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Evolution of number of citations per article in Materials Science: possible causes and effect on the impact factor of journals

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Abstract
An overall rise in the citation parameters used in the metrics of scientific publications (i.e. journal impact factor, *JIF*) has taken place since the last decade of the previous century, coinciding with the electronic distribution of (and access to) scientific literature. This inflation like tendency is herein analyzed in the area of Materials Science and also affects the number of publications. Considering average *JIF* values, its growth is proportional to the number of publications in the area and to its *JIF* value, leading to an inhomogeneous boost that preferentially benefits those journals with high *JIF*. An elevation in the number of publications per year alone cannot explain this behavior but it occurs due to a continuous and widespread increment in the number of citations per article, which only remains limited when restrictions are applied by journals to the maximum number of pages per article. In this work we observe this positive correlation between the increase in the number of references per article and the overall increase in JIF but, in our analysis, a kink point is observed in consistency with the appearance of online databases, particularly those free available in 2004. Online databases along with the widespread of open access publishing option made the research content easily available to the scientific community contributing to an increasing trend (without apparent saturation) in the number of articles used to contextualize the new scientific contributions.

Keywords Citations · Materials Science · Bibliometrics · Web of science database · Journal citation reports

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Introduction

Publication of scientific articles can be considered a final product in the scientific activity. In this sense, they are tangible results easy to be managed and evaluated by the Administration Authorities responsible for the financial support and academic career of researchers. Despite the evident incompleteness in the description of the progress in Science (MacRoberts & MacRoberts, 2018), bibliometric studies based on citation and journal metrics, and developed by Garfield (Garfield, 1955), allow for these comparative analyses. In 1976, the Institute for Scientific Information, ISI, launched Journal Citation Reports (JCR) as a tool to compare and rank the scientific journals. JCR orders the journal by relevance attending to the so-called journal impact factor, *JIF*. The definition of *JIF* for a certain journal in a year y is $JIF(y) = \frac{N_{cites}(y)}{N(y-1)+N(y-2)}$, where $N_{cites}(y)$ corresponds to the number of citations in year y to articles published in the journal in years $y-1$ and $y-2$, whereas $N(z)$ is the number of articles published in year z in that very journal. Thus *JIF* corresponds to the ratio between citations to articles published in the two previous years and the number of articles published in that period. Understanding *JIF* dependencies is of particular interest to both individual researchers and institutions. The influence of *JIF* on the way researchers publish their results has been huge, as it offers a quantitative and friendly usable frame to science founding administrations affecting salary, career promotions, resources distribution and prestige, despite it is not at all free from criticism (Dunleavy, 2022; Gorraiz et al, 2022; Law & Leung, 2020; MacRoberts & MacRoberts, 2018).

For certain article to be cited, its availability and easy distribution to possible users are crucial. This necessity of the scientific community to spread out its research achievements early motivated the development of ArXiv repository (Elizalde, 2021; Ginsparg, 2011). Physicist at CERN contributed to the development of internet and the World Wide Web (although invented in 1989 by the physicist Tim Berners-Lee, World Wide Web Consortium was founded in 1994[1]). This milestone supplied an extraordinarily effective tool that changed for good humankind thinking with respect to immediate access to information.

The reaction of ISI to the birth of internet was the development of Web of Science (WoS) platform in 1997, nowadays collecting information from different databases dating back to 1900. Since the appearance of WoS, databases consulting was easily available to every researcher with a computer and internet access, which did revolutionize the literature research and checking for scientist. Other competitors appear later on, Scopus and Google Scholar, both in 2004 (Cantu-Ortiz, 2018). The former, developed by Elsevier, included an innovative link to the full text of the article, speeding up the literature checking. This was later adopted by WoS (which recently, since 2021, included links to the authors' preprint "first online"). Scopus database and metrics (Citescore launched in 2016 and freely available (Fang, 2021)) have acquired enough relevance in academy to be competitive relative to WoS and considered for evaluation of the research. Both WoS and Scopus are available under subscription unlike the third academic search engine, Google Scholar, which is free.

[1] https://webfoundation.org/about/vision/history-of-the-web/ (access 24/03/2023).

Finally, open access publications, explicitly required by public funding in new calls (e.g. Horizon Europe[2]), contribute to the availability of research documents to a much broader scientific community (Ghane et al, 2020). These free accessible articles can be found in fully open access journals and, as a suitable option for the author, in an increasing number of conventional journals regularly distributed under subscription. Recent studies (Dorta-González et al, 2020) do not find any deleterious effect on the open access articles, comparing the uncited articles whether they were open access or available under payment, except for the extreme quartiles, for which freely accesible articles are less (Q1) and more (Q4) uncited that those articles available under subscription in the same quartile. Gray (Gray, 2020) discusses the effect of article processing charges (APC) on generating inequalities between different countries depending on their wealth. In this sense, free repositories from public institutions (e.g. idus.us.es from University of Sevilla) are now promoted by public research investors.[3] Finally, altmetrics (interest from social media) correlations with open access and no-open access journals has also received some interest in recent works (Bray & Major, 2022; Vadhera et al, 2022; Wang, 2022).

Garfield already identified the importance of the average number of references to define the citation potential of a category (Garfield, 1979) and several studies proposed normalized factors such as the audience factor (Zitt & Small, 2008), the source normalized impact per paper (Moed, 2010) and the reference return ratio (Nicolaisen & Frandsen, 2008; Yuret, 2018).

However, despite several works have analyzed the effect of number of references per article in the number of citations received and the corresponding *JIF*, conclusions are not really clear and disagreement can be found between them. Among those reporting a positive correlation between larger number of references and higher *JIF*, Haslan and Koval (2010) found it for Social and Personality Psychology articles published in 1998. This correlation was also observed for Nanoscience and Nanotechnology journals (Didegah & Thelwall, 2013a) and for Biology and Biochemistry, Chemistry and Social Sciences ones (Didegah & Thelwall, 2013b). Finally, and more recently, Zhou et al. (2020) used Montecarlo simulations to support this interpretation. Mammola et al. (2022) recently reported several factors affecting citation, including the number of references.

However, several papers found that other parameters are more determinant than the number of references. Dorta-González and Dorta-González (2013) reported that the number of references per paper does not explain the differences between impact factors among categories. Falagas et al. (2013) analyzed citations in general medicine journals but unlike number of references, article length and number of authors were used to predict, independently, the number of citations. Patience et al. (2017) studying the 500 articles with more citations in different categories found more relevant the age of the references than their number with a higher number of citations for those articles that cite recent research. Finally, no conclusive results are reported in a recent work on Biomedical research (Urlings et al., 2021) concerning the number of references as determinant for citation bias.

The aim of this work is to show the coincidence between the overall increase in impact factor and the appearance of online databases and open access publications that allow the scientific community to easily and quickly access to scientific content to contextualize the new scientific contributions. This is shown for the JCR category of Materials Science, Multidisciplinary and particularly for several journals of the category. We compare

[2] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en (Access 25/04/2023).
[3] https://ec.europa.eu/info/research-and-innovation/strategy/strategy-2020-2024/our-digital-future/open-science/open-access_en (Access 25/04/2023).

the evolution of regular articles and letters and proceeding contributions, the latter being limited in maximum number of pages, which indirectly limits the number of references per article. Both types of articles, independently whether they are limited in the number of pages or not, seem to be benefited from the overall increase in the number of references per article in the category.

Databases used

Herein Journals Citation Reports (JCR) and Web of Science (WoS) resources from Clarivate have been used to obtain the data concerning the category Materials Science, Multidisciplinary (category Materials before year 2000). Results have been limited to Science Citation Index Expanded (SCIE) and final date of searching 01/28/2022 (unless explicitly indicated). Concerning the analysis of the number of references per journal, we have excluded review articles as well as corrections, retractions, and editorials. This analysis has been limited to publications defined as articles but it also includes articles from proceedings. Five different journals have been taken as examples for a more detailed analysis.

Overall analysis of the Category Materials Science, Multidisciplinary

Time evolution of the Category Materials Science, Multidisciplinary

From JCR database, the category of Materials Science, Multidisciplinary (in the following MSM) appears in 2000. However, using WoS database, it is possible to perform a search for "*Materials Science, Multidisciplinary (Web of Science Categories)*", limited to SCIE, which returns results since 1900. WoS selection of journals has evolved with time. From 1900 up to 1944 a single journal is found in MSM: *Philosophical Magazine* (Taylor & Francis), which is still active. Table 1 collects the publishers with highest production in the category along with their respective country and the first year they appear in WoS (MSM search). Possible bias in WoS has been claimed favoring English language journals (MacRoberts & MacRoberts, 2018) and its effects are recently analyzed in Social Science Citation Index data base (Vanderstraeten & Vandermoere, 2021).

Figure 1a shows the evolution in the number of journals in MSM category (taking into account that the values before 2000 correspond to "*Number of Publication Titles*" as ascribed by WoS to this category). Figure 1a also shows the number of articles per journal and Fig. 1b shows the number of articles per year in MSM category along with the percentage of the number of open access articles. Globally, from over $2.28{\cdot}10^6$ articles collected in MSM (search in WoS June, 16th 2023), about 20% ($0.45{\cdot}10^6$ articles) are open access.

A first rise in the number of journals in the category is observed after 1960 when the journals in MSM exceeded 10 and the articles published per year rapidly increased, coincidentally, one order of magnitude. However, since the 90's, contemporary to the development of internet (Zhang, 1998), an exponential rise is continuing up to date in both the number of articles and the number of journals assigned to the category. Since 1990, the number of articles per journal in a year has also steadily increased, being nowadays roughly fivefold the value before 1980. This increment is statistically meaningful and must be linked to the increase of scientific demand for publication space, which exceeds the

Table 1 Production collected in SCIE of the main publishers contributing to MSM category (without restrictions; date of search 06/16/2023)

Publisher	Production (Nr. Items)	% MSM	1st year in WoS	Country
Elsevier	819,615	31.67	1952	The Netherlands
American Chemical Society	271,730	10.50	1985	USA
American Physical Society	210,665	8.14	1964	USA
Springer Nature	197,928	7.65	1966	Germany
Wiley	149,948	5.79	1970	USA
Taylor & Francis	133,595	5.16	1900	UK
MDPI	132,190	5.10	2008	Switzerland
Royal Society Chemistry	107,242	4.14	1990	UK
IOP Publishing Ltd	65,687	2.54	1986	UK
American Scientific Publishers	30,857	1.19	2001	USA
Trans Tech Publication	18,571	0.72	1989	Switzerland
Northwest Institute for Nonferrous Metal Research (NIN)	16,703	0.65	1997	China
Minerals Metals Materials Society (TMS)	16,552	0.64	1974	USA
Akademie Verlag Gmbh	14,756	0.57	1972**	Germany
Cambridge University Press	14,650	0.57	1986	UK
IEEE	13,192	0.51	1970	USA
Kluwer Academic Publishers	13,043	0.50	1969*	The Netherlands
American Institute of Physics	12,445	0.48	1994	USA
Maik Nauka/Interperiodica	11,703	0.45	1976***	Russia
Sage	11,595	0.45	1967	USA
Hindawi Publishing Group	11,040	0.43	2006	United Kingdom

* Last year 2004; ** Last year 1997; *** Last year 2006

offer from increasing the number of journals. Moreover, the availability of such space was offered by less limited electronic journals (e.g. Interpersonal Computing and Technology Journal in 1993 (Collins & Berge, 1994). Nowadays, almost every journal has electronic version. These versions rapidly overcame the distribution of printed versions (Trajkovski, 2018).

Electronic journals available in Materials Science, Multidisciplinary

Concerning the subject category of interest in this work, MSM, among the 414 journals listed in 2021 JCR, only 14 (3.4%) do not have an e-ISSN but only two of them do not directly have a link in their web page to full content (*SAMPE journal* and *Journal of Materials Education*, both in Q4). On the other hand, 49 journals (11.8%) only have an e-ISSN. Among these journals, 27 are still in the Emerging Source Citation Index (ESCI) and do not have a *JIF*. That database appeared in 2015 to account for the rapidly emerging academia journals and collects the journals that meet the 24 quality criteria of WoS but not the 4 other impact criteria that would allow the journal to be included in Science Citation Index Expanded (SCIE) (Huang et al, 2017; Filipo & Gorraiz, 2020). However, these journals have the new Journal Citation Indicator (*JCI*) which is the normalized impact factor

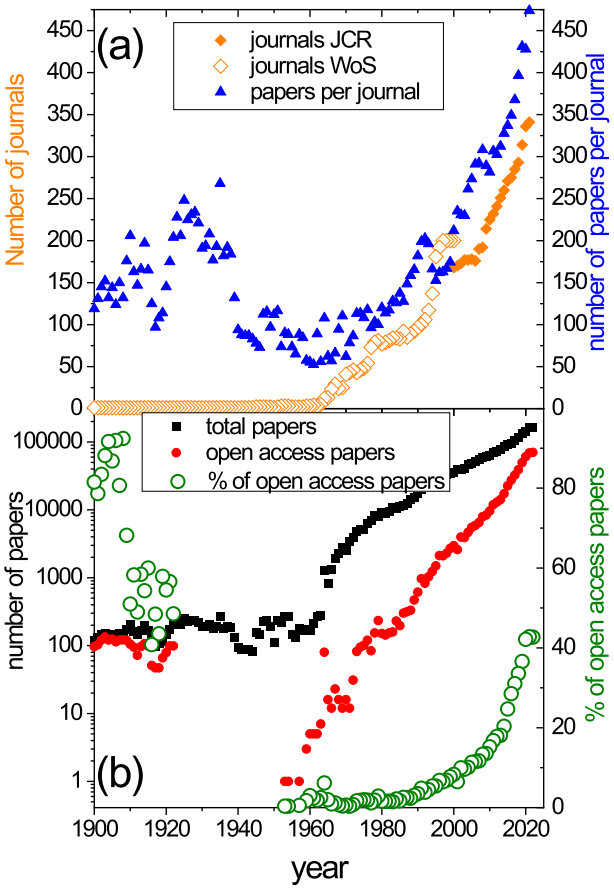

Fig. 1 **a** left axis: Number of journals in "Materials Science, Multidisciplinary" category as a function of the year of publication. Solid symbols correspond to data from JCR (starting in 2000). Hollow symbols correspond to data from WoS (available from 1900 and here limited to 2000); and right axis: number of papers per journal. **b** left axis: Number of articles (black solid squares) and open access articles (red solid circles); and right axis: percentage of open access articles (green hollow circles) as a function of the year of publication. Data taken June 16th, 2023. (Color figure online)

of the corresponding category (Huh, 2021). The normalized index was proposed to allow comparing between different categories. This avoids the boost behavior observed in *JIF*. Among the 49 e-ISSN journals only with electronic version, 12 are in the Q1 of the MSM category. Concerning the capability of electronic journals to increase the number of articles per year, whereas the average number of articles per journal in 2021 in MSM was 326, this number increased to 675 when considering those 49 journals only with e-ISSN. An even higher value of 1109 articles per journal is obtained discarding from this set those journals without *JIF*. Studies on the effect of electronic sources on the scientific production and citation appeared soon after the rise in number of electronic sources, e. g. Zhang (Zhang, 1998) analyzed the period from 1994 to 1996 in the in the area of Library and Information Science. At that moment, they found some bias for articles published in electronic journals to cite more articles published in that sort of journals than it occurs for articles published in print journals. Nowadays, more than 25 years ago almost all the other journals in the category have an available electronic version.

Open access articles in Materials Science, Multidisciplinary

Finally, it is worth mentioning the relevance that open access articles, including those from open access journals as well as those individually selected as open access (see Fig. 1), are acquiring with respect to the total number of publications, reaching 40% in 2021. This indicates increasingly large and easily accessible information freely available to the research community of this scientific area. The role of electronic journals is crucial also to understand the immediacy of access to new results from the scientific community which is directly affecting the overall increase of *JIF* (Althouse et al, 2009; Trajkovski, 2018). Nowadays, journals anticipate the publication of the articles as preprints or uncorrected proofs. In some cases, this provisional version can be accessed the year previous to its volume publication and this could affect the corresponding *JIF* calculation. This will be briefly commented in next section when analyzing the five selected journals of this study.

We compare the behavior of two journals with similar *JIF* but one open access (Metals from MDPI, $JIF = 2.695$) and other distributed under subscription (JOM, from Springer, $JIF = 2.597$) both in Q3. In 2020, Metals published 1699 open access articles and was cited till now (April 12th 2023) by 11,535 articles. In the same year, JOM published 543 articles from which 178 were open access. The remaining 365 articles were cited by 1893 articles, whereas the 178 open access articles were cited by 893 articles (differences in the ratio are not significant). In both cases self-journal citation is the highest contribution (13.3 and 5.2% of the total citations for Metals and JOM, respectively). Considering only those journals that represent above 0.5% of the total citations to articles published in 2020 in Metals and JOM (summing up to 50.2 and 41.9% of the total citations), we found that from them, open access journals represent 3/5 for Metals and less than ¼ for JOM. Limiting the citing articles only to open access (independently of the open access character of the journal), we found 55% of citations to Metals come from open access articles, whereas only 35% of citations to JOM articles corresponds to open access articles. Recently, Momeni et al. (Momeni et al., 2021) concluded that the shift to open access of journals generally led to an enhancement in their bibliometric qualification.

Quantitative evolution of journal impact factor in Materials Science, Multidisciplinary

Figure 2 shows the correlation between mean *JIF* values for the different quartiles of MSM and the total number of publications in the MSM category, N_{MSM}, for the corresponding year of publication. Both parameters exponentially increase with time (see Fig. 1 for N_{MSM}) and they are linearly correlated. As it is shown in the inset of Fig. 2, the slope of the linear dependence observed for $\langle JIF \rangle$ versus N_{MSM}, for the same period of time (2000–2020), linearly increases with mean impact factor, $\langle JIF \rangle$, for a certain range (e.g. Figure 2 shows this for the quartiles but this can be extended for any region where $a < JIF < b$). Therefore:

$$\frac{\Delta \langle JIF \rangle_{[a,b]}}{N_{MSM}} = k \langle JIF \rangle_{[a,b]},$$

where $k = (6.71 \pm 0.15)10^{-6}$ and the subindex indicates the $[a, b]$ range analyzed (in Fig. 2 they corresponds to the different quartiles and the values over whole MSM). From this normalization law, it can be inferred that, as a first approximation, the increase in *JIF* is proportional to the number of publications in the category and to *JIF*. This relative change

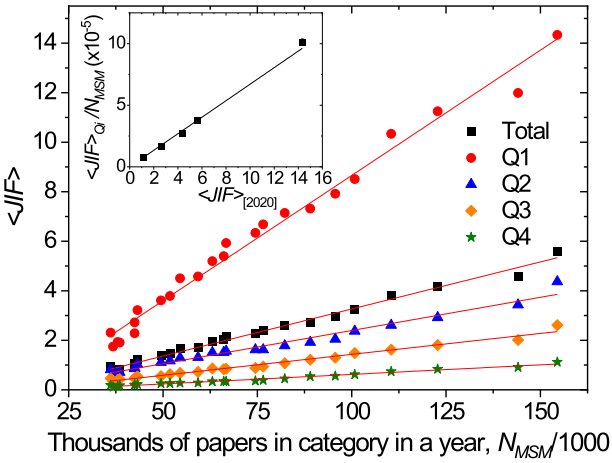

Fig. 2 Evolution of the ⟨JIF⟩ as a function of the year for the total MSM category and for each of the different quartile ranges. The inset shows the linear correlation between the slope of the straight lines in the main panel and the corresponding ⟨JIF⟩ in 2020

in the average *JIF* in a certain range proportional to the number of articles published in the category ($\Delta\langle JIF\rangle_{[a,b]}/\langle JIF\rangle_{[a,b]} = kN_{MSM}$) is an indication of the non-homogenous distribution of citations over the journals in the category but those with a higher *JIF* are more benefited than those with a lower one as it is evident from the increasing slopes of the fitted straight lines to the data of different quartiles in Fig. 2.

This preferential increase is shown in Fig. 3a which plots the increase in *JIF* from 2000 (first appearance of MSM category) to 2020 (i.e. $\Delta JIF = JIF^{[2020]} - JIF^{[2000]}$ as Y axis) for the 106 journals that belong to MSM during that period as a function of their corresponding *JIF* in 2020 (i.e. $JIF^{[2020]}$ as X axis). Increase in *JIF* calculated without self-citations is also shown. We can find a linear correlation for both, which allows us to estimate an expected average $\langle\Delta JIF\rangle$ increase as a function of *JIF* value in 2020. Figure3b shows the deviation of each journal with respect to its corresponding average value as a function of the increase in the number of articles of the journal per year. We can find that most of the journals in MSM have increased their number of articles per year but there is no clear correlation between this parameter and the deviation of actual increase in *JIF* with respect to the expected $\langle\Delta JIF\rangle$ of the journal from 2000 to 2020.

An overall increase in the number of articles in the category should lead to an expected increase in the number of citations as there are more documents published on the subject and, therefore, susceptible to cite articles published in the journal of interest. For example, assuming that, on average, an article published one or two years before the calculation year y in the journal A has a probability to be cited in year y equal to $p(A, y)$ by a research developed in the area and published in that year y, $N_{cites}(A, y)$ can be related with the total number of articles published in the category as $N_{cites}(A, y) \sim p(A, y)N_{MSM}(y)$ (neglecting citations from papers from out of MSM categories). However, the increase in number of articles per year in the journal would be deleterious for *JIF* as it appears in the denominator of its definition. In the period from 1997 to 2020, the whole number of articles per year in MSM, $N_{MSM}(y)$, increased with a ratio $\frac{N_{MSM}(2020)}{N_{MSM}(1997)} = 4.42$, whereas $\langle JIF\rangle$ ratio increased ~ 6, independently of the quartile range. Moreover, as shown in Fig. 1, the number of articles per journal has shown an overall increase with time with a ratio of 2.55 in the period from 1997 to 2020. Therefore, from these ratios we can explore the evolution of the probability of an article in an average journal A to be cited by a research in the MSM category, $p(A)$, in the two years following its publication:

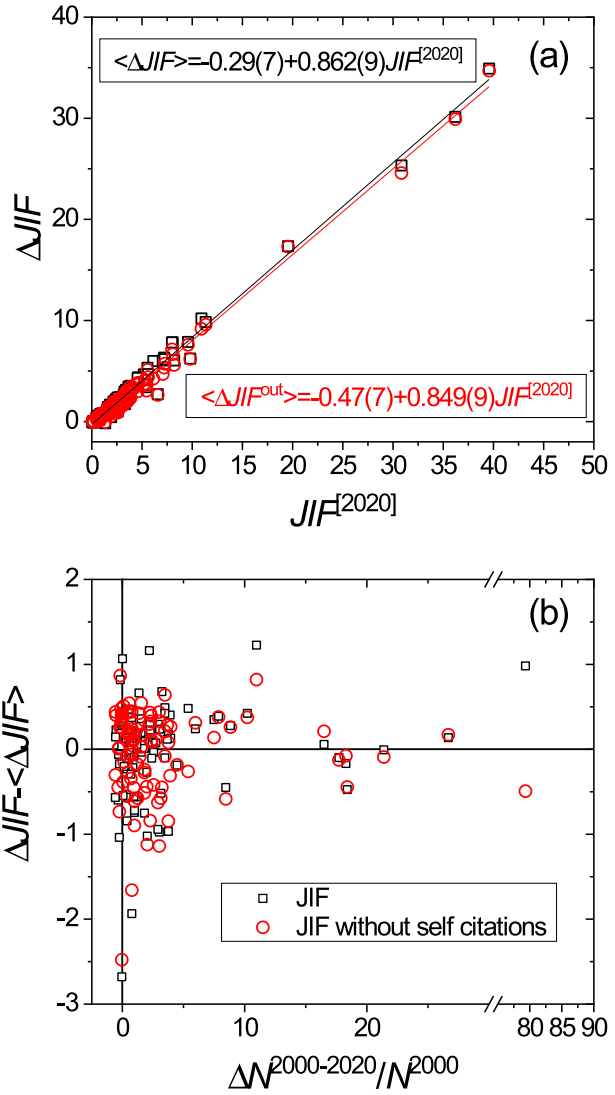

Fig. 3 **a** Increase in JIF from 2000 to 2020 for each journal active in MSM category during this period (total 106 data) as a function of JIF value in 2020. **b** Deviation of actual JIF from expected JIF from linear behavior from (a) as a function of relative increase in the number of articles published from 2000 to 2020

$$\frac{JIF(2020)}{JIF(1997)} = \frac{N_{cites}(A,2020)}{N_{cites}(A,1997)}\left(\frac{N(A,1996)+N(A,1995)}{N(A,2019)+N(A,2018)}\right)$$
$$= \frac{p(A,2020)N_{MSM}(2020)}{p(A,1997)N_{MSM}(1997)}\left(\frac{N(A,1996)+N(A,1995)}{N(A,2019)+N(A,2018)}\right) \sim 11.3\frac{p(A,2020)}{p(A,1997)}$$

This equation indicates that the probability of an average journal A in MSM category to be cited in an article in the category has decreased in 2020, being 53% of that in 1997, even though the value of JIF has steadily increased. Anyhow, as the total number of articles in MSM increases with time, the number of citations increased in 2020 to be close to threefold that of 1997.

This increase cannot be explained merely by the increase in the number of publications because the increased number of citations must be distributed among the increased number of publications. Therefore, the even faster increase with time for $\langle JIF \rangle$ than for the total number of articles must be explained by a continuous increase in the average number of references per article. This trend has been studied by Mammola et al. (Mammola et al, 2021) on ecological journals and would be analyzed in the following section considering individual journals of MSM.

Detailed analysis of five journals of the category Materials Science, Multidisciplinary

In order to go deeper in our analysis, we selected five journals from MSM category published by Elsevier, which is the main editorial for this category (nowadays, close to 30% of the articles in WoS category Materials Science, Multidisciplinary): *Acta Materialia* (AM), *Scripta Materialia* (SM), *Journal of Alloys and Compounds* (JAC), *Material Letters* (ML), and *Journal of Magnetism and Magnetic Materials* (JMMM) (Table 2).

Two of the selected journals (SM and ML) are devoted to publication of short communications or letters and have a limitation in the number of pages. Except JMMM, which is devoted to the magnetism of materials, the rest of selected journals are generalist in the area.

Although not every journal has increased the number of articles per year (AM and SM are almost constant, whereas JAC continuously increases, see Fig. 4), it is observed an overall increase in the number of references per article, except for ML where the limitation in the number of pages to 4 may be the reason why the number of references in an article stabilizes around 15 (Fig. 4). Length restriction in ML is now even stricter than previously, e.g. in 1997, 36.4% of the articles have 5 pages and 27.6% have 6 pages or more, whereas in 2020, 23.6% of the articles have 5 pages and only 1.2% have 6 pages or more). However, in the case of SM, also with limitation in the number of pages, this criterion was not strictly observed. In fact, although 4–5 pages limitation appears in the guide for authors of SM, taking volume 212 (15 April 2022) as an example with 28 regular articles appearing, only 1 article has 4 pages, 14 have 5 pages, 10 have 6 pages and even 3 have 7 pages so around 50% of the articles exceed the limitation in the number of pages. When limitation in the number of pages is strict, reference lists are reduced. This occurs for JAC volumes collecting proceedings from scientific conferences. Taking articles from proceedings in the period from 2000 to 2015, the number of references is almost constant about 18 ± 2, whereas for the regular articles, the average number of references per article continuously increases from 18.7 to 34.4 in the same period. Figure 4 shows the correlation between number of pages and number of references in a year in the case of JAC for regular articles and proceedings articles. Proceedings articles also include those from keynotes and similar ones which length is not limited as a general contribution to that volume. In recent years, JAC has strongly reduced the number of issues devoted to conference proceedings. This type of contribution corresponds to above 50% of the number of articles published by JAC in 1997 and generally more than 20% up to 2007. However, they became sporadic since 2016, mainly corresponding to keynotes and similar contribution without strong limitation in the number of pages (in fact, isolated point for 2018 in Fig. 4 and inset corresponds just to 55 proceedings contributions from a total of 3775 articles published in JAC that year).

Table 2 Journals used in the analysis with the corresponding journal impact factor (JIF), relative position (RP) in Materials Science, Multidisciplinary, maximum number of pages when required and the category in which the journal has its best RP

Journal	***JIF***(2020)	RP 2020	Pages limit	Best RP in other category
Acta Materialia	8.203	53/334	No	2/80 in Metallurgy & Metallurgical Engineering
Scripta Materialia	5.611	90/334	4–5	5/80 in Metallurgy & Metallurgical Engineering
J. Alloys and Compounds	5.316	97/334	No	6/80 in Metallurgy & Metallurgical Engineering
Materials Letters	3.423	163/334	4	52/160 in Physics, Applied
J. Magnetism and Magnetic Materials	2.993	188/334	No	33/69 in Physics, Condensed Matter

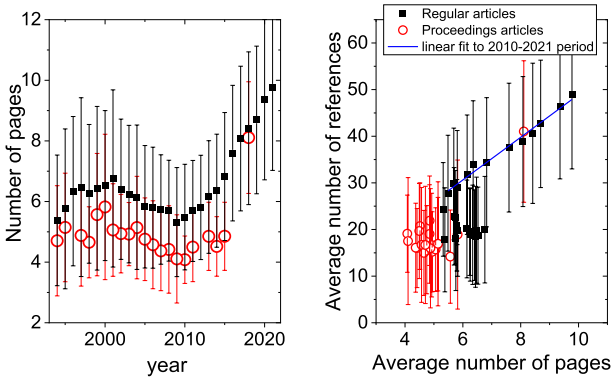

Fig. 4 Evolution of the average number of pages with year of publication (left) and average number of references vs. average number of articles in each year (right) published in JAC distinguishing between (black solid squares) regular articles, (red hollow circles) proceeding articles. The blue line corresponds to the linear fitting of the 2010-2021 period (regression coefficient r = 0.992) Bars show the standard deviation. Statistics were done over a maximum of 1000 articles when available. (Color figure online)

To end with this point, taking into account the reference format used in the journals here described (two columns), between 50 and 60 references would occupy a complete page.

The relationship between number of pages and number of references is not simple. Data corresponding to regular articles previous to 2005 remain with a stable number of references per article, about 15 to 20, although the average number of pages increases up to 7. Therefore, previous to 2005, despite the strong influence of citations in the journals qualification as well as for scientists (Vincent & Ross, 2000), we assume that the facilities that makes possible a wide and easy access to the relevant literature were still not available. Coinciding with the launch of Scopus and Google Scholar in 2004, the triggering for the increase in the number of citations took place.

Figure 5 allows us to identify a clear rise in the number of references per article that occurs around 2005 (except for ML for which limitation in the number of pages presumably blocked this behavior). This fact coincides with the development of new electronic databases such as Scopus and Google Scholar, and particularly the former presenting the capability of direct access to full content via link in the case of Elsevier journals. In addition, during the revision procedure of a research article is typical the recommendation from the reviewers to increase the number of references (whether they supply specific ones or ask for an extended contextualization of the problem). Despite the possibility of misconduct from reviewers to increase citations, recent studies show that this is relatively limited (Baas & Fennell, 2019). All these requirements are in the internet era much easier to be fulfilled.

The roughly twofold increase in the average number of references per article observed in the period from 1997 to 2020, combined with the above mentioned increment in the number of journals do overcome the increase in the number of articles per journal and is the reason for the ~ 500% increase in $\langle JIF \rangle$ described above. Concerning AM and SM, they keep a stable number of articles per year. Therefore, these journals take the advantages of the increase in the number of articles published in the category and the number of references per article in journals of the category, whereas the denominator of the *JIF* formula is not affected. The enhancement in *JIF* in the period from 1997 to 2020 is larger for AM (560%) and SM (770%) than the average in the category for those *JIF* values (see Fig. 2),

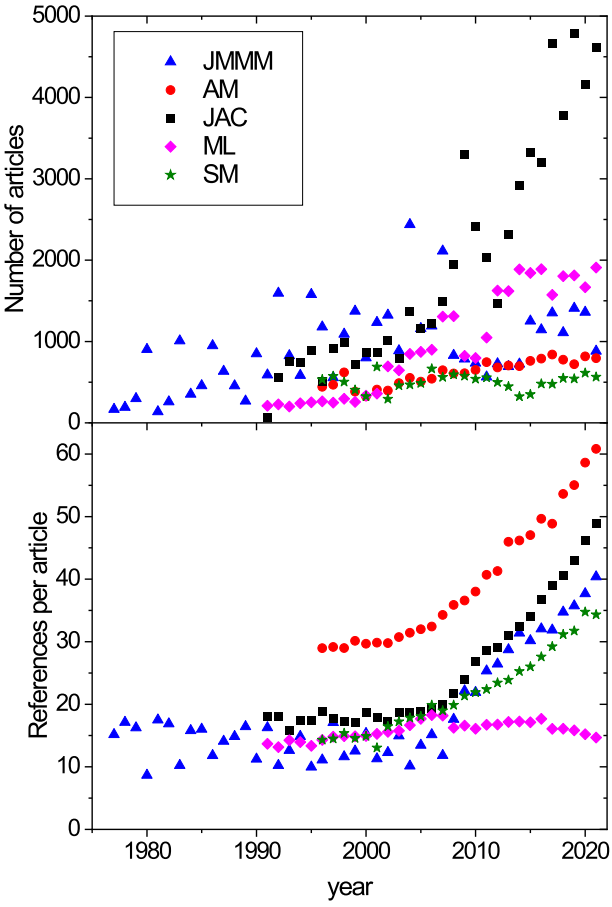

Fig. 5 Number of articles and references per article as a function of the year of publication for Acta Materialia (AM), Scripta Materialia (SM), Journal of Alloys and Compounds (JAC), Materials Letters (ML), and Journal of Magnetism and Magnetic Materials (JMMM)

whereas for JAC, with a clear continuous increase in the number of published articles per year, the corresponding increase in *JIF* is lower (410%). However, this apparently logical trend is not an evident general rule as no clear correlation is observed in Fig. 3b.

Concerning the success of a journal, Fig. 6 shows the evolution of *JIF* for the different analyzed journals along with the average number of citations per year, n_{cite}, calculated as:

$$n_{cite} = \frac{\sum_{j=y}^{2022} N_{cites}(j)}{2022 - y}$$

where y is the year of publication and $\sum_{j=y}^{2022} N_{cites}(j)$ is the sum of the total number of citations for the publication year to 2022 (i.e. unlike *JIF*, n_{cite} is accumulative and does not restrict the time from publication to citation).

A good correlation is observed between n_{cite} and *JIF* (see Fig. 7) except for the highest *JIF* values for each journal that, taking into account the continuous increase in *JIF*, correspond to the most recent years. The decay in n_{cite} observed at high *JIF* is understood as indicative of an average delay that recent articles have before they become regularly used in the research community. At the moment of the redaction of this work,

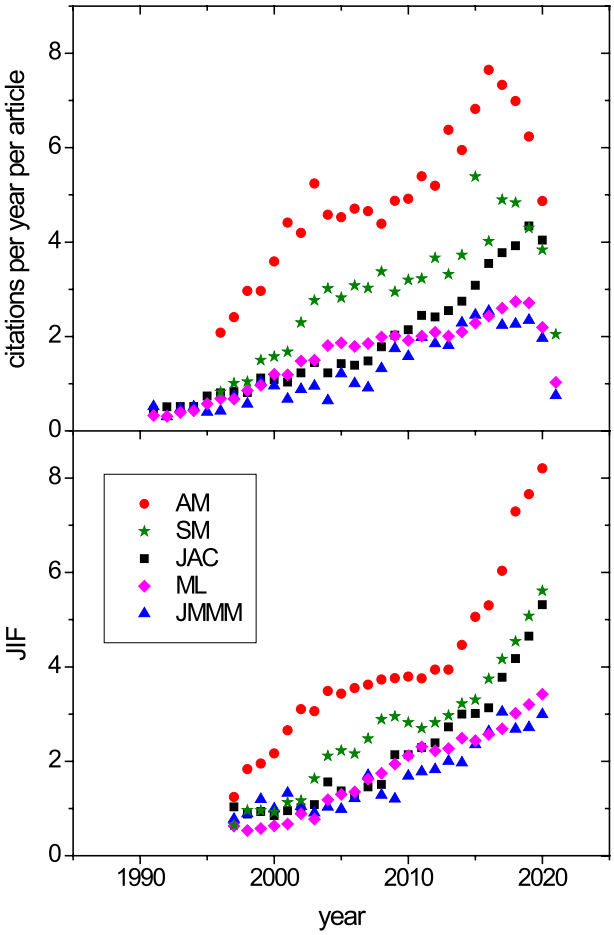

Fig. 6 Average number of citations per year and JIF for the different studied journals as a function of the year of publication

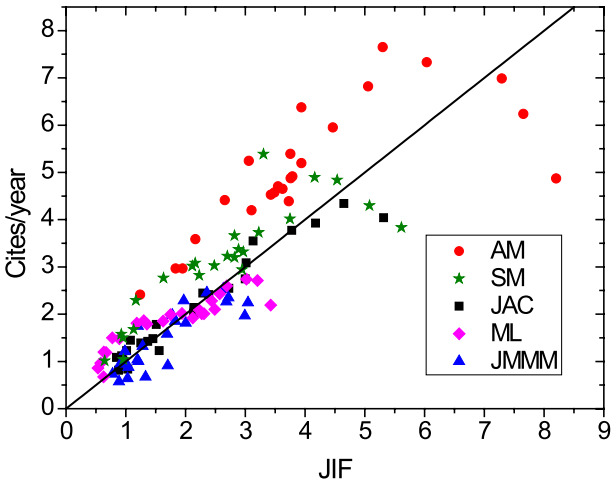

Fig. 7 Correlation between n_{cite} and JIF. Line corresponds to a straight line with slope 1 and null intercept

JIF values are available from JCR from 1997 up to 2020. However, citations taken from WoS are collected up to February 2022. Therefore, we can identify a roughly common behavior for the journals analyzed in this work: an article requires about 3 to 4 years to become regularly used, which is in agreement with the time required by a regular article to reach its maximum number of citations per year as described by Costas et al. (2010) and the 3-year window earlier assumed by Glänzel and Schoepflin (1995). Once this regularity is achieved, a linear correlation with a slope close to 1 is found between n_{cite} and *JIF*, although higher for the journal with a relative better rank position in the category.

Some authors (e.g. Krauss, 2007) point to the self-citation in journals and how this can lead to an artificial increase in *JIF*. On the one hand, this could be justified when the subject covered by the journal is very specific and correspondingly citations would be frequently taken from that very article. In order to briefly comment on this point concerning the explored category and journals, we can define a relative self *JIF*, as:

$$S^{JIF} = \left(1 - \frac{JIF_j^{out}}{JIF_j}\right)100\%$$

with JIF_j the impact factor of the journal j, and JIF_j^{out} (available from JCR) the journal impact factor calculated after excluding citations from the same journal. This is shown in Fig. 8a as a function of *JIF* for the different journals analyzed herein. Moreover, we define a normalized self *JIF*, r_{JIF}^{self}, to account not only for the number of citations from the very journal but also for the relative weight of that journal in the number of articles published in the category. Thus this parameter is defined for each year as:

$$r_{JIF}^{self} = \frac{N_{MSM}}{N_j}\left(1 - \frac{JIF_j^{out}}{JIF_j}\right)$$

where N_{MSM} is the number of articles in the category, N_j is the number of articles in journal j. Results are shown in Fig. 8b. As it can be observed, interpretation of these data must be taken with care. In the case of JAC, S^{JIF} appears to be relatively high with respect to the other journals. However, this is due to the large number of articles yearly published by this journal. Once r_{JIF}^{self} is considered, JAC is even found with the lowest value among the analyzed journals. Independently of the parameter considered, ML is placed in the low values region, except for a general rise observed for $JIF \leq 1$. This journal is the only one among those analyzed herein for which the number of references per article is constant with time. We assume that this is an indirect consequence of the strict limitation on the number of pages. We found no journal instructions concerning the number of references in the article.

Figure 9 shows the number of citations per year as a function of the number of references for all the published articles of the five analyzed journals along with the average values of each journal corresponding to each year (plotted in Fig. 6 as a function of publication year and in Fig. 7 as a function of *JIF*). The aim of this figure is to show that there is a certain correlation between the number of references and the citations per year an individual article receives and that this fact is almost independent of the journal. However, as average values show, the main factor ruling this dependence is the common increase with time of citations per year and the continuous increase in the number of references per article. However, this should be valid for articles published

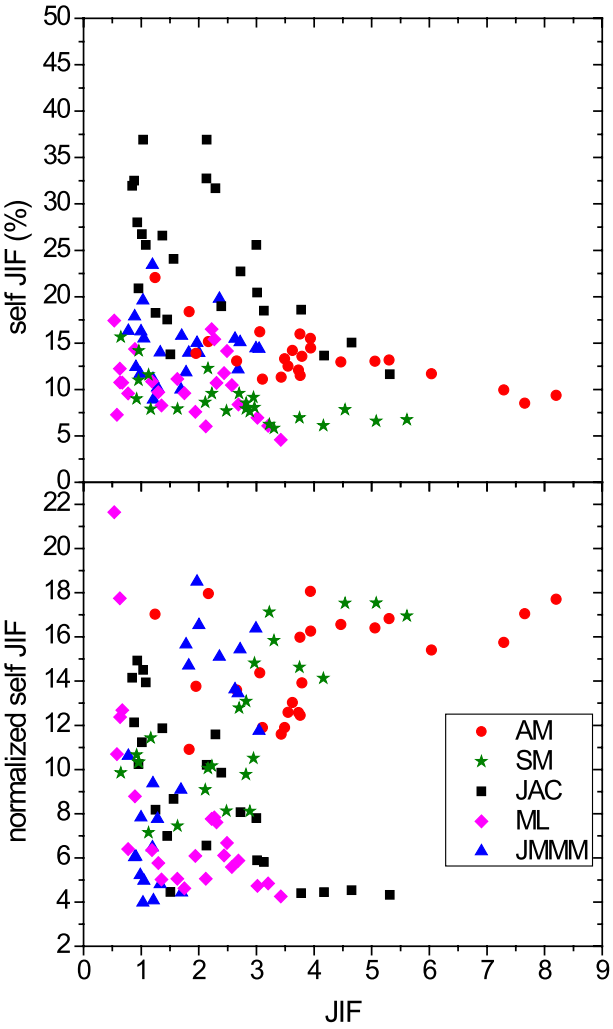

Fig. 8 Self JIF for the different journals analyzed herein. **a** S^{JIF} (in %) calculated as the relative difference between JIF calculated using all citations and excluding citations from the very journal. **b** r_{JIF}^{self}, calculated as the normalized value of S^{JIF} once considered the number of articles published in the corresponding year in that journal

before 2018 (due to the average delay of about 3 to 4 years of an article to be used by the community).

Delay time from submission to final publication is also affecting the availability of the research to the scientific community. Table 3 collects the characteristic times for the different journals analyzed here. Time to first decision, review time and publication time are taken from the corresponding web pages of the journals. As described in the journal web page, time to first decision includes rejected articles, which in the case of desk rejects might be particularly short times. Therefore, this time is much longer for any contribution which is finally published. Analogously, review time also considers rejects, including desk rejects, and for any published article must be longer. Finally, the interesting time for this study is the time from online availability to issue publication. This parameter is not directly available for each journal but this information is supplied for each individual article. Therefore, we have estimated this time from averaging the corresponding time gap for the articles published in the last completed issue at the moment of redaction of these lines

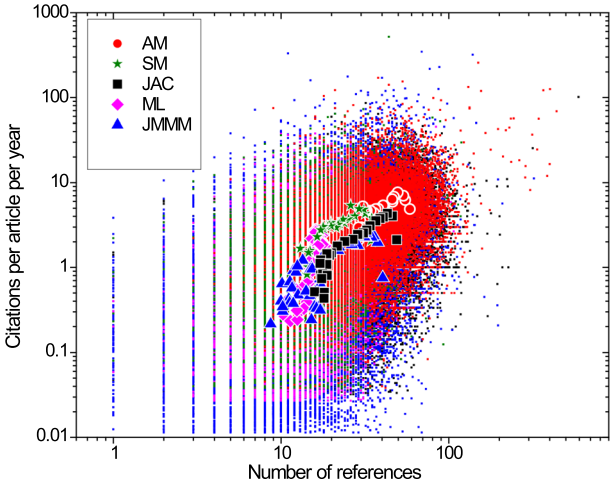

Fig. 9 Citations per article per year as a function of the number of references for articles published in the five analyzed journals. Small dots correspond to individual articles and large symbols to average values over each year

Table 3 Characteristic times of the different journals analyzed in this study

Journal	Time to first decision (weeks)	Review time (weeks)	Online publication time (weeks)	Time from online to issue publication (days)
Acta Materialia	4.5	7.6	0.5	84 ± 6
Scripta Materialia	3.2	4.9	1.2	101 ± 7
J. Alloys and Compounds	3.3	5.4	0.5	155 ± 5
Materials Letters	4.9	7.2	0.5	148 ± 4
J. Mag. & Mag. Mater.	–	8.5	1.1	71 ± 6

* AM estimated from the complete issue: Volume 254, 1 August 2023 (34 articles)

** SM estimated from the complete issue: Volume 234, September 2023 (44 articles)

*** JAC estimated from the complete issue: Volume 959, 10 October 2023 (60 articles)

**** ML estimated from the complete issue: Volume 348, 1 October 2023 (54 articles)

***** JMMM estimated from the complete issue: Volume 579, 1 August 2023 (44 articles)

(15th June 2023). The error shown in the last column of Table 3 corresponds to the average deviation from the average value in the corresponding issue.

Although the article is available since it is published online, *JIF* calculation is referred to the full reference date of publication. Among the analyzed journals, this time is always above 2 months and can be as large as 5 months for JAC.

This anticipation is typically found independently of the publisher: e.g. combining April and May 2023 issues of top journal of MSM Nature Materials (Springer), which publishes regular articles, the average time from online publication to issue date is roughly 50 days. However, the average deviation is also around 50 days and some articles are available less than 10 days previous to issue date, whereas other articles of the same issue are available more than 200 days earlier. This anticipation in publishing gives the articles an extra time of visibility that will contribute to an enhancement in the citations during the period time considered for the calculation of *JIF*.

In this sense, journals are now supplying access to preliminary versions of the articles (i.e. previous to assignment of volume and publication date) that makes this contribution to be known by the scientific community in advance. This can affect the calculation of *JIF*, especially when preliminary versions are available in the previous year than the publication date.

On the other hand, Shi et al. (2017) showed that time gap between the submission and final publication of the articles can lead to inaccuracies in *JIF* calculation. Guo et al. (2021) have recently analyzed this negative effect on JIF and proposed a delay adjusted impact factor. They found a better match between corrected JCR ranking and highly reputed journals (e.g. NATURE INDEX, UTD 24).

Conclusions

A general increase in the number of references cited per article is found in the *Materials Science, Multidisciplinary* WoS category since, roughly, 2005. This occurs one year after the development of Scopus database that supplied a rapid access via a link to the full content (under subscription in most cases) of the research documents. However, when the number of articles is restricted, this indirectly affects the number of references made per article without which it is impossible to explain the notable continuous rise in the journal impact factors that, on average, grows linearly with the number of articles published in the category. It is also quite evident that higher the impact factor of the journal, greater the increase rate.

This increment in impact factor takes place despite the steady rise in the number of articles published per year in many journals. The number of articles per year of two cases studied here, Acta Materialia and Scripta Materialia, remained stable. They both gained two advantages, the increase in the number of articles published in the category and the number of references per article in journals of the category without the increase in their corresponding denominators of the *JIF* formula which explains their particular above average *JIF* level.

The simplicity of access and the immediate availability of the results of scientific research through World Wide Web is one of the key factors in the overall growth of the number of references cited. In this sense, database platforms such Web of Science (1997), Scopus (2004) or Google Scholar (2004) have provided us a tremendously successful tool. Open access journals and free scientific reservoirs, explicitly required by public funding in new calls, makes even more accessible scientific research to researchers.

Taking the advantages of reduced costs and flexibility of online publication, publishers are now anticipating the availability of the scientific results with respect to the correct citation date of publication of the corresponding issue which leads to a factual extension of the valid time for an article to be cited in the period time considered to calculate *JIF*.

However, several questions are open with respect to this apparently inflationary behavior. Is a saturation behavior expected? In our personal experience, the real amount of scientific content of research articles has not increased with time but the contextualization of the research has. In fact, the pressure felt by researchers to publish throughout their career (e.g. CV evaluation strongly dependent on the number of publications) is in

contradiction with the accumulation of scientific results that would justify longest articles with a long reference list.

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Declarations

Conflict of interest The authors declare that they have no known competing financial interest or personal relationships that could have appeared to influence the work reported in this article.

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