clearly state the objective of the experiment. If the experiment is based upon a hypothesis, which is greatly preferred, the hypothesis should be stated and followed with statements describing its basis and evaluation. The subsequent sentences describe how the investigation was carried out. The following sentences describe, with as much precision as possible without being verbose, the results of the experiment. The final sentences describe the significance of the results and the impact of this work on the general field of study.

Introduction

The introduction requires a short review of the literature pertaining to the research topic. The introduction is then best constructed as a descriptive funnel, starting with broad topics and slowly focusing on the work at hand. Perhaps three to four paragraphs are needed. One approach may be to start with one or two paragraphs that introduce the reader to the general field of study. The subsequent paragraphs then describe how an aspect of this field could be improved. The final paragraph is critical. It clearly states, most likely in the first sentence of the paragraph, what experimental question will be answered by the present study. The hypothesis is then stated. Next, briefly describe the approach that was taken to test the hypothesis. Finally, a summary sentence may be added stating how the answer of your question will contribute to the overall field of study.

Methods

This section should be a straightforward description of the methods used in your study. Each method should be described in a separate section. Begin, in a single section, with a statement of the materials used in the study, indicating the vendor and vendor contact information for each material. This information is critical so that readers have the capability to repeat the work in their own institutions. Next describe, in separate sections, each key procedure and technique used in the study. Keep explanations brief and concise. If a specific experimental design is utilized, describe this design in the second section of the Methods, after the materials section. Similarly, if a theoretical or modeling component is utilized, it should also be incorporated in the initial portion of the Methods. Finally, remember to describe the statistical analysis methods that were utilized to analyze the results, most likely in the final section of the Methods section. Although it is typically not recommended, the use of the passive voice is probably appropriate in the Methods section.



Results

The Results section presents the experimental data to the reader, and is not a place for discussion or interpretation of the data. The data itself should be presented in tables and figures (see below). Introduce each group of tables and figures in a separate paragraph where the overall trends and data points of particular interest are noted. You may want to indicate the placement of a particular table or figure in the text. For experimental studies, key statistics such as the number of samples (n), the index of dispersion (SD, SEM), and the index of central tendency (mean, median or mode) must be stated. Include any statistical analysis that was performed, and make sure to indicate specific statistical data, such as p -values. Note that each table and figure in the paper must be referred to in the Results section. Be succinct.

Discussion

The discussion section, often the most difficult to write, should be relatively easy if the previous suggestions have been followed. In particular, look to the last paragraph of the introduction. If the work has characterized a phenomenon by studying specific effects, use the results to describe each effect in separate paragraphs. If the work has presented a hypothesis, use the results to construct a logical argument that supports or rejects your hypothesis. If the work has identified three main objectives for the work, use the results to address each of these objectives. A well-defined study that is described in the Introduction, along with supporting results that are presented in the Results section, should ease the construction of the Discussion section.

Begin the Discussion section with a brief paragraph that again gives an overview to the work. Summarize the most important findings and, if applicable, accept or reject the proposed hypothesis. Next, identify the most interesting, significant, remarkable findings that were presented in the Results section, and contrast these findings in light of other studies reported in the literature. It is often informative if a discussion of the potential weaknesses of the interpretation is also included. Finally, at the end of the Discussion section, consider the other works in the literature that address this topic and how this work contributes to the overall field of study.

Conclusions

Again, first introduce the work and then briefly state the major results. Then state the major points of the discussion. Finally, end with a statement of how this work contributes to the overall field of study.

Acknowledgements

Provide a brief statement acknowledging the efforts of any participants or consultants who are not included as authors of the manuscript. State all of the funding sources for the work, ensuring that the statement adheres to the guidelines provided by the funding institution.



References

Include all references that have been cited in the text. The references should be well considered, so that they contain all key sources in the field as well as previous studies that support or motivate the present work. However, do not include extraneous references in an effort to simply cite particular authors or journals. It may be appropriate to cite previous publications from your own laboratory, but this should be done judiciously.

You must use the reference format that is mandated by the journal to which you are submitting the manuscript. Software packages make citing literature particularly easy.

Tables and Table Captions

Tables should generally be included in a separate section after the References section. The tables should be headed with a caption and title in bold (i.e., **Table 1: Material Properties**), followed by a sentence or two that describes the content and impact of the data included in the table. The table itself should be formatted so that the data is clearly presented and easily interpreted by the reviewer, however the table is likely to be reformatted by journal to conform to its standards. Make sure that each table is referred to in the manuscript text; this will most likely occur in the Results section, but may also occur in the Introduction, Methods, or Discussion sections.

Figures and Figure Captions

As with the tables, figures can also be placed in a separate section after the References section. Again, clarity is the key factor, especially with images and graphs. All images should be as large as possible, and include accurate scale bars. The graphs should be large, with data points and axis labels in a large font. Legends can be included within the graph or in the caption. All figures need a caption. The caption should identify the figure in bold (i.e., **Figure 3**), state a brief title to the figure, succinctly present the significant result or interpretation that may be made from the figure (this may be modified from the Results or Discussion section text), and finally state the number of repetitions within the experiment (i.e., $n=5$) as well as what the data point actually represents (i.e., the data are means and the associated error bars represent standard deviations). As with the tables, make sure that each figure is referred to in the manuscript text.

Authorship and Originality

Finally, we have assembled some points to consider in regards to authorship and originality of manuscripts submitted for publication

- Plagiarism is unfortunately a major concern among editors and publishers. Therefore, be certain of the sources of all data and text. If the article is based upon prior work, be sure to reference that prior work properly. An original research paper can not contain previously published data in any form without a proper citation.
- Authorship and the order of authorship must be agreed upon by all of the authors and any other personnel who participated in the work but are not included as an author.
- It is not permissible to submit a work that is a translation of a previously published paper.



About the Authors

Dr. John P. Fisher is Professor and Associate Chair for Graduate Studies in the Fischell Department of Bioengineering at the University of Maryland. Fisher completed a BS in chemical engineering at The Johns Hopkins University (1995), MS in chemical engineering at the University of Cincinnati (1998), PhD in bioengineering at Rice University (2003), and postdoctoral fellowship in cartilage biology and engineering at the University of California Davis (2003).



Fisher, the Director of the Tissue Engineering and Biomaterials Laboratory, investigates biomaterials, stem cells, and bioreactors for the regeneration of lost tissues, particularly bone, cartilage, vasculature, and skeletal muscle. His research focuses on the development of novel, implantable, biocompatible materials that can support the development of both adult progenitor and adult stem cells, and particularly examines how biomaterials affect endogenous molecular signaling among embedded cell populations. Fisher is the author of over 65 publications, 120 scientific presentations, and 4 patents. Fisher has mentored 3 MS students and 10 PhD students. In addition, Fisher has mentored over 40 undergraduate researchers in his own lab, including 2 who were named University of Maryland Outstanding Undergraduate Researchers, 4 who have received Howard Hughes Medical Institute Undergraduate Research Fellowships, and 18 supported by Maryland Technology Enterprise Institute ASPIRE Awards.

In 2012 Fisher was elected Fellow of the American Institute for Medical and Biological Engineering. In addition, Fisher has received a NSF CAREER Award (2005), the Arthritis Foundation's Investigator Award (2006), the University of Maryland Invention of the Year Award (2006), the Outstanding Graduate Alumnus Award from the Department of Bioengineering at Rice University (2007), the Engalitcheff Award from the Arthritis Foundation (2008), the University of Maryland Professor Venture Fair Competition (2009), and the Teaching Excellence Award from the Fischell Department of Bioengineering at the University of Maryland (2011).

Since 2007 Fisher has directed NSF supported Molecular and Cellular Bioengineering Research Experiences for Undergraduates Site. Fisher has served as editor of several works, and is currently the Editor-in-Chief of the journal *Tissue Engineering, Part B: Reviews*. Fisher has edited 2 books, and was the tissue engineering editor for the third edition of The Biomedical Engineering Handbook (2006).

John A. Jansen, DDS, PhD studied Dentistry at Radboud University Nijmegen and graduated in 1977. In the same year he started a part-time dental practice in Maassluis, the Netherlands. He completed his PhD dealing with the adhesion of epithelial cells to dental implant materials in 1984 at the Radboud University Nijmegen. After working as assistant professor in Amsterdam and Leiden he returned to Nijmegen in 1991 to become associate professor of Biomaterials and Implantology before being appointed Full in April 1996. In April 2008, he was elected as full member of the Royal Netherlands Academy of Arts and Sciences (Section Medicine). In 2009, he was appointed Honorary Professor, Sichuan University, Sichuan, China and in 2010 hired as Research Professor, Dental Implant and Osseointegration Research Chair (DIORC), College of Dentistry, King Saud University Riyadh, Saudi-Arabia. He has contributed to over 500 publications, is the owner of seven patents and editorial board member/editor of eight international scientific journals, including *Tissue Engineering, Part C: Methods*.



Peter C. Johnson, MD is a University of Notre Dame and SUNY Upstate Medical University graduate. After General and Plastic Surgery training, Dr. Johnson practiced reconstructive surgery for ten years at University of Pittsburgh where he founded and was the first President of the Pittsburgh Tissue Engineering Initiative. Subsequent roles were co-founder/CEO of TissueInformatics, EVP of Life Sciences, CMO and CBO of Icoria, and EVP, Entegron, Inc. He presently serves as the VP, Research and Development and Medical Affairs of Vancive Medical Technologies, an Avery Dennison business. He Chaired the Plastic Surgery Research Council, was President of the Pennsylvania Biotechnology Association and the Tissue Engineering Society, International and is presently the Co-Editor-in-Chief of the three-part journal, *Tissue Engineering*. He serves on the Industry Committee of TERMIS, Board of Trustees of the Pittsburgh Tissue Engineering Initiative and the University of North Carolina Medical Foundation. He is an Adjunct Professor of Surgery, Bioengineering and Business at the University of North Carolina at Chapel Hill, of Bioengineering at NC State and of Regenerative Medicine at Wake Forest University School of Medicine.



Antonios G. Mikos, PhD is the Louis Calder Professor of Bioengineering and Chemical and Biomolecular Engineering at Rice University. His research focuses on the synthesis, processing, and evaluation of new biomaterials for use as scaffolds for tissue engineering, as carriers for controlled drug delivery, and as non-viral vectors for gene therapy. He is the author of over 460 publications and 25 patents. He is a Fellow of the American Association for the Advancement of Science, American Institute for Medical and Biological Engineering, Biomedical Engineering Society, Controlled Release Society, International Union of Societies for Biomaterials Science and Engineering, and Tissue Engineering and Regenerative Medicine International Society. He is also a Member of the National Academy of Engineering and the Institute of Medicine of the National Academies. Dr. Mikos is Co-Editor-in-Chief of the three-part journal *Tissue Engineering*.

