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Preprints in Chemistry: a Research Team's Journey**

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The benefits of publishing research papers first in preprint form are substantial and long-lasting also in chemistry. Recounting the outcomes of our team's nearly six-year journey through preprint publishing, we show evidence that preprinting research substantially benefits both early career and senior researchers in today's highly interdisciplinary chemical research. These findings are of general value, as shown by analyzing the case of four more research teams based in economically developed and developing countries.

Introduction

Publishing scientific papers as openly accessible online manuscripts permanently available on specialized internet servers is now a common practice for scholars in both natural and social sciences.[1] In brief, alongside the practice to make research articles openly accessible either by publishing in open access (OA) journals or via self-archiving, preprinting research is the main pillar of the new scholarly communication process typical of open science.[2]

The word "preprint" indicates the fact that the scientific paper is made publicly available prior to publication in printed form by an academic journal following peer review, even though most scholarly journals nowadays no longer print articles but only publish them on the internet in different digital formats.[3]

Far from being anecdotal, the benefits of publishing research papers in preprint form are substantial and long-lasting.[4] "My preprint was the deciding factor when the UT Southwestern hiring committee was deciding whether to give me an interview or not. Once they saw my preprint on bioRxiv, then they gave me the invitation. I'll be starting as an Assistant Professor in January",[5] commented a "post-doc" researcher at Germany's Max Planck Institute of Molecular Cell Biology and Genetics in 2018.

Preprinting their research, early career researchers benefit *inter alia* from immediate publication of research outcomes in OA form, establish priority on research findings, and enhance chances for international collaborations.[6]

Senior researchers, even in disciplines like chemistry whose research community has been reluctant to adopt preprints and OA publishing,[7] benefit from enhanced visibility and citations of preprinted research. Preprints indeed are regularly cited,[8] and vastly increase the visibility and the number of citations of the research articles subsequently published in comparison to research articles published in the same journal but not preprinted.[9]

We have ascribed the aforementioned reluctance of chemistry researchers to adopt open science practices partly to the unique structure of the chemistry publishing market dominated by five organizations publishing more than 70% of chemistry studies in well-known paywalled journals.[10] The poor acceptance of the open science in chemistry, however, also has cultural roots that clearly emerge (see below) when asking renowned colleagues why they do not publish the outcomes of their research in preprint form.

In this study we describe the outcomes of our team's journey through preprint publishing since September 2016, showing evidence that preprinting research substantially benefits both early career and senior researchers in today's highly interdisciplinary chemical research. These findings are of general value, as shown by analyzing the case of four more research teams based in economically developed and developing countries. The results of the study will be useful to further inform courses in open science[3,11] through which effectively promote the culture and the practice of open science in chemistry.

Results and Discussion

Uploading on arXiv a study describing the theory and experimental outcomes of a new beer-brewing process enabled by controlled hydrodynamic cavitation,[12] our team started to jointly publish preprints on September 2016.

To date (early Spring 2022), we have posted 68 preprints on several preprint servers including Authorea, bioRxiv, ChemRxiv, Preprints, Research Square and SSRN. Table 1 lists our preprints next to the preprint server.

For each preprint, except three posted at arXiv, the number of views and downloads to April 5, 2022 are also displayed. Where available, the preprint Altmetric score,[13] a measure of online attention raised by the article on the internet, is also included. The largest preprint repository, arXiv, does not publish

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[**] *A previous version of this manuscript has been deposited on a preprint server (https://doi.org/10.26434/chemrxiv-2022-rsg01).*

either article views and downloads or "altmetric" (alternative metrics) data.

Showing evidence of the high visibility of preprinted chemical research, our preprints as of April 5, 2022 had been viewed 51,282 times and downloaded 38,756 times. In other words, nearly 76% of the online "visits" to our preprints ended with the (free) download of the full study.

Figure 1 displays the distribution of Abstract reads for each preprint, with the exception of 3 preprints published in arXiv. As mentioned above; the latter preprint server does not publish preprint reads and download data. Yet, pointing to the large visibility of preprints posted in the largest and oldest preprint server, our very first preprint, co-authored with Meneguzzo and Albanese, was highlighted by *MIT Technology Review* five days after publication,[14] followed by numerous websites and specialized magazines.

Figure 1 clearly shows a long tail distribution typical for example of research paper citations *versus* the number of research papers.[15] The least read preprints are those published more recently. However, whereas most publications in scientific journal remain barely read and cited for years (i.e., 47% of the 783,339 papers published in 1981 remained uncited in the subsequent 16 years[15]) the least read preprint describing the emerging green routes to nanocellulose[16] in Authorea accumulated 69 reads in three months since publication (Jan 5–Apr 5, 2022).

Suggesting an accelerated production route to a new orange-derived pectin rich in adsorbed hesperidin and other flavonoids for the prevention and therapy of COVID-19, with 4,133 article views our most accessed preprint, again co-authored with Meneguzzo's team, was published in Preprints on March 2020.[17] The peer reviewed study was subsequently published less than two months later in *Processes*.

In general, preprints posted at ChemRxiv were the most viewed and downloaded. The second most cited preprint from our team is a chemistry education study[18] posted on ChemRxiv. Between August 2018 and early April 2022 the preprint has been viewed 3,815 times. The study was subsequently published in the *Israel Journal of Chemistry*.

With 3,300 article views since publication in February 2017, our third most accessed preprint has been published by bioRxiv.[19] The study reports the invention of a new antifouling sol-gel coating driven by solar light ("AquaSun"). At that time ChemRxiv had not yet started to operate and we had to choose a preprint server suitable for a study at the interface between chemistry and biotechnology.

It is also remarkable that with 2,355 views our team's seventh most read preprint is the first study on preprints in chemistry published in Preprints in July 2017.[20] Its high Altmetric score (25) points to the broad interest of the chemistry research community for preprints already in 2017. Confirming said interest, also the journal article published in *ACS Omega*,[21] had been accessed 3,500 times by April 8, 2022.

In the case of a preprint suggesting why heterogeneous catalysis under flow will become the key enabling technology of the fine chemical industry, publication in a peer reviewed journal took nearly two years. Eventually, the study co-authored with Luque was published in *Green Energy & Environment* in late 2020. Yet, the preprint posted at Preprints in early 2019 immediately attracted significant interest receiving online feedback from colleagues in the chemical industry.[22]

Downloaded 1,078 times and indexed in all main research databases, the preprint has been indexed by all main search engines. For instance, a Boolean search on Google with the queries "heterogeneous catalysis" and "flow chemistry" returns the preprint as sixth outcome of the search, and the journal article as the second.[23] Remarkably, the first search outcome is a chapter offering a perspective in catalysis under continuous flow from Kobayashi and co-workers. The third is a highly cited study published by the same team in *Tetrahedron* in 2018.[24]

Hence, thanks to the aforementioned preprint, colleagues doing research in heterogeneous catalysis for synthetic organic chemistry or teaching heterogeneous catalysis could (and can) find a new contribution succinctly suggesting arguments for which manufacturing of fine chemicals and active pharmaceutical ingredients will soon flexibly take place "via catalytic processes carried out under flow under mild reaction conditions in which no 'out-of-spec' (beyond specification) reaction product is collected, thanks to unprecedented high stability of new generation solid catalysts coupled to finely controlled reaction conditions".[22]

Preprinting research also establishes priority. For example, the new circular economy ("LimoFish") process to extract high quality fish oil from fish leftovers rather than from fish using

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Mario Pagliaro, research director at Italy's Research Council, is a chemistry and energy scholar based in Palermo, Italy, where he leads a research Group focusing on nanochemistry, sustainability and the bioeconomy. In 2021 he was elected ordinary member of the Academia Europaea in the chemical sciences class. In 2014 he was designated Fellow of the Royal Society of Chemistry. Publicly advocating for the uptake of open science within the chemistry community via open science education, his team has contributed several seminal studies in the field.

Table 1. Preprints from M. Pagliaro's research team, 2016–2022.[a]

Entry	Preprint	Preprint server Year	Altmetric score	Views/ downloads
1	Volcanic ash as multi-nutrient mineral fertilizer: science and early applications	ChemRxiv 2022	1	111/54
2	Emerging green routes to nanocellulose	Authorea 2022	–	69
3	Cross-linked natural IntegroPectin films from Citrus biowaste with intrinsic antimicrobial activity	bioRxiv 2022	2	509/148
4	Red Orange and Bitter Orange IntegroPectin: Structure and Main Functional Compounds	ChemRxiv 2022	2	166/45
5	Educating the managers of the bioeconomy	Authorea 2021	–	84
6	Reaping the benefits of open science in scholarly communication	Authorea 2021	–	665
7	Preprints in Chemistry: An Exploratory Analysis of Differences with Journal Articles	Authorea 2021	–	147
8	Nanocellulose from citrus processing waste using water and electricity only	Research Square 2021	3	210/19
9	AnchoisFert: A New Organic Fertilizer from Fish Processing Waste for Sustainable Agriculture	Research Square 2021	–	182/21
10	A gluten-free biscuit fortified with lemon IntegroPectin	Research Square 2021	–	143/22
11	Pectin: New Science and Forthcoming Applications of the Most Valued Hydrocolloid	Preprints 2021	1	123/95
12	Economic and Technical Feasibility of AnchoisFert Organic Fertilizer Production	Preprints 2021	1	132/87
13	Green and Quick Extraction of Stable Biophenol-Rich Red Extracts from Grape Processing Waste	Preprints 2021	1	269/143
14	The Limonene Biorefinery: From Extractive Technologies to Its Catalytic Upgrading into p-Cymene	Preprints 2021	–	303/179
15	Towards the Anchovy Biorefinery: Biogas Production from Anchovy Processing Waste After Fish Oil Extraction with Biobased Limonene	Preprints 2021	3	314/110
16	CytroCell: Valued Cellulose from Citrus Processing Waste	Preprints 2021	3	328/128
17	Did you Ask for Citations? An Insight into Preprint Citations en route to Open Science	Preprints 2021	2	348/194
18	Purposeful Evaluation of Scholarship in the Open Science Era	Preprints 2021	10	314/91
19	«Quick, Convenient, and Clean»: Advancing Education in Green Chemistry and Nanocatalysis Using Sol-Gel Catalysts Under Flow	Preprints 2021	3	298/124
20	Tannin: A New Insight into a Key Product for the Bioeconomy in Forest Regions	Preprints 2021	1	294/212
21	Flavonoids in Lemon and Grapefruit IntegroPectin	Preprints 2021	1	596/374
22	Towards AquaSun practical utilization: strong adhesion and lack of ecotoxicity of solar-driven antifouling sol-gel coating	ChemRxiv 2021	–	333/85
23	Neuroprotective and Mitoprotective Effects of Lemon IntegroPectin on SH-SY5Y Cells	bioRxiv 2021	4	498/220
24	Neuroprotective, antioxidant and antiproliferative activity of grapefruit IntegroPectin on SH-SY5Y cells	bioRxiv 2021	2	488/197
25	Mesoporous silica particles functionalized with newly extracted fish oil (*Omeg@Silica*) inhibit lung cancer cell growth	bioRxiv 2021	1	499/205
26	How Reorganizations of Public Research Laboratories Affect the Evolution of Scientific Activity and Production: A Case Study in Italy From 2000 to 2020	SSRN 2020	–	176/13
27	Open access publishing in chemistry: A practical perspective informing new education	Authorea 2020	–	109
28	A new water-soluble bactericidal agent for the treatment of polymicrobial infections	Preprints 2020	1	237/166
29	Exceptional Antioxidant, Non-Cytotoxic Activity of Integral Lemon Pectin from Hydrodynamic Cavitation	Preprints 2020	4	597/6030
30	Superior Antibacterial Activity of Integral Lemon Pectin From Hydrodynamic Cavitation	Preprints 2020	4	262/380
31	Publishing Scientific Articles in the Digital Era	Preprints 2020	1	942/686
32	Sustainably Sourced Olive Polyphenols and Omega-3 Marine Lipids: A Synergy Fostering Public Health	Preprints 2020	4	402/273
33	High Yields of Shrimp Oil Rich in Omega-3 and Carotenoids: Extending to Shrimp Waste the Circular Economy Approach to Fish Oil Extraction	Preprints 2020	1	413/261
34	Technical and Economic Feasibility of a Stable Yellow Natural Colorant Production from Waste Lemon Peel	Preprints 2020	1	179/130
35	Father Verspieren and Mali Aqua Viva: Lessons Learned from Fighting Drought and Poverty with Photovoltaic Solar Energy in Africa	Preprints 2020	3	487/385

Table 1. continued

Entry	Preprint	Preprint server Year	Altmetric score	Views/ downloads
36	Waste-to-Wealth: The Economic Reasons for Replacing Waste-to-Energy With the Circular Economy of Municipal Solid Waste	Preprints 2020	–	261/236
37	Volatile Compounds of Lemon and Grapefruit IntegroPectin	Preprints 2020	4	272/190
38	Renewable Energy in Russia: A Forthcoming Transformation Driven by Economic and Industrial Factors	Preprints 2020	1	335/502
39	Hydroxychloroquine for the Treatment of COVID-19: Evidence, Possible Mode of Action and Industrial Supply of the Drug	Preprints 2020	73	1926/3675
40	Distributed Generation from Renewable Energy Sources: Ending Energy Poverty Across the World	Preprints 2020	1	210/311
41	Accelerated Production of Hesperidin-rich Citrus Pectin from Waste Citrus Peel for Prevention and Therapy of COVID-19	Preprints 2020	4	4133/2694
42	Omeg@Silica: In-Silica Stabilization of Sustainable Fish Oil	Preprints 2020	3	184/163
43	Vanillin: The Case for Greener Production Driven by Sustainability Megatrend	Preprints 2020	–	337/586
44	SilverSil: A New Class of Antibacterial Materials of Broad Scope	ChemRxiv 2020	2	3413/402
45	Towards a new treatment against polymicrobial infections: high antibacterial activity of lemon IntegroPectin against *Pseudomonas aeruginosa* and *Escherichia coli*	bioRxiv 2020	2	825/424
46	Enhancing the Use of E-mail in Scientific Research and in the Academy	Preprints 2019	–	656/353
47	Real-Scale Integral Valorization of Waste Orange Peel via Hydrodynamic Cavitation	Preprints 2019	3	475/340
48	Solar Green Roofs: A Unified Outlook Twenty Years On	Preprints 2019	–	867/605
49	Look better. Single atoms in chemistry, and single atoms in physics	Preprints 2019	–	764/464
50	Lithium Battery Reusing and Recycling: A Circular Economy Insight	Preprints 2019	–	345/641
51	Heterogeneous Catalysis Under Flow for the 21st Century Fine Chemical Industry	Preprints 2019	2	1537/1094
52	A Circular Economy Approach to Omega-3 Extraction	Preprints 2019	–	686/498
53	Polymers of Limonene Oxide and Carbon Dioxide: Polycarbonates of the Solar Economy	Preprints 2018	1	648/1045
54	Single-Atom Catalysis: A Practically Viable Technology?	Preprints 2018	5	804/945
55	Integrating Solar Energy in Rome's Built Environment: A Perspective for Distributed Generation on Global Scale	Preprints 2018	2	710/878
56	Chemistry Education Fostering Creativity in the Digital Era	ChemRxiv 2018	8	3815/1108
57	Green Hydrosilylation of Olefins	ChemRxiv 2018	1	2658/812
58	The Central Role of Chemistry in the Transition to the Solar Economy	Preprints 2017	3	866/661
59	Betanin: A Bioeconomy Insight into a Valued Betacyanin	Preprints 2017	3	673/1824
60	Olive Biophenol Integral Extraction at a Two-Phase Olive Mill	Preprints 2017	2	815/797
61	Valued Bioproducts from Waste *Opuntia ficus-indica* Peel via Microwave-Assisted Hydrodiffusion and Hydrodistillation	Preprints 2017	2	942/795
62	Has the Time Come for Preprints in Chemistry? A Perspective onto a Meaningful Change	Preprints 2017	25	2355/1042
63	Solar Synthesis of Limonene Epoxide	ChemRxiv 2017	3	3053/605
64	Innovative beer-brewing of typical, old and healthy wheat varieties to boost their spreading	bioRxiv 2017	3	1682/1692
65	Advanced Protection Against Marine Biofouling Using Solar Light	bioRxiv 2017	3	3460/1223
66	The energy-population conundrum and its possible solution	arXiv 2016	–	
67	Italy 100% Renewable: A Suitable Energy Transition Roadmap	arXiv 2016	–	–
68	Beer-brewing powered by controlled hydrodynamic cavitation: Theory and real-scale experiments	arXiv 2016	–	–

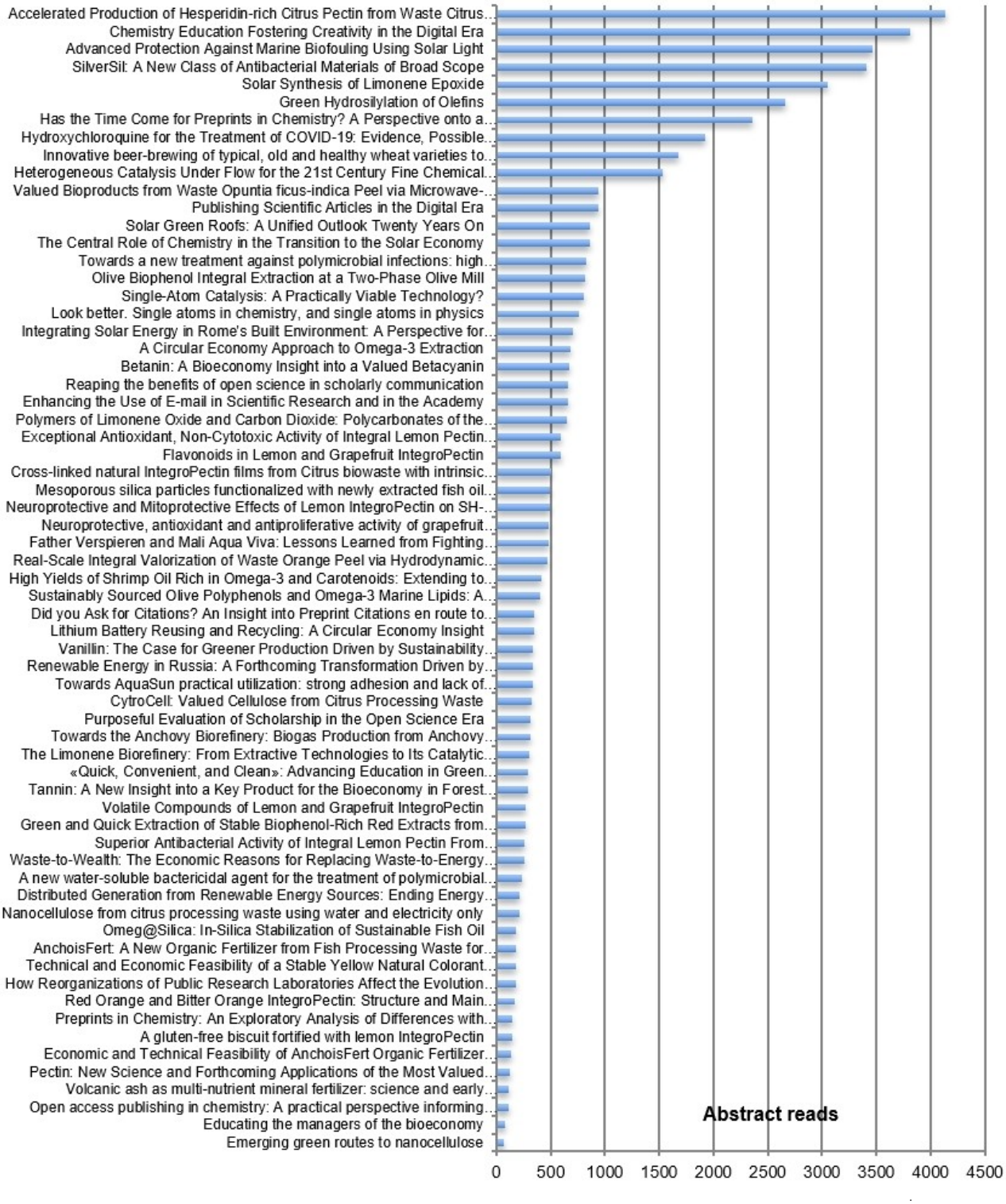

Figure 1. Article views (Abstract reads) for M. Pagliaro's research team preprints as of April 5, 2022. Three preprints posted at arXiv are not listed.

biobased limonene was published in Preprints in February 2019.[25] The process affords a whole fish oil rich in vitamin D_3 and omega-3 lipids far superior when compared to the highly refined fish oil obtained from fish used to produce omega-3 food supplements.[26]

The method is near to commercialization because, along with a better product isolated at a fraction of the cost of the conventional process, it has a largely positive impact on the environment due to the lack of effluents (the citrus-derived solvent is nearly entirely recovered after extraction) and to the

use of fish discards previously dealt with as waste as raw material in place of valued fish.[27]

Why therefore do chemistry scholars continue to publish a small fraction of the preprints published, for example, by life science researchers? One of us on August 2021 decided to invite written opinions on the topic on ResearchGate, a research social network with more than 15 million members.[28]

The viewpoint of Frank Edelmann, a renowned chemistry scholar at Otto-von-Guericke-Universität Magdeburg, Germany, offers an explanation:

«Dear Mario, this is certainly an important technical question which will be of broad interest to many RG members. When you say 'Research chemists continue in their slow uptake of preprints' I can only agree with you from my personal experience. We have 40 + years of experience in chemical publishing, and during this long time we never ever posted a preprint on a preprint server. The reason? I may be old-fashioned, but personally I'm strictly against any form of preprints. I simply see no benefits in them, but only potential disadvantages. We always published our research work in international, peer-reviewed journals. What would have been the benefit of publicly posting an unreviewed manuscript? What if the manuscript is later rejected? What if someone else is 'too interested' in our results and copies them? So why not wait until the peer-reviewed manuscript is published online by the journal? You can always use the waiting time for doing new research, writing the next manuscript, or working on a review article. In any case, I do not plan to post any preprints during the rest of my scientific life[29] ».

In response, one of us wrote:

«Dear Frank,… preprints are particularly purposeful in chemistry, because most chemistry papers describe either new synthetic or new analytical methods. Thanks to preprint publishing, chemists who discovered said new methods immediately establish priority at no economic cost. A very important need, especially for chemists reporting new findings from peripheral countries.

As we wrote in our preprint subsequently published as peer reviewed study by ACS Omega: 'Another key advantage for authors is that they are able to claim priority on new ideas in preprints. Such postings should help authors avoid having unethical referees take ideas and claim them for their own, an issue lamented by several authors and a known misconduct for which the Committee on Publication Ethics has published guidelines already in 2010. However intolerable, this practice continues to occur even when submitting to high-impact-factor journals in all sort of disciplines including medicine, and not only to scientists in their early career, as Noble Prize Lipscomb remarked several years ago: 'I no longer put my most original ideas in my research proposals, which are read by many referees and officials. I hold back anything that another investigator might hop on and carry out. When I was starting out, people respected each other's research more than they do today, and there was less stealing of ideas'[30]».

Taking part into the discussion was Peter Sobolewski, a professor at the West Pomeranian University of Technology, Poland:

«I think a lot is out-reach and education. BioRxiv has been very active in promoting itself and preprints in general. Plus asapbio.org is really excellent–of course the info is not bio-specific, but conferences and audiences they engage with don't often overlap with chemistry/chem eng. I've somewhat succeeded in getting some preprint uptake in our group, plus one colleague, but then in Poland it's been slow going. Other collaborators are reluctant, due to the traditional and rigid system here… For me, the issue right now is how slow publication is… So preprints are a way to shortcut that process, improve access, and foster discussion[31]».

Sobolewski in August 2018 was amid the first chemistry scholars to write about his team's experience with preprints.[32] The researchers submitted a manuscript to a journal in mid November 2017. Nearly six months later (on April 29, 2018) they received notification of rejection without review. On May 22, 2018 the team uploaded the manuscript on ChemRxiv. Editors at the preprint server published the study[33] on the same day. Four days later the preprint was already indexed by Google Scholar. In just one week since publication, the preprint was in the top 10 most viewed ChemRxiv preprints for the week. Furthermore, the researcher in mid July could present the study during an oral presentation given at an international conference.

Hence, Sobolewski concluded:,

"If you're still hesitant, think about grad students and postdocs looking for positions. Consider the next conference you're planning to attend…Finally, consider that grant proposal you are working on - a preprint can help you get funding! But in the end, preprints are about sharing your work (in a way that you can be cited and get credit for it), receiving feedback, and moving forward[32]".

Our experience with preprints tells similar outcomes. We were able to systematically cite preprints in grant applications. Our students could include co-authored preprints in their CV and personal websites. We could establish priority, and avoid delays in publication that in one case for a study co-authored with one of the world's most cited chemistry researchers (R. Luque) nearly approached two years.[22]

Over 51,000 article views and nearly 39,000 downloads show evidence of the large visibility of our preprinted research.

With the exception of two preprints published in arXiv only and five currently undergoing peer review at different academic journals, all our preprints have been published in peer reviewed journals generally owned either by one of the five publishers that dominate the chemistry publishing market (ACS Publishing, RSC Publishing, Elsevier, SpringerNature, Wiley) or by MDPI, an OA publisher that in 2021 has become the world's fourth largest scientific publisher in terms of published research articles.[34]

No journal's editor except one refused to accept our preprints for peer review claiming previous publication. Publishers did not show any bias towards our preprints. For instance, only 12 out of 42 preprints posted at Preprints, a preprint server owned by MDPI, were subsequently published as journal articles at journals published by said publisher. The other 30 preprints were accepted for publication at journals owned by other publishers.

We always informed journal editors of the selected journal that our manuscript submitted for peer review had been posted on a preprint server, including the preprint's DOI (digital object identifier) in the cover letter. In this manner we avoided a common issue in the early days of preprint publishing when submitted manuscripts were accused of plagiarism due to identity of the submitted manuscript with the preprint posted online found by the software used by academic journals to detect plagiarism.

Other teams in other countries

In order to draw conclusions on the generality of the observations for our research team (and that of Sobolewski in Poland), we extended and diversified the analysis to four more research groups, to include active research groups from both economically advanced and developing countries. The teams are those of Francis Olawale Abulude (Nigeria), Junichiro Yamaguchi (Japan), Stefan Kaskel (Germany), and Mohamed Mokhtar (Saudi Arabia).

Abulude published a preprint in 2016 on particulate matter in air pollution[35] that to date has been downloaded nearly 2,000 from Preprints, featuring amid the most downloaded chemistry preprints on the server. The review to date has not been published in a journal, but the preprint has been cited 11 times.[36] The study, furthermore, has been read 8,124 times on ResearchGate and recommended 4 times, generating a high research interest score of 57.7.[37]

The researcher's team subsequently published four more preprints (one short note, one essay and two articles) on the same preprint platform.[38] Only one of them has been subsequently published in a research journal,[39] but the preprint reporting a new low-cost technique in monitoring airborne particulate and toxic elements[40] to date has been downloaded 1,772 times, featuring again amid the most downloaded chemistry preprints from the platform. The team of this reputed analytical chemist working on environmental pollution (indoor and outdoor) at Science and Education Development Institute, Akure, Ondo State, has clearly benefited from preprint publishing. Indeed, the team has later published numerous preprints in other preprint platforms such as SSRN and Research Square.

Professor Mohamed Mokhtar's team at King Abdulaziz University in Saudi Arabia published its first preprint in early 2017.[41] Reporting a new solvent-free Biginelli reaction series catalyzed by zeolite using the ball mill technique, the preprint (to date downloaded 1,351 times) was published as peer reviewed article three months later in *Catalysts*.[42]

The team went ahead and published four more preprints on the same platform (Preprints), one of which published in two versions (to date, early July 2022, downloaded 933 times[43]) eventually featured as peer reviewed article with a different title in a paywalled journal[44] owned by a publisher (Wiley) different from the owner of Preprints (MDPI).

A similar outcome occurred for another preprint, revised four times in Preprints between October and December 2018,[45] eventually published nearly two years later in a paywalled journal.[46] Alone, this example shows how preprint publishing can anticipate dissemination of innovation by nearly two years.

Including preprints posted in SSRN, arXiv and Research Square, the research group to date has published 8 preprints, substantially improving the visibility of its research as most of said preprints have been eventually published as peer reviewed articles in paywalled journals, including the last one in June 2022.[47]

Junichiro Yamaguchi's team at Waseda University, Japan, has published 24 preprints in ChemRxiv between December 2019 and July 2022[48] (all written using elegant journal article templates). Virtually all the team's preprints have been published in prestigious chemistry journals. Yet, even the most downloaded (847 times) preprint[49] posted on December 2019 was eventually published in a OA journal seven months later.[50] Again, this example shows how preprint research can substantially accelerate innovation especially in the case of highly innovative research, in this case in the field of synthetic organic chemistry, that has important practical applications in the fine chemical and pharmaceutical industries.

With an Altmetric score of 13, the preprint from Yamaguchi's team with the highest number of online mentions on the main "social networks" was posted on May 2022.[51] In slightly more than one month, the preprint has been mentioned on Twitter by 18 users located in Japan, Poland, United States of America, Vietnam and Germany.[52] In brief, with 24 preprints published in just three years, Yamaguchi's team likely preprints all its research output, fulfilling the principles and the objectives of open science.[53,3,4]

Based at Germany's Dresden Technical University, Stefan Kaskel's team has published 25 preprints in ChemRxiv between late 2019 and mid-2022, chiefly in the field of materials chemistry and nanoscience. One of them, describing a highly porous metal–organic framework responding adaptively to specific guest stimuli, posted in March 2020,[54] has been subsequently cited 4 times in journal articles published in *Inorganic Chemistry*, *CrystEngComm* (twice) and *Journal of Materials Chemistry A*. It took nearly 15 months for the preprint to be published as a peer reviewed article in late May 2021.[55]

For another of the team's preprints (describing a metal–organic framework functionalized with an azobenzene dye producing light-induced structural contraction of the porous network) jointly co-authored with other teams and posted at ChemRxiv in November 2020,[56] it took nearly two years for a peer reviewed journal to publish the study in April 2022.[57] Thus, once again, when compared to conventional publication in peer reviewed journals, preprinting chemistry research has outcomes largely accelerating innovation. So far (July 2022) downloaded 1,065 times, the latter preprint is the most fully accessed preprint from Kaskel's group.

Outlook and Conclusions

Reviewing the experience of our research team with preprint publishing since late 2016, in this study we show evidence that

preprinting research provides benefits both to early career and to senior researchers.

Most of our 68 preprints posted in nearly six years between late 2016 and early 2022 were published in Preprints (42), followed by bioRxiv (7), ChemRxiv (7), Authorea (5), and arXiv (3). As was the case for Authorea and bioRxiv, we also had a rewarding experience with other preprint platforms such as Research Square (in which we published 3 preprints) and SSRN (1), where preprints are published in computer-readable HTML format and not only as non-actionable PDF files ("a digital photograph of a piece of paper"[58]).

We did not encounter any of the "cons" that would complement the "pros" of preprints, including the main perceived disadvantage of preprints, the lack of peer review, that would not "validate"[59] preprinted research.

Extending and diversifying the analysis to include active research groups based in Japan, Nigeria, Germany, and Saudi Arabia allows us to draw similar general conclusions.

Being permanently and freely accessible, the autonomous route to scholarly communication called "preprinting" intrinsically prevents scholars from publishing poor research as the latter would be easily recognized by the scholarly community damaging the credibility (and the career) of the preprint co-authors.

Indeed, as early as 2002, even researchers in the pharmaceutical industry admitted to "utilize these new sources of information"[60] and that information published on preprint servers could even "lead them to modify a research project".[60] In 2002, the only preprint servers in chemistry were Chemistry Preprint Server and Chemical Physics Preprint Database (alongside Biomed Central, The Lancet ERA, and Clinical Medicine NetPrints in biomedicine and life sciences). Today, researchers from the same pharmaceutical company that in 2002 claimed that preprinting their research was not considered an option,[60] regularly publish their research outcomes in ChemRxiv.[61]

Chemistry scholars still hesitating to uptake preprints should be aware that preprints in chemistry in the first three months of 2022 are finally growing at healthy 600–700 preprint/month rate. Just ChemRxiv in March 2022 published 532 preprints.[62] For comparison, bioRxiv in the same month published 3,189 preprints.[63] If we include in the latter figure the large number of preprints posted at Research Square, the number of life science preprints published monthly exceeds by more than one order of magnitude that from the chemistry community.

By early April 2022, namely in less than five years, the number of preprints posted at ChemRxiv by China-based scholars had not yet crossed the 1,000 threshold (893).[62] Clearly, researchers from China, by far the first contributors of scientific papers in chemistry,[64] are still largely omitting to publish their research in preprint form. Self-publishing research in preprint form, however, does not aim to eliminate research publication in academic journals following peer review, but rather to enhance and simplify the communication process of research findings to the scientific community.

Preprinting chemistry research not only fulfills the objective of open-access to maximize research impact by maximizing research access,[65] but it also frees and improves the scholarly communication process.

The community benefits because the prolonged time interval between a manuscript submission to an academic journal and its publication following peer review is eliminated, whereas the research is freely available at no financial cost beyond that for an internet connection. Research teams, in their turn, benefit by establishing priority and maximizing the visibility and impact of their research.

In conclusion, following preprint publication and prior to its publication as a peer reviewed article in a academic journal, research chemists preprinting their research can, as put by Edelmann, "always use the waiting time for doing new research, writing the next manuscript, or working on a review article".[29]

Disclaimer

The opinions expressed in this publication are the view of the author(s) and do not necessarily reflect the opinions or views of *ChemistryOpen*, the Publisher, or the affiliated editors.

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Conflict of Interest

The authors declare no conflict of interest.

Keywords: preprint · open science · preprints in chemistry · open access · research impact

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Preprints in Chemistry: a Research Team's Journey

Preprints in chemistry: Benefits? Risks? Tradeoff? The outcomes of our team's nearly six-year journey through preprint publishing, show evidence that preprinting research substantially benefits both early career and senior researchers in the chemical sciences. These findings are of general value, as shown by analyzing the case of four more research teams based in economically developed and developing countries.