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Galileo, Fourier, and Openness in Science

I am always amazed at the speed at which societal changes and behavior are happening in response to the emergence of large Internet-based powerhouses such as Amazon (founded in 1994), Yahoo (1995), Netflix (1997), Google (1998), Wikipedia (2001), Facebook (2004), YouTube (2005), Twitter (2006), Uber (2009), and others. All these companies were founded after I completed my Ph.D. degree in 1992 at Stanford University. What a ride it has been! Social communities have become global, information is reached with the click of a button, and news spreads at the speed of light. Students graduating today from college have grown up in this new environment, surrounded by an avalanche of online apps and material. Their interaction with information is different from a generation before them. For this younger generation, and for many of us today, whether right or wrong, our first stop when looking for information has become the Internet. We expect information to be easily accessible and generally free. For example, the dates in this article were obtained online, mainly from Google searches and Wikipedia.

There is so much good that can be done in this new reality and also so much harm when privacy, trust, and the equal right to access are lost. Let us focus on the positive aspects in this writing.

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It is time for the scientific community at large, and for professional organizations like ours, to embrace this openness more radically. Consider just one example: the current academic exercise of publishing scientific articles in archival journals. In our field, the IEEE is the leading organization in publishing refereed work with over 420,000 members worldwide. These published works are made available online through the IEEE *Xplore* platform, which was launched in 2000 and has exceeded 2 billion article downloads since then. The platform has been a step in the right direction and has facilitated access to published science. This access, however, is only available to institutions and members in return for a subscription fee. The IEEE has not yet embraced the full potential of the Internet revolution to make scientific information more accessible to hundreds of thousands of researchers worldwide, including those who cannot afford it. The same is true for other publishing houses that argue in favor of subscription fees to cover publication costs.

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I believe that more can be done, especially since many organizations today have been able to find innovative ways to offer users free access to services online. One example is news organizations with expansive online presence where readers can access news and even videos for free, such as the BBC and CNN, among others. Examples also exist of online peer-reviewed journals that provide free access to published articles, keep copyright with authors, and do not charge overlength page charges. Viable models should be sought. The IEEE, given its prominence and leadership, can and should be playing a defining role in this evolution.

Many of us agree that the current publishing process is moving toward a bottleneck. The number of submissions to scientific journals is increasing exponentially, the size of many editorial boards is inflating, and the quality of the reviews is sometimes questionable. Is this serving the advance of science? We need to embrace the online medium and its potential for innovative solutions more creatively. More open platforms should be developed to allow the participation of a broader pool of certified reviewers and the free and wide sharing of manuscripts, data, and code. The platforms could also allow for open discussions on drafts and even provide collaborative mechanisms for pools of researchers to work together on open problems. The online medium can and should be exploited more forcefully to promote new modes of generating, assessing, and sharing science. There are laudable efforts in this direction, with

many of them today occurring outside the realm of the IEEE.

For example, free online repositories for manuscript preprints have become very popular and are being embraced almost daily by growing communities. Among these we may mention arXiv (physical sciences), bioRxiv (biological sciences), socArXiv (social sciences), chemRxiv (chemistry), agriXiv (agriculture), The National Bureau of Economic Research (NBER), Social Science Research Network (SSRN), Zenodo (data sets), and others. Most of these acronyms refer to repository platforms where manuscript drafts are posted online by their authors for broad dissemination. ArXiv is one of the earliest bottom-up efforts and is closest to our field of interest. It is widely popular in the mathematics and physics communities and has also gained a strong following within computer science and engineering. Many authors in our research community have embraced arXiv, and our Society has recently launched a signal processing category within arXiv. The growth of arXiv is living proof that there is strong interest in advancing new ways of sharing science. At times, even news outlets like the BBC and CNN report on "fresh" results posted on arXiv. Founded in 1991, it has crossed over 1 billion paper downloads since then. It has also motivated several of the subsequent platforms like bioRxiv (launched in 2013), socArXiv (2016), and chemRxiv and agriXiv (2017). Most of these open platforms are focused on "sharing" science online and less on exploiting the online medium for "assessing" or "generating" science. While more can be done, these platforms are a positive step forward.

Others are exploring more effective solutions, with more features and opportunities, and new tools are waiting to happen. However, success in promoting the "sharing," "assessment," and "generation" of science more broadly will require directives from large institutions, leading universities, funding agencies, and governments. Some nontrivial changes in culture will be required. I believe that effective progress is possible. After all, this is the 21st century! We can send Tesla cars into orbit and Mars Rovers to a remote planet. And yet, we cannot sit down and explore ways to solve a more mundane problem: how can we vet the ever-increasing amount of research more thoroughly? How can we make it freely available for the entire world to see? And how can we get researchers from remote corners of the world more excited about collaborating on open problems online? Amazingly enough, despite the huge progress we have witnessed over 100 years, our current vetting of science is somehow between what Galileo and Fourier experienced.

Galilei Galileo, the noted Italian astronomer, looked through his crude telescope in 1610 at a remote object in the sky and discovered some anomalies around Saturn. He was not able to recognize these anomalies as the rings around the planet. He instead thought that he had observed a composite of three objects and wrote "oOo" in his notes to refer to the shape of the object. Galileo was a superlative scientist, and he had a clear instinct that he had discovered something very important. He wanted to make sure that he would get the credit for it once it became clear what it was. So he sent a coded message to Johannes Kepler, another giant of astronomy, with garbled letters [1]. Once decoded, these letters would result in a sentence attesting that Galileo had discovered the phenomenon first. This form of communication, through coded messages, was not unusual during Galileo's time. That is how some scientists used to share their discoveries to claim priority. It took almost 50 years until, in 1656, the mysterious objects observed by Galileo were finally discovered to correspond to rings around Saturn by Christiaan Huygens, of wide fame in the field of optics. Huygens also announced his discovery in a coded message only to be decoded a few years later! Imagine if we were to write papers today in that same manner in code! Fortunately, we have moved away from that mode of (not) sharing science.

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Move forward almost two centuries to 1807 when Jean-Baptiste Fourier presented his masterpiece work on the propagation of heat for review to the Academy of Sciences in Paris. His work was reviewed by a notable committee, which included giants such as Laplace, Lagrange, Legendre, and Monge (the father of differential geometry). What is remarkable about this story is that we know who reviewed Fourier's work, and we also know how accomplished they were. We even know more. We know that the committee rejected Fourier's work, and we also know the reason why. There were shortcomings in the proof of convergence of the series representation (now known as the *Fourier series*), which he introduced in hissolution of the heat equation. It was natural to wonder how the sum of smooth sinusoidal functions could add up to rectangular pulses with sharp transitions. The concerns that were raised by the committee evaluating Fourier's presentation in 1807 were technically sound. Dirichlet, who was a student of Fourier, would give the first rigorous proof of the convergence of the Fourier series only two decades later in 1829. The rejection in 1807 did not deter Fourier. He knew that he was working on something singular. In remarks he made about his work on the heat equation, he commented on connections to Newton and on how "heat, like gravity, penetrates every substance of the universe" [2]. The reference to Newton's gravity does not go unnoticed. Fourier pursued his work and resubmitted it again four years later to the 1811 Grand Prize competition; the award committee this time again included Laplace, Lagrange, and Legendre among others. He was awarded the prize albeit with some reservations, which delayed the publication of his work until 1822 (that is an 11-year wait in a publication queue in our modern language)! Today's Fourier's tools are at the core of the signal processing discipline. What is noteworthy about this story is how giants of their fields vetted this work in the open and how this openness only made the

work stronger and more impactful and not less.

Today, we operate in a different setting in our field. We are not as secretive as Galileo's time but we are also not as open as Fourier's time. Reviews today are confidential, with some reviewers offering top-notch feedback and others simply repeating statements from the draft they are reviewing. Some experts even refuse to respond to repeated invitations to review papers that build up directly on their own works! Compare their attitude with that by giants like Lagrange, Laplace, and Legendre who did not shy away from reviewing Fourier's work twice in 1807 and 1811! A paradigm shift is needed given the evolving dynamics in the number of submissions and the need to share results more broadly. Imagine if works were to be subjected to a more open discourse and assessed by a larger pool of certified reviewers, and if we were to tap into the power of the online medium to facilitate and promote these interactions and make research results available broadly and freely. Changes of this type would require careful planning. But the time to consider solutions and to open up the process by which we deal with publishing and sharing scientific results is upon us. I am personally convinced that the way we vet science today in our community is not sustainable in the long term and will need to become more open again. The online medium offers opportunities for effective solutions and more openness in science. So I conclude with an anagram à la Galileo: *letuferomecneicsnissennepoe carbmesully*.

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References

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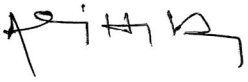

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