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Commonalities and differences in the research contributions of authors and subauthors

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Abstract

Purpose – The purpose of this paper is to identify the research contributions of authors and subauthors in order to outline how authorship, as opposed to acknowledgment, is awarded in the lab-based life sciences.
Design/methodology/approach – The work tasks described in author contribution statements and acknowledgments sections of research articles published in *Nature Chemical Biology* were classified according to a three-layered taxonomy: core layer; middle layer; outer layer.
Findings – Most authors are core or middle layer contributors, i.e. they perform at least one core or middle layer task. In contrast, most subauthors are outer layer contributors. While authors tend to be involved in several tasks, subauthors tend to make single contributions. The small but significant share of authors performing only outer layer tasks suggests a disconnect in author attribution between traditional author guidelines and scientific practice. A level of arbitrariness in whether a contributor is awarded authorship or subauthorship status is reported. However, this does not implicate first or last authorships.
Research limitations/implications – Data from one journal only are used. Transferability is limited to research in high impact journals in the lab-based life sciences.
Originality/value – The growth in scientific collaboration underlines the importance of gaining a deeper understanding of the distinction between authorship and subauthorship in terms of the types of research contributions that they de facto represent. By utilizing hitherto unexplored data sources this study addresses a gap in the literature, and gives an important insight into the reward system of science.

Keywords Authorship, Collaboration, Bibliometrics, Contributorship, Acknowledgements, Subauthorship

Paper type Research paper

Introduction

Authorship is widely considered to be the currency of academia (Cronin, 2001). It is a vehicle for attributing credit and epistemological responsibility for published truth claims in science (Biagioli, 2003), as well as the basis for establishing priority and receiving peer recognition (Merton, 1973). The importance of authorship in the academic reward system is evident in the nature of the performance metrics used in hiring and promotion (Abbott *et al.*, 2010; van Arensbergen, 2014), which is in turn reflected in pressure on scholars and scientists to "publish or perish" (Müller, 2012; van Dalen and Henkens, 2012).

Co-authorship is often taken as a proxy for some form of collaboration (e.g. Melin and Persson, 1996); the appearance of several names in the byline of a document may be taken as evidence of a collaborative project. Some scholars (Laudel, 2002; Patel, 1973; Paul-Hus *et al.*, 2017) have also suggested that collaborative activity is not only indicated by multiple entries in the bylines, but by the acknowledgments section. In a paper from 1995, Cronin and Weaver (1995, p. 172) argue that acknowledgments can be envisioned as the silent and unmeasured third part of a "reward triangle" – sitting between citations (as a measure of impact) and authorships (as a measure of productivity) – and may therefore be regarded as registering a form of "subauthorship" (Patel, 1973). Subauthors named

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in acknowledgments are individuals or organizations providing assistance to the research performed but who or which, for various reasons, are not awarded a place in the author bylines.

In most fields of science the average number of co-authored publications, together with the average number of authors per publication, has increased significantly over the years (Larivière *et al.*, 2015; Wuchty *et al.*, 2007). A similar, though not as dramatic, increasing trend goes for entities registered in the acknowledgments section (Cronin *et al.*, 2004; Cronin and Franks, 2006). The growing emphasis on collaborations and research teams in science (Larivière *et al.*, 2015; Wuchty *et al.*, 2007) has led to discussions regarding what really constitutes a scientific author. Where there are two or three names in the bylines it is highly believable that those individuals authored the publication together, but can the same thing be said when there are 10 or 20 authors? And how should questions regarding responsibility, authority, credit and accountability be judged? When the number of authors is even more extreme, rising to hundreds or even thousands on a single paper, the "early modern conception of authorship, with its privileging of originality, expressivity, and individual genius," seems outdated (Cronin and Franks, 2006, p. 1909). Such extreme examples, coined as "hyperauthorship" (Cronin, 2001, p. 558), together with a perceived increase in ghost and gift authorship, has prompted certain sections of the scientific community to propose alternatives to the standard model of authorship.

In biomedicine an alternative concept – contributorship – has been put forward by Rennie and colleagues (1997). Recognizing that writing is only one part of the modern scientific endeavor, the proposal "requires disclosure to readers of the contributions made to the research and to the manuscript by the contributors, so that they can accept both credit and responsibility" (Rennie *et al.*, 1997, p. 579). Such a "contributorship policy," where each author's contribution is listed, is also strongly encouraged by the International Committee of Medical Journal Editors (ICMJE) (2016). However, the model proposed by Rennie and colleagues (1997, p. 579) goes further than just exchanging authorship with contributorship; it aims to make a radical break from the "artificial" division of authorship and acknowledgments by replacing them both, hereby putting an end to the state of "confusion regarding the criteria for awarding authorship as opposed to acknowledging colleagues" (Cronin, 2001, p. 565).

A number of previous studies (e.g. Cronin *et al.*, 2004; Cronin and Franks, 2006; Paul-Hus *et al.*, 2017) have used facets of the scholarly article's paratext, mainly the acknowledgment section and the bylines, to explore the collaborative nature of science. Other paratextual elements have not been utilized to the same extent. The fact that the specific work tasks of co-authors are traceable through the author contributions statements provided by some journals, has not as yet been the focus of systematic study in the bibliometric community – the only identified studies being Danell (2014), Yang *et al.* (2017) and Larivière *et al.* (2016). This is to be expected, as the provision of these statements is a rather new phenomenon, at least outside the field of biomedicine. They also require some additional work to harvest and be rendered useful.

Below is an example of an author contribution statement, taken from the data set constructed for this paper, which clearly illustrates the potential it holds for studying the division of labor in collaborative research projects:

> H.B.B. conceived the work, W.L. and T.A. designed and performed the myxobacterial sporulation assay, and W.L. designed and performed all of the other experiments. Molecular modeling and ligand docking experiments were performed by K.A.J.B. H.B.B. and W.L. wrote the paper.

The author contribution statements do not, of course, give the whole picture regarding what went on in the lab. Rather, they provide short and concise descriptions of the most important work tasks performed by the authors in order to produce the paper. Thus, such statements can be studied on a higher level of aggregation, as exemplified by Larivière *et al.* (2016), and the results may serve as an important complement to lab-based ethnographic research (e.g. Knorr-Cetina, 1999; Müller, 2012) and survey studies of authorship decision (e.g. Seeman and House, 2010). In addition, the collection and analysis of author contribution statements is unobtrusive and can help redress biases associated with research based on interviews or questionnaires (Lee, 2000).

The current paper is one of the first to combine data from the author contributions statement and the acknowledgment section of research articles (the only other study is Yank and Rennie, 1999), to explore the research contributions of authors and subauthors. In doing so it aims to outline how authorship, as opposed to acknowledgment, is awarded in the lab-based life sciences, and provides a more nuanced understanding of the production of scientific knowledge and texts in highly specialized and collaborative fields. The study also addresses a clear gap in the literature.

As the attribution of authorship and acknowledgment, and the dividing line between them, as well as practices surrounding collaboration, vary significantly between academic fields, this paper focuses on chemical biology, a sub-area of the life sciences. This choice is motivated by the fact that life science: has provided, especially in the sub-area of medical biology, an arena for extensive discussion and re-evaluation of the meaning, responsibility and attribution of authorship (e.g. Davidoff, 2000; Flanagin *et al.*, 1998); to a higher degree than most fields provides author contribution statements as part of each research paper, specifying the contributions of each individual author; has an established, albeit not formalized, practice of recognizing subauthorship (Cronin and Franks, 2006); is an inherently collaborative field going by the extent of co-authorship and acknowledgments, thus providing ample amounts of data for analysis (Cronin and Franks, 2006).

Data and method

The journal *Nature Chemical Biology* was chosen to represent the area of chemical biology, and in a broader way the lab-based life sciences. It is considered one of the top journals in its field. The data set was constructed by downloading the full bibliographic records of all original research papers (Articles and Brief Communications) published in the journal during the years 2013 and 2014 from Web of Science. Using the digital object identifiers present in the records, the author contribution statements and acknowledgments sections of the papers were retrieved from the full text html-files found at the journal's home page. After excluding three papers due to errors, 225 papers – all co-authored – were left for further analysis.

Constructing the contributorship-task database

Each author contribution statement and acknowledgment was manually scanned for descriptions of contributors performing specific work tasks (e.g. performing biochemical analyses, providing chemicals, etc.). For each task performed by a contributor an entry was created in a contributor-task database linking that contributor to that task. If several contributors performed the task an entry was created for each of them.

Classification of tasks in the contributorship-task database

Tasks in the database were initially classified using the same three-layered taxonomy as the one used by Danell (2014), which in turn is a modified version of a taxonomy originally developed by Davenport and Cronin (2001). New headings in the taxonomy were created when needed (i.e. when there were enough tasks of a type not readily captured by existing categories). The classification procedure suggested in Baerlocher *et al.* (2007) was followed: classification; pilot-testing; subject expert review; modification; and re-classification.

Thus, after going through all tasks and classifying them, a preliminary analysis was made. Following discussions with a chemical biologist, some modifications (see below) were made to the taxonomy and the new headings as well as the way certain tasks were classified. The data were then re-classified, using the taxonomy in Table I, and were then used for the analysis presented in this paper.

Taken together the core and middle layers broadly overlap with the contributions defined in the first and second criteria of the ICMJE authorship recommendations:

> Authorship credit should be based on 1) substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; 2) drafting the article or revising it critically for important intellectual content (ICMJE, 2008).

Contributions that fall into the outer layer are not covered by either of these criteria. Research leadership is typically associated with having responsibility for conception or design, or drafting the article (Danell, 2014). This underlies the division of contributions listed in the criteria, into a core layer and a middle layer. Although slightly rephrased,

Type of task	Example text from the ACS and/or AS of articles in *Nature Chemical Biology*
Core layer task	
Conception and design	"Designed the biological experiments" (ACS)
Drafting article	"Wrote the manuscript with input from all of the authors" (ACS)
Middle layer task	
Assisting in the design of the study[a]	"Contributed to study design" (ACS)
Assisting in drafting article[a]	"Contributed to editing the manuscript" (ACS)/"for critical review and manuscript editing" (AS)
Collecting data[b]	"Collected (XAS data)" (ACS)/"for XAS data collection" (AS)
Conducting experiments	"Performed enzyme activity assays" (ACS)/"for performing MV4-11 proliferation assays" (AS)
Data analysis	"Analyzed cellular growth assays" (ACS)/"analysis of the ASC speck assays" (AS)
Outer layer task	
Advice, expertise or discussion	"Discussion of the chemical work" (ACS)/"for discussion of the reaction mechanism" (AS)
Financial support	"Funded part of the research" (ACS)/"funded the 800- and 600-MHz NMR spectrometers" (AS)
Supervision	"Supervised the collection and analysis of CD spectra" (ACS)
Technical assistance	"Provided technical help" (ACS)/"for technical help" (AS)
Creating specimens/samples[a]	"Generated mutant receptors and cell lines" (ACS)/"generated GFP-CLIP-115 plasmid" (AS)
Reviewing/proofing manuscript	"Reviewed the manuscript" (ACS)/"for reviewing the manuscript" (AS)
Other[a]	–
Programming	"Wrote scripts for automated photoswitching and imaging" (ACS)/"for aid with […] Perl scripts that were used for array data extraction" (AS)
Organizational support	"For access to X-ray apparatus" (AS)
Project management[b]	"Managed the overall project" (ACS)
Providing equipment/software	"Provided the protocol for Mdm2 expression and purification" (ACS)/"for providing protocols" (AS)
Providing specimens/samples[a]	"Provided plasmids and cell lines" (ACS)/"for providing plasmids and bacterial strains" (AS)

Notes: The example text from the ACS and/or AS is taken from the analyzed data set. [a]Type of task not found in the taxonomy used by Danell (2014); [b]type of task found in another layer in the taxonomy used by Danell (2014)

Table I.
A three-tiered taxonomy for classification of tasks found in the author contribution statement (ACS) or acknowledgment section (AS)

the two sets of criteria cited above can also be found in the most updated version of the authorship recommendations (ICMJE, 2016).

Adjustments to Danell's taxonomy are clearly marked in Table I. The resulting three-layered taxonomy is a better reflection of the ICMJE author recommendations as cited above, and matches up to the subject expert review. For example, two additional tasks were added to the middle layer, namely: "Assisting in the design of the study"; and "Assisting in drafting article." These headings described tasks of the same kind as the two core layer tasks but indicated a lower level of involvement (meaning that the contributor took a more partial, assisting role, as opposed to being the main responsible for this kind of task). The outer layer task "Created and/or provided samples" used by Danell (2014) was split into two tasks, namely: "Creating samples/specimens" and "Providing samples/specimens." This was also done with regard to creating and providing equipment. The heading of "Other" was added, grouping various contributions that occurred only sporadically in the data (nine times or less).

The reliability and reproducibility of the taxonomy used for the final classification was tested by enlisting a second person who was tasked with classifying a portion of the data independently. The portion was selected by way of disproportional stratified random sampling (10 of each heading) that was then structured in a random order. The intercoder reliability rate was 91.6 percent, which is comparable to the number reported by Cronin *et al.* (2004). There were some patterns in the errors. Over half of the errors involved outer layer contributions being classified as other types of outer layer contributions. This indicates that the proportions of core, middle and outer layer contributors reported in the current paper are quite robust as they are not influenced by such errors. Tasks classified as "Provided equipment/software" by the author were sometimes classified as "Organizational support" by the second person (and vice versa). Such errors indicate that the classification of these types of contributions is less reliable than those of other contribution types.

Constructing the contributorship database

From the entries in the contributorship-task database a contributorship database was created where each contributor was represented by only one entry per paper and classified hierarchically according to a three-step procedure: First, for each paper, all contributors performing at least one core layer task were classified as core layer contributors; second, for each paper, all contributors performing at least one middle layer task, but no core layer tasks, were classified as middle layer contributors; third, for each paper, all contributors not performing any core or middle layer tasks were classified as outer layer contributors. The results of this classification process together with subsequent analysis are presented and discussed in the following sections.

Definition of terms

In this paper the term contributor is used for individuals and organizations registered in either the author contribution statements or the acknowledgments section. The terms author and authorship are used interchangeably for readability, and so are also subauthor and subauthorship, and contributor and contributorship. However, what is really measured is authorship, subauthorship and contributorship. To be specific, if one contributor performs tasks on several papers he or she is represented by several items in the contributorship database.

Results

A total of 8,520 tasks, 5,796 performed by authors and 2,724 performed by subauthors, were classified. Table II gives specific details regarding the number of core, middle and outer

Table II. Number of contributors performing a type of task: divided into authors and subauthors and further subdivided into core, middle and outer layer authors/subauthors

	Authors			Subauthors		
Type of task	Core layer	Middle layer	Outer layer	Core layer	Middle layer	Outer layer
Core layer task	*941 (100.0%)*	*0 (0.0%)*	*0 (0.0%)*	*0 (0.0%)*	*0 (0.0%)*	*0 (0.0%)*
Conception and design	749 (79.6%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Drafting article	616 (65.5%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Middle layer task	*739 (78.5%)*	*956 (100.0%)*	*0 (0.0%)*	0 (0.0%)	*101 (100.0%)*	*0 (0.0%)*
Assisting in the design of the study	15 (1.6%)	39 (4.1%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Assisting in drafting the article	192 (20.4%)	209 (21.9%)	0 (0.0%)	0 (0.0%)	13 (12.9%)	0 (0.0%)
Collecting data	16 (1.7%)	33 (3.5%)	0 (0.0%)	0 (0.0%)	36 (35.6%)	0 (0.0%)
Conducting experiments	456 (48.5%)	688 (72.0%)	0 (0.0%)	0 (0.0%)	37 (36.6%)	0 (0.0%)
Data analysis	501 (53.2%)	341 (35.7%)	0 (0.0%)	0 (0.0%)	15 (14.9%)	0 (0.0%)
Outer layer task	*442 (47.0%)*	*350 (36.6%)*	*266 (100.0%)*	*0 (0.0%)*	*7 (7.7%)*	*2,116 (100.0%)*
Advice, expertise or discussion	116 (12.3%)	91 (9.5%)	55 (20.7%)	0 (0.0%)	3 (3.0%)	413 (19.5%)
Financial support	2 (0.2%)	5 (0.5%)	2 (0.8%)	0 (0.0%)	0 (0.0%)	948 (44.8%)
Supervision	89 (9.5%)	13 (1.4%)	32 (12.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Technical assistance	15 (1.6%)	36 (3.8%)	62 (23.3%)	0 (0.0%)	3 (3.0%)	318 (15.0%)
Creating specimens/samples	115 (12.2%)	120 (12.6%)	98 (36.8%)	0 (0.0%)	0 (0.0%)	13 (0.6%)
Reviewing/proofing manuscript	108 (11.5%)	124 (13.0%)	40 (15.0%)	0 (0.0%)	0 (0.0%)	106 (5.0%)
Other	22 (2.3%)	8 (0.8%)	5 (1.9%)	0 (0.0%)	0 (0.0%)	106 (5.0%)
Programming	6 (0.6%)	4 (0.4%)	8 (3.0%)	0 (0.0%)	1 (1.0%)	4 (0.2%)
Organizational support	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	37 (1.7%)
Project management	62 (6.6%)	6 (0.6%)	10 (3.8%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Providing equipment/software	0 (0.0%)	10 (1.0%)	1 (0.4%)	0 (0.0%)	0 (0.0%)	16 (0.8%)
Providing specimens/samples	16 (1.7%)	35 (3.7%)	43 (16.2%)	0 (0.0%)	4 (4.0%)	277 (13.1%)

Notes: The percentages are calculated as the share of contributors (authors or subauthors) assigned to a certain layer (core, middle, or outer) performing a certain task or type of task. The denominator used for each column is the one marked as 100.0 percent. For example: 53.2 percent of the 941 core authors perform data analysis; the sum of contributors exceeds the actual total because many contributors perform more than one task. The percentages therefore sum up to over 100 percent

layer contributors – divided into authors and subauthors – performing a specific task or task type. As alluded to in the title of this paper (inspired by Cronin, 2005), the diversity of tasks in the table is an indication of the many hands involved in research, especially in the life sciences, in order to progress from a working hypothesis or idea to a finished manuscript published in a scientific journal. These hands – conceiving and designing the project, conducting the experiments, analyzing data, supervising, providing or creating reagents and equipment - are in the present analysis either recognized by authorship, as authors in the bylines, or by subauthorship, as entities mentioned in the acknowledgment section.

Table III provides a comparison of authors and subauthors with regard to the numbers of core, middle and outer layer contributors as well as the mean number of tasks performed.

As shown in Table III there are no subauthors classified as core layer contributors. This means that no one in the acknowledgment sections analyzed for this paper designed the research or drafted the article. Involvement in such tasks are, however, quite common for authors as we see from the number of core layer authors. While most authors are core or middle layer contributors, most subauthors are outer layer contributors. Authors tend to be involved in several tasks, subauthors often only make single contributions. There is a significant difference between core, middle, and outer layer authors in terms of the mean number of tasks performed. Core layer authors perform most, on average almost twice as many as middle layer authors, and more than double the tasks performed by the average outer layer author.

Figure 1 visualizes the mean number of tasks per contributor and the mean number of contributors per publication, plotted against the size of the author team.

Table III. Number of contributors and mean number of tasks performed by contributor layer

Contributor type	Core layer	Middle layer	Outer layer	All layers
	Contributor layer			
Number of contributors (%)				
Authors	941 (100.0%)	956 (90.4%)	266 (11.2%)	2,163 (49.4%)
Subauthors	0 (0.0%)	101 (9.6%)	2,116 (89.8%)	2,217 (50.6%)
All contributors	941 (100.0%)	1,057 (100.0%)	2,382 (100.0%)	4,380 (100.0%)
Mean number of tasks performed				
Authors	3.7	2.0	1.4	2.7
Subauthors	0	1.1	1.2	1.2
All contributors	3.7	1.9	1.3	1.9

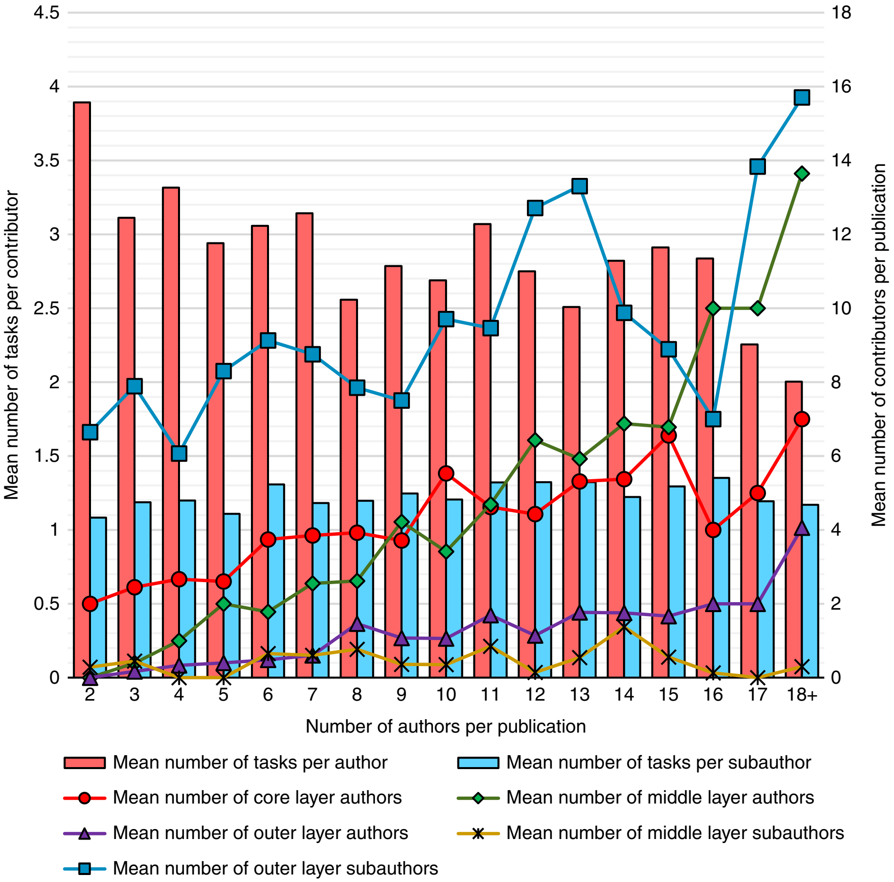

Figure 1. The mean number of tasks per contributor and the mean number of contributors per publication by size of author team

As seen in the figure, middle layer authors and outer layer authors are only present on publications with an author team of three or greater. As the author team increases in size the increase in outer layer authors is quite small compared to the increase in core layer authors and, especially, the increase in middle layer authors. As a matter of fact, when the author team is 11 the mean number of middle layer authors per publication has clearly surpassed the mean number of core authors per publication. The increase in the size of the author team after this can largely be attributed to an increase of middle layer authors, a result that is in line with Danell (2014). Outer layer authors are more commonly detected in larger author teams, explaining the dramatic increase in outer layer authors in publications with 18+ authors. The mean number of outer layer subauthors fluctuates, but a slight general increase with the author size can be observed. This pattern remains even when non-human entities are removed from the acknowledgment data, indicating that the conclusion made by Paul-Hus *et al.* (2017, p. 85) that "as more contributors get credited as authors on collaborative papers, less get acknowledged" does not apply to articles found in *Nature Chemical Biology*. However, the proportion of authors to subauthors increases as the author team increases; for a publication with two authors the authors make up only 22.4 percent of the total number of contributors, while the same number for an author team size larger than 17 is 60.7 percent.

While the mean number of tasks per subauthor in Figure 1 is rather stable through all sizes of the author team, the same cannot be said for authors. Instead a steady decrease is seen; from a mean number of 3.9 tasks per author for publications with 2 authors to 2.0 for publications with 18+ authors. This decrease can be explained by the influx of middle and outer layer authors as the author team increases in size; these authors tend to focus on one or two tasks, as opposed to core layer authors who typically contribute to several tasks. This suggests a clearer division of labor as the number of authors per publication increase.

The following two subsections, the first focusing on authorship and the second on subauthorship, will explore Tables II and III more and elaborate further on the tasks performed by these contributors.

Authorship

There are 2,163 authorships in total of which 941 (43.5 percent) belong to the core layer, 956 (44.2 percent) belong to the middle layer and 266 (12.3 percent) belong to the outer layer.

The main tasks performed by authors in the core layer are those of the typical research leader: conceiving and designing the main parts of the project and experiments, and/or writing the majority or specific sections of the manuscript. The first of these tasks is quite often performed by several members of the research team, where each member is individually responsible for conceiving or designing specific parts of the research and/or experiments. Combining the core tasks of conception and writing is quite common in the core author collective - around half of them are involved in both. About a third of the core authors only perform core tasks related to conception and design, while a fifth are classified as core authors due to performing writing-related core tasks only. Being part of the core author collective does not mean limiting oneself to only performing core tasks – on the contrary, 90.6 percent of the core layer authorships perform at least one or more middle or outer layer tasks. Table II points to the following as specifically important here: data analysis (53.2 percent of the core layer group also performs this task); conducting experiments (48.5 percent); assisting in drafting the article (20.4 percent); providing advice, expertise or discussion (12.3 percent); creating samples or specimens (12.2 percent); reviewing/proofing manuscript (11.5 percent); and supervision (9.5 percent).

In contrast to the core layer, the work done by middle layer authors is more focused on tasks belonging to their layer; around a third of these authors perform one or more outer layer task. Save for the tasks of reviewing/proofing the manuscript (13.0 percent of the middle layer authors perform this task, see Table II), creating samples or specimens (12.6 percent), and providing advice, expertise or discussion (9.5 percent), no outer layer tasks are performed by middle layer authors to any large extent (meaning being performed by over 5.0 percent of authors classified as such). A majority (72.0 percent) of the middle layer authors takes part in the experimental work, and many perform analytical work (35.7 percent). In comparison to the brief and general descriptions of core tasks found in the author contributions statements, these tasks are described in greater detail. Thus a variety of experiments – proteomic, biochemical, structure related, cell based, *in vivo*, immunological – together with experimental and analytical techniques or methods – various assays, liquid chromatography, mass spectrometry, western blotting, x-ray crystallography – are documented. Not seldom do author contribution statements report combinations of these aspects – for example, *in vivo* and cell-based experiments. It is also quite common that the statements evidence a division of experimental work of different types between researchers or groups of researchers – for example, one group performing the crystallography experiments and another group performing the biochemical experiments. This indicates that there are complexities involved in the research that require a multitude of experimental expertise commonly not found in one or two individuals.

The authorships found in the outer layer do, by definition, only perform outer layer tasks. Among these tasks, the most common is creating specimens/samples (36.8 percent of the outer layer group perform this task, see Table II). The contribution statements, being quite specific in these cases, make it possible to identify a variety of important ingredients used in the experimental work. The creation and provision of such ingredients – reagents (substances used in order to bring about a chemical reaction) of different kinds, antibodies, extracts from various sources, proteins (often in purified form) – would appear to constitute tasks that can be exchanged for authorship status. In about two thirds of the cases where outer layer authors provide or create specimens/samples, this is the only task they carry out. Other tasks performed by authors belonging to the outer layer are: providing technical assistance (23.3 percent of the outer layer group perform this task, see Table II); providing advice, expertise or discussion (20.7 percent); providing specimens/sample (16.2 percent) reviewing/proofing manuscript (15.0 percent); and supervising the work of co-authors (12.0 percent). The overlap between creating and providing samples/specimens and other tasks is very small in the outer layer author group. This indicates that in cases where the author creating or providing samples or compounds belongs to the outer layer, his or her role would appear somewhat separate from the team responsible for the main experimental work. It should be added, however, that an overwhelming majority (73.6 percent) of the outer layer tasks is performed, not by outer layer authors, but by authors found in the core and middle layer.

The majority of authors (66.4 percent) performing the task of supervising the work of co-authors belong to the core layer. Knowledge and know-how important for supervising others' work is thus most often provided by those involved in designing the research and/or writing the article. 23.9 percent of the authors providing supervision are outer layer authors. In other words, this supervision is provided by authors who are removed from the tasks of designing, analyzing, and/or conducting experiments, indicating an inflow of knowledge from outside the group of key research participants. It is interesting to note that individuals performing supervision are in every observed case awarded with authorship (the task of supervising co-authors does not figure in any of the acknowledgments sections investigated for this paper).

With regards to author position there is a marked difference in contributions between being first or last author and being positioned in the middle (i.e. being positioned anywhere on the byline except for first or last, not to be confused with being classified a middle layer author). As shown in Table IV the authors positioned first or last were in the main classified as core authors while authors in the middle had a more varied characteristic; 30.3 percent

Table IV. Number of authors and mean number of tasks performed according to position

Author layer/type of task	Position of author First	Middle	Last
Number of authors (%)			
Core layer authors	199 (88.4%)	519 (30.3%)	223 (99.1%)
Middle layer authors	26 (11.6%)	928 (54.2%)	2 (0.9%)
Outer layer authors	0 (0.0%)	266 (15.5%)	0 (0.0%)
All authors	225 (100.0%)	1,713 (100.0%)	225 (100.0%)
Mean number of tasks performed			
Core layer tasks	1.6	0.4	1.9
Middle layer tasks	2.4	1.3	0.8
Outer layer tasks	0.7	0.7	0.6
All tasks	4.6	2.3	3.5

were core layer authors, 54.2 percent were middle layer authors and 15.5 percent were classified as contributing only outer layer tasks.

Actually, all authors classified as only contributing with outer layer tasks were positioned in between the first and last author. Last authors were somewhat more likely to design and conceive the research and/or write the article than first authors were. However, the mean number of tasks performed reveals another facet of the contributions of first, last and middle authors. First authors participate in more tasks than any other group, significantly more than last authors and twice as many as middle authors. And while they are somewhat less involved in core tasks than last authors (much more than middle authors though), authors positioned first perform a higher number of middle layer tasks, compared to last and middle authors. The extent of involvement in outer layer tasks is basically the same in all author positions.

The top-ranking contributions for authors positioned first are: conducting experiments (90.7 percent perform this task), drafting article (77.3 percent), conception and design (70.2 percent), and data analysis (64.0 percent). For authors positioned last the same list reads: drafting article (92.0 percent), conception and design (82.2 percent), and data analysis (48.0 percent). Last authors are seldom involved in experimental work – only 11.5 percent of them have listed this task in the author contribution statement – but are much more likely to supervise the work of co-authors (22.2 percent), and handle project management (15.6 percent), than authors listed first or in the middle.

Subauthorship

There are 2,217 sub-authorships in total of which none belong to the core layer, 101 (4.6 percent) belong to the middle layer and 2,116 (95.4 percent) belong to the outer layer.

The few subauthors who are classified as belonging to the middle layer are most often involved in conducting specific experiments (36.6 percent, see Table II) – for example, experiments involving nuclear magnetic resonance (NMR) spectroscopy, toxological experiments, or proliferation assays – or in the acquisition of data (35.6 percent). The acknowledgments describe the tasks relating to data analysis (14.9 percent) and experimental work in quite specific ways, while tasks such as assisting in drafting the article – performed by 12.9 percent of the middle layer subauthors – are described in very general terms.

The majority of tasks performed by acknowledgees are, as stated, to be found in the outer layer. Of the contributors belonging to this layer providing funding (44.8 percent, see Table II) is by far the most frequent task performed. Reading the acknowledgment section of *Nature Chemical Biology* one is bound to witness the important role played by large funding bodies such as the National Institutes of Health and the Department of Energy in order to get access to expensive research infrastructure – such as NMR facilities or the beamlines at various synchrotrons around the world – or receive grants supporting the experiments performed. Of course, the recommendations from the funding agencies to be mentioned in the acknowledgments section of the projects they sponsor are an additional reason for the domination of this task.

After financial support, the three most frequent tasks performed by outer layer subauthors – providing advice, expertise or discussion (19.5 percent), providing technical assistance (15.0 percent), providing specimens/samples (13.1 percent) – all bolster ideas about a culture of trading in the life sciences (Cronin and Franks, 2006). The majority of research articles studied in this paper register contributors providing chemical compounds, reagents, and DNA strains, or special competences, know-how, and knowledge, in exchange for a place in the acknowledgments section.

Discussion

Attribution of first, last, and middle authorship

Researchers in most sciences seem to regard the amount of work put into a paper, rather than an individual's prestige or position, as the basis on which to determine authorship order (Marušić *et al.*, 2011). In the biomedical field, as well as in other natural sciences, first authorship holds the greatest prestige and is bestowed on the individual who makes the greatest contribution. The last author position is often associated with seniority, group leadership, and being the intellectual and financial driving force (Knorr-Cetina, 1999; Laudel, 2001; Müller, 2012).

The results presented in the current paper provide additional support to this understanding of first and last authorship being qualitatively different. First authors are somewhat less likely than last authors to be core contributors but report higher values for the average number of tasks performed. Furthermore, first authors are generally more deeply involved in the different steps of the research process, while last authors focus their efforts on tasks typical for a research leader (i.e. designing the study, writing the manuscript, and to some extent data analysis, and supervision). First authors' presence is especially high, compared to last authors, when it comes to conducting experiments, a task which is often quite time consuming. According to Yank and Rennie (1999), first and last authors are more likely to be involved in study design, manuscript writing and data analysis, and in general perform more tasks than middle authors, an observation that resonates with the data presented here.

Other studies (Louis *et al.*, 2008; Müller, 2012; Wren *et al.*, 2007; Larivière *et al.*, 2016) report a "lost in the middle" effect – i.e. that authors in the middle are perceived as having contributed less – an interpretation that could be brought to bear on the findings presented in this paper. Authors positioned in between the first and last author tend to concentrate their efforts on middle layer and outer layer tasks, and in general participate in fewer tasks on average. The increase in articles reporting "equal contributions" of authors (Hu, 2009) might be taken to reflect contributors' resistance to the "lost in the middle" effect; it may be a way of saying "I contributed more than the usual middle author and do not want to become lost in the middle." Still, according to Müller (2012, p. 21), shared first authorship is met with distrust by postdocs in the life science, as they express doubts concerning "its ability to undermine the traditional reading of authorship conventions."

Unethical attribution practices?

Adding an "undeserving" author to the bylines (so-called gift authorship or honorific or guest authorship) or downgrading a "deserving" author from the bylines to the acknowledgments section, or indeed excluding a "deserving" author altogether (ghost authorship), would naturally result in an incorrect or unjust distribution of recognition, credit and responsibility. Such problematic attribution practices have been documented in many previous studies, especially in biomedicine (e.g. Flanagin *et al.*, 1998; Eisenberg *et al.*, 2011; Marušić *et al.*, 2011). Using survey methodology, these studies uncover a significant proportion of authors not doing enough to warrant inclusion, and bona fide contributors being excluded from a place in the bylines. In a survey of corresponding authors, Flanagin *et al.* (1998) found that 19 percent of co-authored articles in peer-reviewed biomedical journals contained honorific authors; contributors were denied credit in about 11 percent of the co-authored articles, findings confirmed in a follow-up study (Wislar *et al.*, 2011). Can such irregular attribution practices be observed in the articles of *Nature Chemical Biology*? It is difficult to answer this question definitively but the analyzed data give some indication.

All individual authors in the analyzed data had one or more contributions attributed to them, indicating that all authors made at least one contribution worth remembering and recording. Of course, this comes as no surprise as the contributions of all listed authors are required by the journal. However, about 12 percent of the authors in the data set only perform outer layer tasks. This is not strictly speaking gift authorship, as these authors have contributed to the research – for example, by providing or creating reagents or technical assistance – but the nature of their contributions does not meet the ICMJE authorship recommendations. One may assume that at least a fair proportion of these individuals "have not been part of the research team in any normal sense of the word, and therefore cannot be held responsible for the content of the article" (Danell, 2014, p. 129). The percentage of outer layer authors reported here is similar to that in the field of Neuroscience, where Danell (2014) finds that 13.8 percent of the author collective belongs to the outer layer. About five percent of subauthors have contributed to middle layer tasks, and should therefore be considered potential authors according to ICMJE. Further, and as indicated in Table II, there is considerable overlap between the nature of the tasks registered in the author contribution statements and the acknowledgments sections; only five types of tasks are performed only by authors and only one type of task is performed only by subauthors.

The ethical problem hinted at above, could equally mask the failure of formal authorship guidelines to accommodate a growing predominance of team research (Larivière *et al.*, 2015; Wuchty *et al.*, 2007) and its accompanying complex divisions of labor (Larivière *et al.*, 2016). In other words, the results reported in this paper could be interpreted in light of a disconnect between guidelines and scientific practice (e.g. Haeussler and Sauermann, 2013).

The trading culture in life science

That aspects of the trading culture in life science can be uncovered by analyzing acknowledgments is convincingly shown by Cronin and Franks (2006). The present paper lends credence to this idea; the acknowledgments sections bear witness to the many hands of science required to solve a research problem. As detailed in the results section, this multifaceted trading culture depends on a variety of organizations providing funding and infrastructure, and on colleagues around the world lending their expertise, technical assistance and advice, as well as contributing samples and chemical compounds. In return for services rendered, contributors' names and contributions are inscribed in the acknowledgments text – signaling the presence of a gift economy, in which contributions are exchanged for recognition and a "tacit expectation of reciprocation" (Cronin and Franks, 2006, p. 1916). However, the acknowledgees only make up one part of the network of contributors involved in this trading culture.

By utilizing information contained in the author contribution statements, it is possible to extend the mapping of this culture: Whilst outer layer contributors providing valuable resources and knowledge are largely to be found in the acknowledgment section, they also constitute a significant portion of authorships, as indicated by the numbers presented above. Outer layer authors, along with outer layer acknowledgees, provide "epistemic things" and "technical objects" (Rheinberger, 1997) such as reagents and chemical compounds, as well as advice and expertise. As Cronin (2001) suggests, rewarding the provision of a sample with a place in the acknowledgments section or author bylines, could be taken as an expression of reciprocal altruism. This could partly explain the large share of outer layer authors whose only contribution is the creation and provision of samples and compounds. An additional factor might be that the materials provided by authors are more complex and harder to get a hold of than those provided by acknowledgees, although this is hard to verify based on the data. In some cases it is clear that the samples provided by acknowledgees are of minor complexity, different flower seeds, for example, than those that are traded for authorship status; but other services, such as providing genes and RNA, may be rewarded with either an acknowledgment or authorship.

Limitations of the study

The reliability of data from standardized author contribution forms is subject to questioning by Ilakovac *et al.* (2007) due to the problem of recalling past events – a critique that is also applicable to survey studies. Although the nature range do not utilize standardized author contribution forms but instead opt for fully written statements, it is important to recognize that processes of autobiographical memory construction might influence the accuracy of the statements given. However, the free-form format of the statements used to construct the data in the present paper, does not introduce events or promote the recall of "untrue" memories, and thus should not, to the same extent as suggested by Ilakovac *et al.* (2007), be subject to the same bias. A related issue involves the statements being deliberately constructed in ways unfaithful to what really went on in the lab. In an academic world increasingly governed by the maxim "publish or perish" it might be perceived as advantageous to edit the contributions in one's favor, if this were to increase one's publication count. As Nature does not use the contribution statement for determining questions of authorship, there should not be any real motive to list untrue contributions, to any large extent.

This is a study based on one journal in one field, and thus caution is warranted with regards to generalizability. However, the study does allow for transferability, as previous studies report similar results – for example, Danell (2014) in the distribution of core, middle, and outer layer authors, and Larivière *et al.* (2016) regarding the contributions of first, middle, and last authors. Still, the conclusions of this paper should not be extended beyond high impact research in the sub-areas of the lab-oriented life sciences.

Conclusions

The aim of this paper is to explore the research contributions made by authors and acknowledgees in order to outline how authorship, and acknowledgment, is awarded in the lab-oriented life sciences. This was done by classifying and analyzing the author contribution statements and acknowledgments sections of *Nature Chemical Biology*. It is the first study since Yank and Rennie's (1999) investigation of the Lancet to take such an approach, thus addressing a clear gap in the literature.

In summary, of the 2,163 authorships, 941 (43.5 percent) belong to the core layer, 956 (44.2 percent) belong to the middle layer and 266 (12.3 percent) belong to the outer layer. Core authors, while focusing their efforts on designing the research and experiments, are almost always involved in other non-core tasks. The majority of middle layer authors perform experimental work and data analysis, while outer layer authors are most commonly engaged in creating samples, specimens, and chemical compounds. As the author team increases in size a clearer division of labor is reported in the author contribution statements.

Of the 2,217 sub-authorships, none could be attributed to the core layer. Only 101 (4.6 percent) belong to the middle layer and 2,116 (95.4 percent) belong to the outer layer. The acknowledgees in the middle layer mostly perform specific experimental work and data collection. The outer layer is dominated by the organizations funding the experiments and providing research infrastructure. The human contributors in this layer most commonly provide valuable expertise, special technical assistance and samples.

There are some important differences between authorship and subauthorship: first, most authors are core or middle layer contributors while most subauthors are outer layer contributors; second, authors tend to be involved in several tasks, whilst subauthors most often only make single contributions; third, no subauthors make core contributions while this type of contribution is quite common for authors. Although such differences can be identified, the findings of this paper reinforce the conclusions made in Yank and Rennie (1999, p. 667), namely, that the contributions of individuals "exist along a continuum of activities and that researchers may be applying idiosyncratic criteria when they draw a line between the 'authors' and 'acknowledgees' on their teams." For example, outer layer contributors providing compounds and samples, or expertise and advice, may be either registered in the acknowledgments or the author bylines. This suggests a disconnect in author attribution between traditional author guidelines and scientific practice, and highlights the need to extend the use of co-authorship as a proxy for collaboration to also include individuals and organizations mentioned in the acknowledgments section.

The data presented in this paper show that the line between authors and acknowledgees is not clear cut; that there is some level of arbitrariness in the choice between assigning a task authorship or subauthorship status. In cases of authorship, this arbitrariness is most in evidence among middle authors, and does not seem to implicate first or last authors. It is in the middle position that the authors that do not meet the authorship recommendations of the ICMJE (i.e. outer layer authors) can be found, and together they constitute a substantial share (15.5 percent) of this position.

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