# SCIENCE 3.0: THE FUTURE OF SCIENCE IN THE INTERNET

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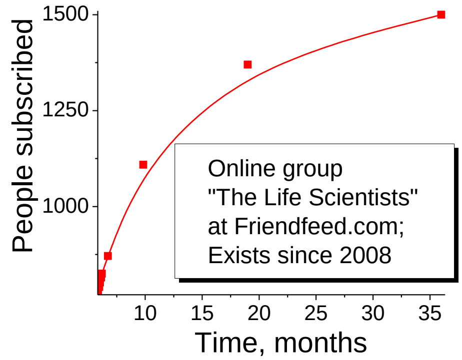
## ABSTRACT

The concept of "Science 2.0" was introduced several years ago to describe the new generation of online-based tools for researchers allowing easier data sharing, collaboration and publishing. The process of scientific discovery has been gradually changing during the decades of the internet era, gaining new features such as self-publishing, online discussions, experiments with peer-review, open access and online brainstorming. Significant resources invested recently in Science 2.0 mean that it can soon revolutionize the way we do research. This could be very beneficial for science, if done properly. Therefore it is important to analyze the successes and failures of Science 2.0, dissect its problems and find potential solutions. Here we first make a brief overview of the current state of the art of scientific communication online and then provide a systematic line of arguments to modify the concept of Science 2.0, making it less dependent on the fashionable Web 3.0 developments, while more consistent with the spirit and traditions of both the science and internet. Our first correction to the Science 2.0 paradigm concerns the publication model charging publication fees to the authors instead of the readers. We show that the monopoly of such publishing models can increase biases and inequalities in the representation of scientific ideas based on the author's income. Our second correction concerns post-publication comments and discussions online, which are all essentially non-anonymous in the current Science 2.0 paradigm. We conclude that scientific discussions at web sites of peer-reviewed journals require special anonymization systems.

## INTRODUCTION

The term "Science 2.0" was introduced several years ago to describe online-based medium for research, documentation and collaboration in analogy with the "Web 2.0" term coined for the description of the next generation of internet. In 2008, several influential journals such as *Science*, *Nature* and *Scientific American* endorsed the use of this term and encouraged scientists to move online (1-3). One of the main features of Science 2.0 is the global networking facilitated by the internet. This feature can be already seen: almost all science bloggers from the US and Europe are *de facto* connected in one network, the think tank of the future science-online community. At the present time there are around one thousand of Science 2.0 bloggers. This number can be estimated from the amount of scientists subscribed to online networking groups devoted to Science 2.0 at web sites such as LinkedIn.com, ResearchGate.net, Academia.edu, Nature Network and Mendeley.com. For example, Figure 1 below shows the saturating dynamics of the number of subscribers of the online group "The Life Scientists" at Friendfeed.com (statistics collected by the author). This relatively small number and tight connectedness allowed a lot of coordination in the thinking and writing about Science 2.0. Currently accepted views about Science 2.0 can be summarized as follows (4):




1) Online networking is good because it multiplies efforts of many people and adds complementary expertise.

2) Online data sharing is good because it facilitates the process of discovery and is a more effective way of spending taxpayer's money.

3) Open-access publishing is good because it provides free access to professional articles for everyone. Open-access will be the only publishing model in future.

4) Online sharing of unfinished works, unpolished thoughts and critic is good because it allows any scientist to expose his/her opinion and receive credit for it. An honest, fearless researcher always putting his name under all his writings in the internet is the Science 2.0 hero.

The first two points already work pretty well and, therefore, we will not discuss them in detail. Instead, we will concentrate on the last two points to show that their current understanding needs corrections. In addition, we distinguish another point of Science 2.0, which is apparent for those who closely watches online processes, although it has not been clearly articulated yet. The point is that the virtual "Republic of Science", connecting worldwide researchers online, has been *de facto* created, and it operates by the rules of direct democracy rather than the rules of any individual governing body, something that the inventor of this term Michael Polanyi could not foresee in 1962 (5). This point will become important in our discussions since the conceptual features of Science 3.0 that we aim to derive below should be generic, applicable to any country.

**1. Self-publishing can supplement but not substitute peer-reviewed journals.**

Since peer-review appears to be at the core of the functioning of the current scientific system, a lot of people have been thinking about ways to improve it. One radical view that only few people endorse is that peer-review is not needed at all (6). This perspective comes with the idea of self-publishing, either on a personal web site/blog, or using public repositories such as ArXiv.org or Nature Precedings. ArXiv.org successfully functions for several decades; it is common for physicists and mathematicians to upload there the drafts of their manuscripts before submitting to peer-reviewed journals. In addition, there are examples of extraordinary good works ending at online archives and not published in peer-reviewed journals at all. Perhaps the best known example of this kind is the work of Grigory Perelman, who solved a long-standing mathematical problem of great importance and published the solution online at ArXiv.org (7). He was recently awarded the Fields medal (the highest award in mathematical sciences, which he refused to accept). He never submitted this paper to a peer-reviewed journal. This is a nice story, but it is just an exception from the rule that preprints are usually not the end-products. Perelman was already well known in the mathematical community before posting this preprint, and he made a serious claim that had to be verified. That is the reason why his manuscript was considered seriously. For a less charismatic person and a less important topic, ending up in a public repository just means getting less attention for the manuscript in comparison with journals. It is less attention and prestige, but the same functionality in preserving the authorship and incorporating this piece of work in the science.

Many Science 2.0 proponents go further and consider blogs as promising tools for self-publishing. Aggregated scientific blog systems have been created, including thousands of personal blog, such as scientificblogging.com, blogs.nature.com, researchblogging.org, scienceblog.com, and scienceblogs.com. Some of these systems even allow peer-review of individual blog posts. However, the gap between blogs and scientific articles is so large, that blogs cannot substitute for scientific publications. (They can have other important purposes though). One of the main problems with blogs is that the amount of information increases tremendously, and so does the "information noise" to which the blogs contribute. Within a narrow field, a good personal taste and connections might still help to find the balance between the must-read and may-read articles. However, a few steps out of the scientific niche the scientist finds himself surrounded by unknown names and myriads of potentially useful works that cannot be explored in the whole life (8).

Classical peer-review journals have many problems, but they help decreasing the level of information noise by preventing obvious nonsense and violations of the scientific ethics. Since life is short and the internet is addictive, before investing the valuable time into reading a proposed manuscript, scientists would usually check that they are familiar either with the name of the author or the name of the journal, or that they know the research institution where the work was done or that they at least know the publisher. As discussed elsewhere, peer-review has a potential danger to become the peer-censorship for a specific journal or a group of journals (9). However, with many new journals competing and getting recognition at a fast pace, these fears can be significantly alleviated (it may be difficult to get it published in a *specific* journal, but usually no problem to publish elsewhere). In addition, a lot of enthusiasm in Science 2.0 has been associated with different types of alternative peer review systems such as the non-anonymous peer-review prior to publication (already works successfully, e.g. at *Biology Direct* and *Frontiers*) or the post-publication peer-review (10) (it was announced by several publishers such as PLoS, but does not work properly yet for the reasons that will be explained later).

Citation tracking systems further help ranking the articles in their potential usefulness/quality according to the number of citations they get. As a nice time-saving tool, rankings based on the citation metrics will definitely survive in the Science 3.0, because citations provide a realistic estimate of the utility of a paper (11). On the other hand, new internet rankings introduced in Science 2.0, which are based on the number of linked web pages or the number of users clicked the "like" button, have small chances to reflect the utility of a paper for a serious researcher. Even with the classical paper citations, technical players can figure out winning ranking strategies beyond making good science, and the performance of individual scientists and journals will depend on many non-scientific parameters, as with the stock market where the value of the stock does not necessarily reflect the performance of the company. An additional parameter which is difficult to predict for all players is the pressure from emerging scientific countries and new journals which would significantly change the citation distribution.

To summarize this section, we see that peer-reviewed journals common for Science 1.0 will be retained in Science 3.0, but will feel strong pressure from self-publishing Science 2.0 components. In order to win this competition, journal publication models will probably undergo changes in Science 3.0. Some of these changes are discussed below.

**2. Requesting money from authors can lead to biases and inequalities in the idea selection.** The common consensus in Science 2.0 is that all journals should be accessible online. In addition, free access to journals is highly coveted. The idea of having articles available freely to readers is called "open-access". In a more narrow sense, open-access is also a business model which is based on charging the publications costs to the authors instead of the readers. This model has also been applied long ago in the advertisement industry. In fact, several journals have explicitly printed in the past that, "page charges for this article have been partially paid by the authors, and the publication should therefore be considered as an advertisement". Those days are now gone, and paying for your article to be published is considered as a rule rather than an exception in Science 2.0.

Many scientists believe that the open-access model should win, and other publishing models should pass with the times. Essentially, the terms open-access and Science 2.0 are sometimes even interchanged. The problem is that while the open-access business model is looked upon favorably by readers, it also has its serious caveats for authors. In particular, the current open-access costs for one paper are comparable to the average monthly income of a person in US/Europe, and the situation is even worse for the majority of other countries. With regard to these large fees, only few countries have adopted funding systems where the author is compensated for both research and publishing. The list of these countries will hardly increase, because the countries which do not profit from their own high-impact journals have few reasons to bail out foreign publishers. Furthermore, even in the countries which have adopted such funding systems, not all scientists have access to them. It is frequently written in the journal rules that the journal would consider publishing an article for free if the author cannot pay. However, in practice the editors of open-access journals are under pressure to avoid free articles. Although journals have some limited funds to give waivers to authors who cannot pay, yet they are still a business, and their bottom line would suffer if this were to be their regular activity. Young scientists and scientists who have only modest budgets would typically avoid such journals, thus creating an income-based bias for scientific ideas, which is inacceptable. Therefore, balanced publishing models are required to ensure the fair distribution of both the access and contributions to the common knowledge (12,13).

What are the alternatives to the open-access business model, allowing everyone's free access to the articles? Many traditional publishers grant free access to the papers published several months ago – this is a nice option. (Actually, open access journals were very important as competitors to force classical publishers into granting free access). Further, due to common several-year gaps between the discovery and its implementation in medicine or technology, a several-month delay would not actually make papers outdated for the lay audience not involved in the intense scientific competition. Another possibility is for governments to subsidize open-access journals making them completely free both for the reader and the author. Note, however, that if the government subsidizes open-access journals only partially, allowing waivers to *some* authors, an income-based bias mentioned above remains. Finally, another possibility to allow public access to scientific articles is through the system of public libraries, as it was in the USSR more than two decades ago. In this scenario, internet era libraries can provide citizens' online access from their homes. Countries that cannot afford public libraries can be granted free or low-fee access by the publishers. For example, the journal PNAS had granted free access to 139 low-income countries. PNAS had nothing to lose since these countries would not pay for subscriptions, anyway, yet they produced a lot of articles citing PNAS.

**3. Post-publication comments and discussions will require special anonymization systems.** Post-publication peer-review (10) as well as comments at web sites of online journals are already considered as an essential constituent of Science 2.0. Several publishers have implemented online commenting systems, but up to now they do not work as expected. Scientists read but do not comment. Why not? The general idea was quite simple. In the traditional science, journals accept "comments" on the articles, subject to the journal's approval, which is usually at the editor's discretion. This is a very time-consuming process, which requires the authors to prepare a well-written text, and then the editor decides on the acceptance. Finally, a technical editor needs to work on the page layout. It is a serious work and responsibility for everyone involved, not surprising that comment articles are quite infrequent in the traditional journals. Comments online should have dramatically facilitate this process. A scientist just reads the article online, clicks the "comment" button and adds a couple of lines, e.g. that equation 15 is incorrect, or the figure caption is misplaced, or there is some fundamental problem with the method, or a literature reference is missing. Usual internet forums receive from 1 to 10 comments per 100 reads of the article, this ratio being roughly constant for a given forum (statistics, collected by the author). Based on such statistics, one would predict at least several comments being provided for each of the scientific articles online, since they already have thousands of reads weeks after publication. However, this is not what happens in reality. Most articles have no comments at all, even those which are highly disputable. Why is it so?

Let us look at the internet discussions in general. What we know from non-scientific internet forums is that the most democratic and open discussions occur when people have the option to remain anonymous. These are the old internet traditions. Even in the recent internet history, the most authoritative online collaborative tool Wikipedia is anonymous, while attempts to create analogous non-anonymous common knowledge tools such as Google Knol have failed so far. On the other hand, non-anonymous online social networking sites provide a new twist in the internet history. Several projects such as LinkedIn.com, ResearchGate.net, Academia.edu, Nature Network, Mendeley.com tried to use social networks for scientific collaborations. It was shown that many fruitful discussions take place in the informal, relaxed atmosphere of closed groups in social networking sites. However, scientists become more reluctant when it comes to the exposure of their opinion to the "whole internet" under their real name instead of a nickname.

While there are known open-science projects where participants decided to open to the public completely, such as the Polymath project devoted to mathematics, the general tendency is that scientists are reluctant to exhibitionism. For example, a relatively old online group "Genomics: Next Generation DNA Sequencing (NGS) and Microarray" at LinkedIn, consisting of almost 7,000 professionals including a lot of senior scientists from both academy and industry, was discussing for about two weeks the new option offered by LinkedIn to open the group content to the public. Not all people agreed with the argument that it is safe to open up if their surnames and profiles will not be visible. Up to now the group remains closed.

To understand the basis for the cautiousness with respect to the real-name policy, let us forget for a minute about the internet and return to the traditional science. It appears that scientists actually used to comment anonymously in most cases when this requires criticism. Disclosing the real name is incompatible both with the anonymous peer-review system and the anonymous voting system (the basis of the current understanding of democracy). Not surprisingly, most scientific internet forums with intense discussions are anonymous.

Following are several examples of popular internet forums in the field of molecular biology: biology-online.org, protocol-online.org, molecularstation.com, biotechniques.com, SEQanswers.com, and molbiol.ru. Each of these forums has around 20,000 users, covering, in total, approximately 100,000 molecular biologists. It happens that some of the users on these forums know each other's identities, but in general all these forums are anonymous. Anonymity allows asking stupid questions and getting quick professional answers; exchange ideas without revealing your current or nearest-future plans; peer-to-peer sharing of published papers; and honest evaluations of the works of the others. Anonymity also presents some inherent problems. For example, we cannot rely on the authority of the scientist who provided the answer. But that is in line with the basic science functioning: The validity of the arguments should not depend on the name of their author.

Scientific forums are very different from the journals. An important lesson we learn from them is that most discussions in the internet happen either in closed groups or under nicknames. However, if we do not disclose our name, we are not getting recognition for our contribution, which is the driving force of science (14). This is the point where internet is very different from science. What forces internet users to spend their time making comments at professional web sites? If we ask a question on a forum, we may derive a benefit directly from the answer. If we answer or comment on someone's answer by adding more details, there is still a possibility to learn, especially if we expect that someone will comment after us, checking our arguments. In addition, many people comment because they have an emotional motivation to do so.

Consequently, are we motivated enough to comment on a scientific article? In analogy with forums, the answer is definitely "yes". A student can ask a question and get an answer directly from the authors (e.g. if they are getting automatic email alerts for each posted comment) or from someone else who happened to read the same paper and found the question interesting. That would be useful for the others who will come months or years later, and will see some Frequently Asked Questions already answered. For those who are at the same level of expertise with the authors, online comments are more an opportunity to express their opinion and check whether other scientists feel the same about specific details of the article. Almost any paper has some weaknesses or points difficult to understand, which can be resolved by comments. (This is also true for the current manuscript!) There is usually no reason commenting if we agree with everything or understand everything. We comment if we have something to say or to ask. In this case, we are professionally and emotionally motivated and do not need additional profit of identifying ourselves, like in the examples with internet forums.

Anonymity allows for minimal efforts for the commenter. Importantly, it allows checking that our own arguments are right (or wrong) in a risk-free way to gain something from the discussion and not to reveal even a slight incompetence. This means that low quality comments can also arise, which is normal. The quality of comments should be regulated by the Netiquette (internet ethics), not by the science ethics. Inappropriate comments violating the Netiquette can be simply reported and removed. More than 10-year experience with anonymous scientific forums tells us that there are actually not so many situations when moderation is required. Furthermore, existing comments e.g. at *Nature* are of reasonably high quality. A recent quantitative study of the statistics of non-anonymous comments made at PLoS Journals and Biomed Central further supports this point, reporting just around 1% of comments as spam.

Now let us look from the point of view of the authors of the article that is being discussed online. From the first glance there could be fears that one day someone can find our mistake and openly dismiss online our work, trashing our efforts, time and money, something that is much less likely to happen in the traditional science system. One possibility to relieve these fears is to allow the authors a full moderation control over the discussion thread devoted to their article. However, careful thinking shows that the benefits of open comments significantly outweigh potential risks. Indeed, in the worst case we risk losing mere months of work rather than years (in the case if no one would point out to our mistake early enough). Most importantly, we will have a prompt interactive feedback (we could also have it through personal contacts, but internet does this without filtering, faster and more efficient). Finally, it is nice to have a chance to promote our article in a world-wide "journal club" of its readers with questions, answers, comments and interactive discussions that will be valuable many years after the publication.

Returning to the web sites of online journals that exist at the moment, we see that in most cases comments are not allowed at all. In the non-scientific internet there are analogies to this behavior. Comments are usually allowed under news articles, but prohibited under paid advertisement-type articles. This is understandable, since someone has paid for the advertisement and does not want comments to interfere with its message. However, scientific articles are not advertisements (at least, they are not supposed to be). Those few scientific journals that allow comments online take precautions: they force the user to register, mandatorily indicating his identity and institutional address. Technically, this takes some time. Every additional second spent on the web site decreases chances that a busy scientist will keep his intention to comment. (There are few journals which allow comments without registration, e.g. some journals of the Cambridge University Press and the British Medical Journal, but the users still need to provide their legal identity). In general, all comments are currently expected to be non-anonymous.

To address these issues, several networking sites performed attempts to establish post-publication discussions away from the publishers, such as the project Papercritic.com. In addition, users of commercial bibliographic software such as EndNote and Papers have the option to share their reading lists and comments with other users of this program online. Unfortunately, these comments are not linked directly to the journal web sites and therefore they might be unnoticed by the majority of scientists who read articles online. Furthermore, due to the intrinsic non-anonymity of social networking, such systems have difficulties in solving the main issue pointed out above, namely that critical non-anonymous comments are not natural both for Science and Internet. Therefore, massive online commenting will have to wait until journals allow the option of anonymous comments without registration. Furthermore, the journals would probably need to implement a special system erasing the history of the commenter's IP addresses or at least ensuring that this information remains strictly confidential. In addition, a system allowing basic forum features would be needed to insert quotes, images and upload files. Most importantly, the missing culture of anonymous comments online should be established.

A reader familiar with the Science 2.0 concepts might be disappointed that the picture outlined above seemingly goes away from the current state of the art of Science 2.0, not making use of many fashionable Web 2.0 features which are all essentially non-anonymous. But it should be understood that Web 2.0 is also not something frozen. It would be overly naïve to think that the Facebook-type behavior is the top level of the evolution of Internet. The next era of Internet, the Web 3.0, will be very different from Web 2.0, most probably including sophisticated privacy-protecting systems. There could be different understandings of the privacy online. It is different for teenagers, for scientists, for politicians… The privacy of a scientist is the privacy of his thinking. For many scientists who work seriously on a problem, non-anonymous sharing of the current reading lists and comments with the whole internet is a breach of privacy, comparable to putting a web-camera in a bathroom. It is worth to note that historically, science was leading Internet, not the other way round. Therefore Science 3.0 could take the same role for the conceptual defining of Web 3.0, requesting new internet features rather than adopting itself for the existing ones.

## CONCLUSIONS

Internet evolves very quickly and so does science. Most of the features considered as revolutionary several years ago are now either trivial or have been tried and did not work out. For example, it is quite interesting to read today an article entitled "The future of medical journals…" written in 1998 (15). Not so long ago, but still before the digital journal era, the authors were able to foresee many of the features that we have today. Hopefully, the predictions made in the current manuscript will be also realized in the near future. We have concluded that the pre-publication peer-review will survive as the way to ensure the quality control check, but will be complemented by self-publishing at online preprint repositories and by the post-publication comments on the articles. Among other things, we have shown that charging the open-access article fees to the authors can lead to scientific biases based on the author's income. We have also provided the first systematic argumentation showing that Science 3.0 components including post-publication discussions in the form of world-wide "journal clubs" at web sites of online journals will be mostly anonymous. These are obviously not the only new features of Science 3.0, and the futuristic analysis should continue.

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