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The Integrity of Science III

A Different Kind of Scientific Revolution

Barbara A. Spellman

The troubling litany is by now familiar: Failures of replication. Inadequate peer review. Fraud. Publication bias. Conflicts of interest. Limited funding. Flawed statistics. Perverse incentives. Each of these concerns has been pointed to as a cause of the current crisis in science. Yet none of these is novel; they have all previously been acknowledged by scientists and criticized by science watchers. Accordingly, we should not only ask why science is going through its current moment of self-examination, but also why science is going through it *now*.

To some extent, the change has to do with the nature of scientific research itself. Scientific claims are supposed to be justified by their reliance on observable and repeatable events, providing methods and conclusions that can be (and are) vetted by expert peers. And yet science seems increasingly to make what are tantamount to appeals to authority: the measurements of scientific phenomena are often far removed from direct sensory observations, studies often require materials or instruments that are not widely available, and chains of inference from data to theory have become ever longer and more subtle. All this adds up to a feeling of (to borrow a phrase familiar to parents of young children) "because I said so." In a way, these are not new developments; modern science has always been somewhat abstruse and distant and complicated. But with the proliferation of subspecialties in subfields, this problem seems to be worsening.

If we wish to understand why the critical self-evaluation phase in science is occurring now, however, we should consider relatively recent changes in technology and demographics. They are among the structural forces that have contributed to the current situation, which I call a revolution in science. I don't mean that it is a scientific revolution as

Barbara A. Spellman *is a professor of law and a former professor of psychology at the University of Virginia. She was editor of* Perspectives on Psychological Science *from 2011 to 2015, during which time the journal published over a hundred articles relating to the ongoing self-examination within psychological science.*

described by Thomas Kuhn in *The Structure of Scientific Revolutions*; it does not involve overturning the core knowledge in any particular scientific field. Rather, we are going through a technological and social revolution that is transforming the way scientists interact with each other and with the larger scientific community. These same changes in technology and demographics are also likely to help us find our way out of the morass we are now in. New procedures for performing, evaluating, and communicating science will, ironically, help us to return to the fundamental values of the scientific method from which we have drifted.

Opening Up Science Online

Information and communication technologies—computers and the Internet, smartphones and their apps—have changed science in myriad ways. Many types of research can be done more quickly; more data and more *kinds* of data can be easily collected; and what used to be painstaking analyses have become much easier, sometimes even trivial. Literature searches have become immensely simpler, and distant collaborations are now more common.

Yet over the past quarter century, while our new computing power and interconnectedness were speeding up the production of science, their effect on the publication of science was in some respects harmful. There were more journals than ever before, and they were pumping out more articles than ever before, but this was accompanied by growing competitive pressures on researchers to publish more. Meanwhile, many print journals lowered their word limits on articles. In my own discipline of psychology, the papers in some journals often had descriptions of methods and results that were lacking important information; researchers would choose not to include study conditions or measures that did not fit the stories they wanted to tell. The odd result: while there was more research being published there was less of it available for scrutiny. Meanwhile, all of these factors combined to make peer review both less efficacious and more of an endless, unrewarding chore.

The new technologies had other effects as well. For example, the ease of communication among scientists led to an increase in private exchanges among scientists. Discussions about failed attempts at replicating a colleague's research, which were once limited to fortuitous conversations at conferences, could now be held across continents. It was becoming easier to learn that it was not just your own ineptitude that was to blame when you could not replicate a highly cited finding. There were worrisome

things happening in scientific publishing, and more people were finding out about them.

Technology thus instigated some problems in science, but it also provides some solutions. Most importantly, thanks to the web, the processes of production and dissemination of science can be made more transparent and more open. For example, the methods sections of research reports need not be subject to the word limits imposed on standard print publications. In the behavioral and social sciences, it is not uncommon to see methods sections that include links to detailed descriptions of what was done and why, online appendices with full written materials such as instructions or surveys, or even links to videos of the procedures. Data sets and analyses can now be made easily available for others to scrutinize or use. Online versions of articles already contain live links to cited research (and perhaps someday digital archiving will inform us when an article we would like to rely on has been retracted). And now, not only can papers be "prepublished" so that research results can be available before journals get around to "officially" bringing them out, but also hypotheses can be publicly registered before studies are even run. Registering hypotheses ahead of time may help reduce the creation of *pre*-dictions after the results of an experiment have already been revealed—what is sometimes called HARKing, or hypothesizing after the results are known. This matters because predictive power is traditionally held up as a key characteristic of robust scientific theories, whereas theories that offer explanations of observed phenomena only after the fact are considered *ad hoc*.

New Methods for a New Generation

The other important change is not only remaking the face of science but also affecting how it operates. The growing number of scientists and their growing diversity have likely contributed to tension in many fields. The highly visible and productive members of the older generations of scientists who made their way to the top under the status quo have an interest in keeping scientific practices as they have been. The younger generations, who are under increasing professional pressure to publish in today's less chummy and more competitive environment, are more comfortable with the public sharing of information. They would like scientific publishing to become more open and also more fair to researchers who are not already on top or who were not spawned from the labs of those who are. The successful members of the older generations are now the editors of journals, the chairs of award and hiring committees, and the

members of grant panels. The social dynamics are predictable: people like people who are like them, and people trust people who are like them (and, of course, people who *agree* with them). And they will help each other. A prominent psychologist once said to me, "No friend has ever rejected a manuscript of mine before." And, indeed, before I rejected his manuscript, he had had plenty of friends who had been editors. Publications, promotions, grants—the procedures for awarding them have long helped maintain a status quo in science.

Of course, in science as in other endeavors, generational divides are a perennial source of tension, and generational turnover is a perennial source of innovation—as witness the old saw that "science only progresses one funeral at a time." But today's generational turnover is coinciding with the technological transformation described above. And so it profoundly affects how different scientists view the present moment of crisis in science—as tragedy or opportunity. The generational divide can be seen in the divergent content of publications about the crisis, the names in the lists of authors on replication studies, the tone of blogs, and the comments on listservs and Facebook groups. It can also be seen in the constituencies of the many organizations that have arisen to push for the improvement of scientific practices. About six years ago, during the early discussions about the publication of replication attempts, some members of the older generation expressed concern that the demand for replication might unduly damage the reputations of good scientists, while others argued that only people who were incompetent or who had no creative ideas of their own would ever attempt to replicate someone else's research. (Such cries lessened when these scholars were reminded that they themselves had often instructed their students to replicate previous research when beginning a related research project.) There have been cases in which successful senior researchers have refused to share their data with others—for example, declining to share data with researchers performing meta-analyses—sometimes for legitimate reasons (e.g., the study was performed decades ago and the punch cards were lost in a fire), sometimes not, despite having acceded to publication rules that required them to do so, and despite the fact that their data collection was funded by a federal granting agency.

So now the younger scientists are doing most of the replications. And the younger scientists are developing the technological tools that will enable all of us to conduct more open science. And the younger scientists are the ones more likely to be using those tools.

The Next Scientific Revolution

We are past the early skirmishes. During the phase we are now entering, we can expect to see long-lasting changes in the operation of science. We have seen prominent research findings debunked and prominent researchers forced to retract papers. We have seen funding and publication practices beginning to transform. We have seen the success of (some) online-only journals. And we have seen the establishment of organizations, within and between disciplines, aimed at making science more open. In psychology, a new organization, the Society for the Improvement of Psychological Science, held its inaugural meeting in June 2016. In the social sciences more broadly, the Berkeley Initiative for Transparency in the Social Sciences has been at work since 2012 with the goal of "strengthen[ing] the quality of social science research and evidence used for policy-making." And a group of social scientists, editors, publishers, funders, and leaders of academic societies wrote the Transparency and Openness Promotion Guidelines—published in *Science* in 2015—suggesting ways that journals could improve transparency and openness. Over seven hundred journals from across the sciences have now signed on to the guidelines.

Once all these changes are in place, it seems to me that we may well end up with something closer to the way science was conducted in the days when scientists knew each other personally, the disciplines were smaller, and the research was slower and simpler: *It's not that I don't believe you but I want to be able to understand what you did and how you came to your conclusions—because that is how science works.* I call that a revolution.