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Authorship best practices in biophysics

Research publications are the currency of science, and authorship is the main mechanism for attributing credit and assigning responsibility to individual scientists for their contributions. The continuously evolving publication landscape poses complex challenges; therefore, it is necessary to introduce up-to-date authorship expectations and best practices for researchers to evaluate individual contributions and clearly define the criteria for authorship. This editorial provides guidelines and resources to help junior researchers navigate the authorship process, approach potential issues and conflicts, and promote ethical authorship practices in the biophysics community.

Academic hiring, research funding, promotion, and tenure, as well as awards, are largely based on a scientist's publication record. Equitable attribution is thus particularly important, specifically for trainees and junior researchers, whose early success heavily depends on their output. Consequently, the publication process requires all authors to be held to the highest ethical standards (1). Professional societies and scientific journals (2) often provide guidelines, and funding agencies such as NIH often require training for investigators on agency-funded projects (3,4). Despite this, most junior scholars receive limited training on best practices in attribution or authorship and often rely on more senior researchers, such as a principal investigator (PI), throughout the publication process.

EMERGING CHALLENGES AND THE MODERN PUBLICATION LANDSCAPE

Biophysics has undergone transformative changes over the past two decades. These changes prompt review and revision of traditional approaches to determining authorship, as well as the creation of a set of guidelines that can benefit both junior and senior researchers. Some of these challenges can be grouped into the following categories.

1. Collaborative science: projects containing numerous authors spanning multiple labs are now the norm as the fraction of "single-PI" papers decreases. As a result, attributing credit, especially to junior researchers, may be challenging, as the contribution from any single author may only account for a small portion of the project. Additionally, individual laboratories may adopt different approaches to data collection, analysis, and writing. Such collaborations across labs may enable new science but may also present additional challenges in determining authorship. It is thus important to discuss authorship throughout a project and certainly before the writing process begins.
2. Online preprint and data repositories: sharing preprints, code, data, analysis tools, and resources in open-access archives or repositories has become a standard part of the publication process. This distribution creates difficulties in determining authorship because tools, figures, specific datasets, or portions of a manuscript can be shared separately by individual researchers. In addition, even after a version of record is published in a peer-reviewed journal, manuscripts can continue to evolve. In other words, additional data may be incorporated in follow-up drafts made available after official publication (5). Authorship can be altered across different versions, even after publication, further complicating attribution. This suggests that clear and uniform attribution guidelines should be applied across all publication steps.
3. Ownership of data and research tools: the barriers to publishing continue to decrease. Senior authors and journal editors are no longer exclusive gatekeepers. Preprint servers and data repositories allow junior lab members to publish preliminary results, or even raw data, without the traditional peer review process (6). Manuscripts can be "unbundled" and individual portions published separately. Questions on data ownership arise when figures, datasets, or portions of a manuscript can be shared independently. For these reasons, PIs need to train junior lab members on the ethics of disseminating scientific results or publishing research tools.

"SUBSTANTIAL INTELLECTUAL CONTRIBUTION"

Co-authors are individuals who make a substantial intellectual contribution to the conception, design, or execution of the research and approve the manuscript before publication (7–9). This definition serves as a starting point, but key

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challenges arise from such broadly defined criteria, as assessing a substantial contribution is inherently subjective. In addition, this definition does not explain how contributions should be ranked or how the order of authors is decided. It is therefore essential to establish a set of best practices within the context of the modern publication landscape. Below, we discuss key considerations and provide specific guidance and criteria to initiate conversations among researchers to determine authorship in manuscripts, preprints, or other documents in the biophysical sciences.

GUIDELINES FOR DETERMINING AUTHORSHIP

1. The most important component of the above criteria is the word "intellectual," which implies authors must provide insight to shape the study or the conclusions instead of simple "mechanical" contributions. One possible test to assess the importance of individual contributions is to ask the question "which conclusions are derived from the author's intellectual contribution?" Similarly, one can ask the reverse question: "If a given author's contribution was removed, then how would the conclusions change?" This is a starting point for assessing individual contributions, but it is important to understand that this should not be used solely as a test to include or exclude authors given the intricacies of scientific projects, where often an intellectual contribution does not necessarily lead to a specific conclusion, and there is often no direct mapping between authors and conclusions.
2. The term "substantial" suggests that the author dedicated a nontrivial amount of time, effort, or resources to the project, beyond what is considered routine. However, in addition, an author must have provided conceptual or theoretical input to shape the project and its outcomes. Staff scientists, such as those managing shared instruments in a department or campus-wide user facility, for example, often maintain instruments and make measurements for users. However, while staff scientists generate data, they are not typically included as co-authors because measurements routinely follow standard protocols, and the data are commonly provided to the user without further scientific interpretation. Scientists whose contributions do not meet the criteria for authorship should be listed in the acknowledgments section. Therefore, while contributions may be substantial in terms of effort (i.e., the number of hours spent on measurements), such contributions do not necessarily satisfy the "intellectual" criterion. Providing advice on how to prepare samples, collect measurements, develop analytical tools, or interpret data is not usually sufficient but can be in specific cases. In certain scenarios, staff scientists should be included as co-authors, for example, if the measurements require modifying instruments, developing custom measurement protocols, developing analysis tools for the specific project, or interpreting data within the scientific hypotheses of the project. These contributions should qualify for authorship in nearly all cases.

Consider this scenario: a postdoc wishes to apply a previously described machine-learning approach in data analysis, but they are not an expert in computer programming. The postdoc asks an undergraduate student for help installing machine-learning libraries and writing a simple interface to load the data and run the model. The model output provides evidence that supports one of the main conclusions of this study. The postdoc makes the figure that includes the data and the analysis. Should the undergraduate student be listed as a co-author in the manuscript?

Appropriate resolution: It is not immediately necessary to include the undergraduate student as an author since installing a program does not constitute an intellectual contribution; however, the postdoc should attempt to get the student further involved in the data analysis process such that the student can earn authorship in the paper.

In general, an author should fulfill at least one of the following roles:

1. Conceptualized the project. This role is usually fulfilled by a senior author who conceptualizes the overarching scientific hypothesis that guides the entire study. Typically, this is referred to as the "main PI" of the project and is the corresponding author (see below for an additional discussion on the role of the PI). The PI also commonly provides a substantial fraction of the funding to support the project. Other authors can also be involved in conceptualizing certain portions of the project, specifically as it applies to specific measurements or simulations. For example, collaborators across different labs can be involved in designing certain experiments or presenting additional hypotheses that may be central to the study but outside the main PI's core expertise.
2. Performed measurements and analyzed data. This is most often the role of students, postdocs, or laboratory scientists who perform the bulk of the hands-on work to address the scientific question. In most projects, this involves measurements but can also include producing samples, designing and constructing instruments, or developing analytical tools. Often these authors also create figures for the manuscript.
3. Contributed text or figures and provided substantial comments on the manuscript. Typically, the authors who

perform the measurements also include the description, analysis, or interpretation of the data in the respective methods or discussion sections of the manuscript. Note that contributing text or figures alone (but not data) is often insufficient.

4. Was involved throughout the manuscript preparation, submission, and revision process and approved the initial submission as well as all revised drafts of the manuscript.
    a. All authors should be knowledgeable about the contributions of all other authors and ultimately be responsible for the content of the paper. This can be challenging in manuscripts with a large number of authors, where an individual may not be intimately knowledgeable about all techniques and experiments reported in the paper. However, all authors should have at least basic knowledge of the methods used in the study and how they ultimately shape the conclusions.
    b. Each author should approve versions of the manuscript before and after peer review, as well as any publicly available preprints.

Consider this scenario: a student made measurements and recorded the results in their lab notebook without further analysis. Several years later, after the student graduates, a postdoc continues the project and uses the previously recorded data to support the conclusions in a manuscript. The former student is no longer interested in contributing to the project and does not want to be involved in the manuscript writing process. Should the former student be listed as an author?

Appropriate resolution: In principle, the student should not be included since the student only contributed data without further analysis. However, including a researcher's data without attribution is not ethical. Since the student is no longer involved, an attempt should be made to involve them. If the resources allow, the appropriate approach may be for the postdoc to collect the same data again to ensure reproducibility and only include the new data in the publication. If the student is not involved in the analysis and writing process, the acknowledgments should be used to describe the student's contributions.

The above-mentioned roles, along with additional categories, have been outlined in the Contributor Roles Taxonomy framework, which outlines fourteen roles and has now been adopted by numerous journals (7,10,11). Though Contributor Roles Taxonomy does not specify criteria for authorship, the classification serves as a foundation for delineating contributions. Authorship roles should be discussed during the initial planning phase and throughout the project, particularly if project goals or hypotheses change while it is ongoing. If a member's contributions are not sufficient to warrant authorship, whenever possible, that member should be allowed to contribute to the project more substantially, thereby earning authorship. In the case of a member who has departed the lab, the PI should attempt to contact the former member and offer them the opportunity to become involved in the writing and revision process.

THE ORDER OF AUTHORS IN A MANUSCRIPT

Assembling the authors' list is the first step, and determining the order in which the authors are listed is the next important task. The authors' sequence is used to delineate individual contributions, and thus it is important to establish an order that appropriately and fairly reflects individual contributions. Determining the order can arguably be the most difficult task, particularly when authors contribute similarly to a project and it is difficult to balance the weight of each contribution. For these reasons, the authorship order should be evaluated throughout the project and updated depending on the individual author's involvement in the research and publication process.

The first author provides the largest contribution to the project and is responsible for the drafting of the manuscript. The first author is typically a student, postdoc, or research scientist whose primary focus is the project reported in the manuscript. The first author is often involved in measuring data and analyzing the results leading to the main conclusions and should have a leading role in generating figures and writing the manuscript. When researchers contribute approximately equally, they should be co-first authors; however, there are challenges with this arrangement because there must be an agreed-upon order. There are reasonable arguments in favor and against the practice, and journals provide little to no guidance on equal contributions.(12,13).

The order of contributions from non-PI authors is the next important consideration. There are few concrete guidelines to rely on. Generally, this order reflects individual contributions in decreasing order of significance. For example, a second author may have provided a more substantial contribution compared with the third or fourth author, but it can be difficult to arrive at a specific ranking. All authors should consider individual contributions throughout the research and writing process. It may be useful to ask individual authors to rank themselves and observe whether a natural ordering emerges. If not, discrepancies could be resolved by having an open discussion with all authors present, particularly during the early stages of writing and certainly before any of the results are disseminated. This process should be repeated as the

project evolves and initial results become a complete manuscript.

Consider this scenario: a graduate student is unable to find tools to analyze a data set to advance a project. During a short, casual 10-min conversation with a postdoc in another lab, the postdoc learns about the student's problem and provides an idea for a data analysis approach. The student tries the suggestions and makes quick progress on the analysis. The results from this analysis become central to addressing the hypothesis and the main conclusions of the paper. Should the postdoc be listed as an author on the paper?

Appropriate resolution: It is not immediately clear whether the postdoc should be included or not. If the analysis technique is standard and has been used in previous papers, it should be sufficient to cite prior literature, and the postdoc should be named in the acknowledgments section. If the technique comes from a new idea that the postdoc came up with and is not published, it may be possible that the postdoc should be included as a co-author due to their substantial intellectual contribution. However, if the other authors determine that the contribution is sufficient for authorship, the postdoc should be involved in the manuscript writing process, particularly in the description of the new analysis technique, and should approve all drafts of the paper.

THE ROLE OF THE PI

The main PI is often responsible for conceptualizing the initial scientific hypotheses and the initial design of the project, including specific experiments or analytical tools needed to address such hypotheses. Typically, this contribution involves writing a proposal outlining the hypotheses within the context of the broader scientific literature, defining the overall goals of the project, and sometimes describing specific measurements to be carried out. Proposals are the main component of a funding application and are typically submitted to a federal agency, private foundation, or industry partner. It is important to note that securing resources alone is not sufficient to warrant authorship, but the process of obtaining resources often requires detailed conceptualization of the project. Following a funding decision, the PI is also responsible for recruiting lab members and collaborators to join the project. As a result, the PI is often the corresponding author in a manuscript, and their name is listed last, as the corresponding PI. Finally, the PI is ultimately responsible for ensuring that all authors have agreed to the content of the manuscript before submission of conference abstracts, public preprints, or submission for peer review (14). Unless a project changes substantially after initial conceptualization, it is unlikely that the corresponding author would change during the execution of the project or manuscript writing or revision phases.

NEW AND ONGOING CHALLENGES

The scientific publishing landscape has changed significantly over the past decade, and many aspects continue to evolve. In addition to the recent explosion in the number of peer-reviewed journals, there are now several other avenues to make scientific results available to the public, including preprint servers and repositories. The publication of preprints, code, figures, and data sets is common practice in the biophysics community. Furthermore, the number of authors in a manuscript continues to increase, most likely a result of increased collaborations among labs (15,16). Such complex teams present ongoing challenges when individual portions of a study, such as single data sets, analysis tools, or other resources, are made available. This unbundling then poses additional questions concerning "ownership" of data. Authorship must be evaluated whenever data, results, or tools from a project are publicly available.

Another ongoing challenge is the gender disparities across many areas of science but specifically in publications, where women are underrepresented, particularly in senior author roles, and women receive unequal treatment in the peer-review process and editorial decisions (17). It is also known that women are more likely to be involved in authorship disputes compared with men and are more likely to report receiving less credit than is deserved (18). These are important issues that must be addressed at all levels, and the disparities highlight the important duty of senior researchers to protect and educate junior researchers, promote a culture of ethical authorship, and ensure credit is assigned fairly.

LOOKING TOWARD THE FUTURE

The replacement of traditional print journals with digital-only journals opens exciting possibilities for changing perspectives around authorship. The emerging open-review models mentioned above are among the first important steps in modernizing the publication process, but there are many other prospects that researchers, editors, and publishers should consider. A new model can be envisioned where scientific contributions can be tracked similar to code revisions in a repository, where the individual lines of code are automatically tracked and tagged. It may be possible to track and report author contributions at a granular level, for example, by indicating the specific authors responsible for making specific figures, writing, or editing certain sections. While a manuscript is more than a collection of figures and text, authors should receive credit for their specific contributions. In the case of collaboration, it may be possible to estimate

the level of resources each lab contributed toward the project (funding resources used in the project, computing resources, etc.), particularly when public funds are used. Finally, the current sequential list of authors is outdated and conveys very little information about the extent of each contribution (11). One can envision, for example, the development of multidimensional metrics to quantitatively delineate the specific contribution of each author, and fractional authorship could be attributed to all authors according to those metrics.

Overall, these innovations present new opportunities to adapt the assignment of credit to individuals, and journals should play a leading role in accelerating these changes. Granular tagging and tracking, combined with open science and data-sharing policies, should provide increased transparency and accountability for all researchers involved in a project. In addition, there is a clear need for up-to-date training and education in the biophysics community, particularly for junior scientists, through workshops and seminars, and overall publication best practices should be regularly discussed among researchers.

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The author declares no competing interests.

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