Routledge
Taylor & Francis Group

Innovations in Education and Teaching International

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/riie20

Teaching scientific research integrity: A case study

Andrea Saltelli

To cite this article: Andrea Saltelli (24 Jul 2023): Teaching scientific research integrity: A case study, Innovations in Education and Teaching International, DOI: 10.1080/14703297.2023.2237949

To link to this article: https://doi.org/10.1080/14703297.2023.2237949

Published online: 24 Jul 2023.

INNOVATIONS IN EDUCATION AND TEACHING INTERNATIONAL
https://doi.org/10.1080/14703297.2023.2237949

Routledge
Taylor & Francis Group

Teaching scientific research integrity: A case study

Andrea Saltelli [a,b]

[a]UPF Barcelona School of Management, Pompeu Fabra University, Barcelona, Spain; [b]Centre for the Study of the Sciences and the Humanities, University of Bergen, Bergen, Norway

ABSTRACT

The focus of this case study is the question, 'How can research integrity be taught in higher education?' I will share my experience of teaching this topic over the past three years, organising the various dimensions of research integrity under the broader theme of integrity in science, specifically in terms of norms, functions, and unity. Norms refer to how science conforms or deviates from normative standards, such as those proposed by Robert K. Merton. Functions relate to how science and research are endowed with a functioning, non-damaged mechanism. The third meaning pertains to the notion of science as an unbroken and undivided entity. This innovative approach may aid students in understanding the various aspects of research integrity, help them addressing the contradictions they may encounter in their work, and introduce them to the historical, philosophical, and sociological elements of science, including those from the field of Science and Technology Studies (STS).

KEYWORDS

Sociology of science; science and technology studies (STS); science reproducibility; projectification of research; scientific publishing; scientific review

Background

In recent years, many universities, hospitals, and research institutes have created offices to ensure research integrity, which has now become a research area in itself. Given that ethics itself is polymorphic, and different 'orders of worth' (Boltanski & Thévenot, 2006) can lay legitimate claims to our attention, it is not surprising that integrity is multidimensional. Its facets may include the quality of research as a craft whose tradition challenges the usury of time, the ever-changing existential characteristics of a life spent in science, in academia or outside it, and the ethical compass of researchers and the institutions they work in. All of these aspects evolve under the rapid changes of the relation of science with society (Saltelli & Boulanger, 2019).

For example, in the field of medical research, warnings have grown louder in recent times, focusing on bad or corrupted practices (Harris, 2017), the influence of industrial (Goldacre, 2012) and financial (Ioannidis, 2016) pressure, the resulting decline in the

CONTACT Andrea Saltelli andrea.saltelli@gmail.com UPF Barcelona School of Management, Pompeu Fabra University, UPF - Balmes, Carrer de Balmes, 132, 134, 08008, Barcelona, Spain

quality of preclinical (Begley & Ioannidis, 2015) and clinical (Ioannidis et al., 2016) research, and the so-called 'reproducibility crisis' (Ioannidis et al., 2016; Saltelli & Funtowicz, 2017).

This case study addresses the integrity of science within the broader context of research integrity, drawing on my experience teaching this topic to PhD students from various disciplines in Barcelona over the last three years (la Caixa Foundation, 2023). The lectures, which were held twice a year, lasted about half a day and included practical exercises. Additionally, some of the ideas discussed here come from lessons I taught in Bergen within the 'Theory of Science and Ethics' course from 2019 to 2022 (University of Bergen, 2023). Specifically, my contribution to the course in Bergen focused on the ethics of quantification and mathematical modelling (Saltelli & DiFiore, 2020).

Purpose of the work

This paper is an open-ended proposal for a course aimed to PhD students from all faculties, rather than a fully formatted syllabus. The teacher can select from this text according to the learning context and personal preference. Reflecting on the challenged integrity of science becomes a way to reflect on what science is – also in the hearts and minds of the students taking the course – and on the prevalent sociotechnical imaginaries (Jasanoff & Kim, 2015): how visions of scientific and technological progress carry implicit ideas about public purposes, collective futures, and the common good. In particular, the proposal is to bring to the attention of students the contradictory nature of intimations of research integrity in a context of commodified knowledge, pursuit of efficiency, the practice of publish or perish, and the overall neoliberal imprinting prevailing in higher education (Mittelman, 2017). Although the half-day course forms the basis of the present contribution, I also offer suggestions for expanding the topics to cover a brief course on the subject.

Relationship to past or current work

Ščepanović et al. (2021) surveyed over 100 works on research integrity, including both academic articles and guidelines, and identified a need for more training aimed at research funding organisations and specific disciplines. Sponholz (2000) offers advice for a course covering both scientific integrity and research ethics. He notes the students' positive reception of the theme and the need for more extensive teaching of research ethics in both undergraduate and postgraduate academic education. Sachs and Siegler (1993) share their experience with a two-year course on the topic, which allows students to develop an understanding of their own values in the context of potential ethical conflicts in research and scientific training. Schrag (2005) discusses a web-based resource for teaching research integrity, while Erasmus University Rotterdam (2020) offers a downloadable application that contains up to 75 research dilemmas for students to consider. Pritchard (2005) warns against relying on online material for 'quick fixes' when teaching this topic and emphasises the importance of in-depth and longer-term opportunities for both students and faculty to work together on integrity issues.

Integrity as the adherence to a set of norms

The course naturally begins with an exploration of the Mertonian norms of science, known by the acronym CUDOS: Communalism (initially Communism), Universalism, Disinterestedness and Organized Skepticism (Merton, 1973). These norms are sometimes challenged in the practical life of researchers by counter-norms[1], which were studied by Ian I. Mitroff (1974) in his interviews with scientists involved in the Apollo program. Anderson et al. (2007) also provide a useful case study on 'cognitive dissonance', in which interviewed researchers perceive themselves as following Mertonian norms while perceiving their colleagues as following the opposite counter-norms. Drawing on these three sources, a productive exercise for students is to debate the issue in small groups and elect two opposing advocates to defend either the norm or the counter-norm in front of the class. Richard (Feynman's, 1974) Caltech lecture 'Cargo Cult Science' is a valuable text to explore the organised scepticism norm: his call to 'lean over backward' to permit an opponent to falsify one's own work is a possible suggested reading for the course (Table 1). In discussions with students, it has often been hypothesised that this norm is crucial in distinguishing science from other enterprises.

Max Weber's (Weber, 1946) famous lecture 'Science as a vocation' is also relevant to the topic of research ethics. Two elements are particularly noteworthy: first, Weber's disenchanted view of an academic career; and second, his normative caveat that science can tell us how to explore nature, but not why we should explore it. According to Weber, those who think otherwise are 'big children'.[2] This could be an interesting subject for discussion in the course. Regarding disenchanted if not outright satirical views of academic life, the teacher can mention Cornford (1908) piece entitled *Microcosmographia Academica*.

The topic of open science is highly relevant in the context of science and research integrity. Various views on this subject can be found in the literature, ranging from overall optimism (Fecher & Friesike, 2014), to outright criticism (Mirowski, 2018; Pooley, 2020). As a starting point, I suggest looking at the work of Paul A. David (2008), who reconstructs the historical evolution of secrecy and patronage versus openness in science as a result of the scientific revolution. He stresses how science was initially born secret and under the tutelage of powerful patrons, as revealed by a quote from Galileo:

> Regarding the everyday duties, I shun only that type of prostitution consisting of having to expose my labour to the arbitrary prices set by every customer. Instead, I will never look down on service a prince or a great lord or those who may depend on him, but, to the contrary, I will always desire such a position (cited by David, 2008, p. 63).

Table 1. Suggested readings: *** Essential, ** Important, * Useful.

Integrity as the following of a norm	Richard (Feynman's, 1974) Caltech lecture 'Cargo Cult Science'	***
	DORA (2013) San Francisco Declaration On Research Assessment	**
	Steven Shapin (2016) about the prodigies of 'invisible science'	*
	Saltelli and Funtowicz (2017) on the crisis of science	*
Integrity as functioning	Monbiot (2018) on the publishing system as a 'rip off'	***
	Smaldino and McElreath (2016) on the Darwinian fitness of bad science	**
	Edwards and Roy (2017) on the contradictions between proposals and results	*
	Osterloh and Frey (2020) on impact factors and the grants system	**
Integrity as unity of science	Crowe (1969) on why science's disunity is a problem	***
	M. Polanyi et al. (1962) Republic of Science	*
	Mirowski (2020) on democracy, expertise, post-truth and science wars	*

A potential digression here would be to discuss with students the romantic image of Galileo as portrayed for example in Berthold Brecht's 1943/2013 play, versus the accounts of STS scholars such as Feyerabend (1975). David (2008) presents open science as a fragile social construction resulting from the movement away from secrecy and princely patronage of the age of Galileo towards state patronage, academies, and other modern institutions of science that took place in the period between the Renaissance and the Industrial Revolution. According to David, open science exists today, funded by public and private actors, based on a distinctive ethos, and coexists with commercially oriented research. Yet, he notes that open science faces a tension between defending the existing Mertonian CUDOS and 'public knowledge' against proprietary science, secrecy, and visions of a knowledge economy. For David, the acceleration towards 'intellectual capitalism' risks moving science back to the age of princely patronage, from CUDOS back to the pre-Renaissance ethos of secrecy in the pursuit of Nature's Secrets.

A radical version of David 's concerns is found in (Mirowski, 2018), who warns about the 'Uberization of science' (an allusion to the transportation app). Reading Mirowski may be intriguing since most students either use or know platforms, such as Academia, arXiv, Mendeley, Research Gate and others, that – in the perspective offered by Mirowski (2018, p. 191), may compete to become 'the' one stop shop for a scientific activity. For Mirowski – an author who has written extensively about the commodification of science – 'the future is with us already', as scientists already live in 'a quasi-market that constantly monitors their "net worth" through a range of metrics, scores and indicators' such as the H-index, impact factors, peer contacts, network affiliations, and others.

In the course, I then move to the question 'To what kind of science, as a young student, am I pleading allegiance to?' After introducing Stephen Toulmin's (1992) work *Cosmopolis*, students can be asked whether they agree about having been nourished and trained in what Toulmin calls 'The hidden agenda of modernity': the vision of a society as rationally ordered as the Newtonian view of nature. This so-called 'Cartesian Dream' can be illustrated with material from Davies and Hersh (1986) and Pereira et al. (2015), and a text by Francis Bacon (1627) from *New Atlantis* about the promise of the prodigies to come from science.[3] A short reading from STS (Science, Technology and Society) scholar Steven Shapin (2016) about the 'invisible science' is relevant here to discuss how in our daily experience we are surrounded by objects resulting from some manufacturing process that fits the Baconian promise of a new world, and how this invisible science is in fact visible in all devices that equip the very classroom where the course takes place. The purpose of this discussion is to confirm the success of the dream and permit its critique.

This section on alternative visions of science can start from Conner's (2005) work on where science comes from, whether academia or the crafts. Conner's book, entitled *A People's History of Science: Miners, Midwives, and Low Mechanicks*, discusses our debt towards the forgotten protagonists of 'knowing how', who according to Conner made the bulk of scientific discoveries, against the 'knowing why' provided by academia, with plenty of interesting case studies. In this regard, it also worth mentioning the so-called 'Zilsel thesis' (2003, p. 232) that science results from the efforts of great artisans, secular humanists, and university scholars. For Zilsel, 'Science originates in urban cultures, money economy, market economy'. This thesis is also found in Marxist scholar Boris Hessen (1931). Both authors are keen to distinguish between an image of science as the product of a few great minds and an image of science – as described by Hessen – as originating

from the commercial and capitalistic needs of the nascent bourgeoisie in the 17th century, or – as described by Conner – as resulting from the humble work of craftsman, barbers and midwives. It may also be interesting to note here how the history of science has largely focused on men, and to discuss the great women of science, including the cases where their achievements were attributed to men.[4] The absence is visible in photos of the Solvay society in 2 meetings several years apart, in 1911 and 1927, showing a solitary woman in the person of Madame Curie.[5]

The course has now taken the direction of an epistemological therapy, where some of the cherished notions learned in college are revisited in a critical spirit. Thomas Kuhn (1962) was one of those who believed the teaching of science to be too dogmatic, and some quotes from his *The Structure of Scientific Revolutions* may illustrate this point:

> the 'educational initiation that prepares and licenses the student for professional practice . . . is both rigorous and rigid . . . It is a narrow and rigid education, probably more so than any other except perhaps in orthodox theology . . . the member of a mature scientific community is, like the typical character of Orwell's 1984, the victim of a history rewritten by the powers that be' (p. 192).

I conclude this part of the lesson with a discussion of industrialised or commodified science (Mirowski, 2011), where science itself is seen as an instrument of domination, lobbying and regulatory capture. This includes cases where science is used in the new media to create astroturfing – an apparent grassroots support for corporate practices or products made in the name of science. This is the topic of the so-called 'Guardians of Reason', who are enrolled to uphold the industrial position on pesticides, genetically modified products, nuclear energy, or unregulated use of artificial intelligence (Foucart et al., 2020; Saltelli, Dankel, et al., 2022).

Integrity of research in its functions

Among the components of the research system whose integrity appears to be under threat, I have divided the discussion into three chapters:

- The challenge to the quality control system of scientific production, leading to the reproducibility crisis;
- The challenge to the publishing and review systems, which includes issues related to predatory publishers, unfair profits and exorbitant fees of publishing houses, as well as authorship for sales and many others;
- The challenges arising from the projectification of research and the mechanisms for the adjudication of grants.

The literature on the reproducibility crisis is extensive. One can introduce students to the early prediction of an impending crisis made by Derek de Solla Price (1963), who believed that science might eventually succumb to senility under the weight of its own production. Another prescient voice is that of. Ravetz (1971), who was aware of the strain that the quality control arrangements of science would experience in the transition from little science to the big or mega science.

Also worth mentioning are scholars such as John Ioannidis, Brian Nosek, Glenn Begley, and Ben Goldacre, among others, as reviewed by (Saltelli & Funtowicz, 2017). Nosek's Centre for Open Science (Open Science Collaboration, 2015) and Ioannidis' Meta-Research Innovation Center at Stanford (METRICS, Ioannidis et al., 2015) are noteworthy institutional attempts to address the crisis. Perspectives of other scholars worth mentioning are those of Fanelli and Scalas (2010) and Munafò et al. (2017). The activity of the collective known as Retraction Watch (https://retractionwatch.com) also deserves a few words.

If all students come from the same field of study, the teacher may select texts for this section accordingly. However, it would be useful to discuss for all the role of statistics in the reproducibility crisis, as well as the use and misuse of the P-test and the phenomenon of HARKing, which involves testing multiple hypotheses until one pass the significance level (Kerr, 1998; Stark & Saltelli, 2018). If time and audience permit, this would be a good opportunity to introduce students to the sociology of quantification (Mennicken & Espeland, 2019; Popp Berman & Hirschman, 2018). For those in the room who work with mathematical modelling or data analysis, it would be worth discussing the nature of these models and their political implications (Morgan, 2012; Saltelli & DiFiore, 2023; Saltelli et al., 2020).

Moving on to issues with the publishing system, two articles that appeared in *The Guardian* (Buranyi, 2017; Monbiot, 2018) provide a good introduction and can be recommended for reading. The first covers a 2005 Deutsche Bank report, which describes the 'bizarre' 'triple-pay' system in which 'the state funds most research, pays the salaries of most of those checking the quality of research, and then buys most of the published product' (Buranyi, 2017). The profit margins of the publishing sector are exceptionally high: the second article, written by Monbiot (2018), describes the system as a 'rip off'.

There is also a vast literature on predatory publishing (Singh Chawla, 2021) – a phenomenon that unfortunately continues to increase as a downside of open science. Jeffrey Beall (of the eponymous list) defines predatory publishing the Achilles heel of the article processing charge (APC) model. Shen and Björk (2015) are a good source for this topic.

Additionally, there are malpractices in the citation system, including excessive self-citations, citation cartels (groups of scientists quoting one another), and citation stacking (the same but with journals this time; see Van Noorden, 2013). The review system is also flawed, as reviewers may try to pump up their record by asking their own papers to be cited (Van Noorden, 2020).

Ghost authorship or the outright sale of authorship, according to Holly Else (2023), have become a multimillion-dollar business. Furthermore, the proliferation of fake papers has become such a problem that artificial intelligence is now being used to detect them (Else, 2022).

Another important theme to discuss is the 'projectification' of research, where researchers spend inordinate amounts of time writing grant proposals, few of which will actually be funded. Interestingly, this funding model was already satirised in 1948 by Nobelist Leo Szilard in a science fiction short story as a perfect recipe for slowing down the advancement of science, by keeping scientists away from their labs. Still, the dystopian aspects of science funding and academic carrier arrangements are delicate topics, as the teacher has to weigh the chance of discouraging students against the need to give them realistic expectations about what lies ahead. A tenure-track scientist may end up 'biting the dust' (Ruben, 2017) for failing to secure a grant within a given time window.

This reading can be used to open a discussion on how the grant selection system already has features of a lottery of sorts, which could suggest the need to transform it into an explicit lottery (Osterloh & Frey, 2020). The same reference also offers an excellent description of how misleading a journal's impact factors (IF) can be. It shows that IF, being the mean of a highly skewed distribution,[6] has no practical relation to how often a paper will be cited. Only elementary statistics are needed to appreciate the plots offered in the paper.

The issues of dark money (Mayer, 2017), tainted donations (Rogers, 2019), or other dubious funding practices can be mentioned here, depending on the duration of the course, and with an eye to letting students discuss among themselves where the bar should be set.

Malpractices are a consequence of science's governance model and its 'publish or perish' zeitgeist. A suggested reading here is Smaldino and McElreath (2016), who discuss the Darwinian fitness of bad science to the present system of incentives. Edwards and Roy (2017, p. 52) provide a description of how good intentions to improve science (or to make it more efficient) end up making it worse. To give an example from one of the tables in their work, the incentive whereby 'Researchers [are] rewarded for increased number of publications', whose intended effect is to 'Improve research productivity, provide a means of evaluating performance', has the actual effect of an 'Avalanche of substandard, incremental papers; poor methods and increase in false discovery rates leading to a "natural selection of bad science"[. . .]; reduced quality of peer review' (p. 52).

Many initiatives have been taken to improve research evaluation, from the DORA (Declaration On Research Assessment) of 2013, which will be ten years old in May 2023, to the ALLEA – All European Academies code of conduct for research integrity (2017), to the 'Hong Kong Principles for Assessing Researchers: Fostering Research Integrity', established at the 6th World Conference on Research Integrity in 2019 (Moher et al., 2020).

Integrity: Is science divided?

At this point in the course, I suggest discussing how science came to be divided, from the vision of a Republic of Science defended by Polanyi et al. (1962) to the present state of attrition between the two great families of science – the natural and the social, as argued by (Crowe, 1969). Although Polanyi and Crowe are not that far in time, both writing in the sixties, they describe two worlds apart. In Polanyi's world, scientists can muster their own craft, leveraging overlap among disciplines and identifying the most promising avenues for research. For Crowe, writing two decades before the infamous Sokal affair (Various Authors, 1996), the insularity of the two main families of science was already a major cause for 'the tragedy of the commons', in which science is unable to solve pressing societal and environmental problems. It would be useful to discuss with students how the Sokal affair or hoax, which exploded in 1996 and was followed by other hoaxes such as the grievance studies affair (Pluckrose et al., 2018), left 'lasting scars' in the relationship between social sciences and humanities on one side and natural sciences on the other (Mirowski, 2020, p. 1).

Some useful points to debate and possible classroom exercises include: what Mertonian (or other) rules were violated by the hoaxes? Or by some particularly acrimonious attacks against 'erring' disciplines, such as the attacks against social sciences in Neil

Table 2. Online resources.

Content	Type	Location
Lesson on Research Integrity, recorded at Open University of Catalonia in April 2023	Video	See https://materials.campus.uoc.edu/cdocent/PID_00296394/
	Slides	fhttps://github.com/andreasaltelli/MyLessons/blob/main/Integrity_April2023.pdf
Lesson on Ethics of quantification, recorded at Open University of Catalonia in July 2021	Video	https://www.youtube.com/watch?v=eHtJUSxoiol&t=309s
	Slides	https://github.com/andreasaltelli/MyLessons/blob/main/EQ_Saltelli_4.pdf

Postman (1992) or in Steven Pinker (2018)[7]? How could a true 'peace' be negotiated when the political economy of science seems to encourage insularity?

It's worth discussing how this ongoing conflict between natural and social sciences hinders necessary interdisciplinary dialogue and may lead to reductionism when science is applied to address social or environmental issues (Stirling, 2023). Furthermore, this division may also weaken science's ability to deal with the so-called crisis of post-truth.

Concluding remarks

How long should this course be? The case study presented ("la Caixa" Foundation, 2023) in this paper lasted half a day, but a longer course could allow for a more in-depth exploration of the topics. Indeed, my experience is that students are very eager to hear more about current conflicts and debates, such as those around artificial intelligence and COVID-19, as well as the 'dark sides' of research practices.

Thus, the course could be easily extended, say, to a total number of lessons between five and ten. As mentioned, the suggestions in this paper are not exhaustive, and other topics could be added to extend the course:

- **The 'hype' of science**, whereby scientist are requested by their universities to exaggerate the worth of their results (Sumner et al., 2014) and to 'brand' themselves, including with a display of 'humble brag' (Lenardic et al., 2022). Mertonian norms don't include rules on politeness and composure that were, according to some, a feature of 'little science' (de Solla Price, 1963; Ravetz, 1971). Interestingly, for some scholars such as Steven Shapin (2008), these unwritten norms are still a feature of scientists, even in their modern 'entrepreneurial' guise. Who is right? This is also an interesting subject for discussion, related to the legitimacy of hoaxes discussed above.
- The purported **decreased creativity of science** (Graeber, 2014; Kozlov, 2023), a theme likely to be of interest and relevant under the second meaning of integrity as functioning.
- How **science's numericization** of the real, made possible by big data, artificial intelligence and cognitive sciences, may be having effects of democratic agency. Warnings in this direction are coming from philosophers (Han, 2017, 2022; Zuboff, 2019), jurists (Supiot, 2017), statisticians and sociologists of quantification (Bruno et al., 2014; Mennicken & Salais, 2022; Salais, 2022).

- **The transformation of higher education into a global market** (Mittelman, 2017), boosted by rankings of higher education (Saltelli, Theben, et al., 2022). This topic can also be used to open a discussion on metric obsessions and 'dataism' (DiFiore et al., 2022).

We have already given in the text above some traces for exercises in the classroom, and a tentative suggestive reading is in Table 1. Online resources are offered in Table 2.

To conclude, an important feature of this syllabus proposal is to confront students with the contradictions that they may encounter in their professional lives while striving to maintain their own integrity. Living an academic carrier will often call for compromise between vocation and survival, especially when subject to a constant regime of evaluations that have become the norm of a life in academia (Pardo-Guerra, 2022).

It is essential to stress that contradictions are hard to resolve in the context where they arise (Watzlawick et al., 2011). How to live through dilemmas with personal choices, where to strike a balance among competing norms, can form the basis for interesting conversations with the student.

Notes

1. In brief, these are Solitariness (secrecy, miserism) instead of communalism; particularism instead of universalism, interestedness instead of disinterestedness and dogmatism instead of organizedorganised scepticism.
2. 'Who -- aside from certain big children who are indeed found in the natural sciences -- still believes that the findings of astronomy, biology, physics, or chemistry could teach us anything about the meaning of the world?!', Weber (1871).
3. 'The prolongation of life; The restitution of youth in some degree; The retardation of age; The curing of diseases counted incurable; The mitigation of pain; More easy and less loathsome purgings; The increasing of strength and activity; The increasing of ability to suffer torture or pain; The altering of complexions, and fatness and leanness; The altering of statures; The altering of features; The increasing and exalting of the intellectual parts; Versions of bodies into other bodies; Making of new species; Transplanting of one species into another; Instruments of destruction, as of war and poison; Exhilaration of the spirits, and putting them in good disposition; Force of the imagination, either upon another body, or upon the body itself; Acceleration of time in maturations; Acceleration of time in clarifications; Acceleration of putrefaction; Acceleration of decoction; Acceleration of germination; Making rich composts for the earth; Impressions of the air, and raising of tempests; Great alteration; as in induration, emollition, &c; Turning crude and watery substances into oily and unctuous substances; Drawing of new foods out of substances not now in use; Making new threads for apparel; and new stuffs, such as paper, glass, &c; Natural divinations; Deceptions of the senses; Greater pleasures of the senses; Artificial minerals and cements'. Magnalia Naturae, in New Atlantis, 'Wonders of nature, in particular with respect to human use', Francis (Bacon, 1627).
4. Examples include Lise Meitner and Elsie Franklin, but also Eunice Newton Foote, of whom there is not even a confirmed photo.
5. See photos at https://en.wikipedia.org/wiki/Solvay_Conference
6. Many papers have few or no citations, few papers have very many.
7. A discussion of Pinker's position can be found in (Saltelli & Reinert, 2023).

Acknowledgments

Cinzia Colombo of Mario Negri Institute Milan (IT), Laura Elisabet Drivdal, of the University of Bergen (NO) and Adrian Lenardic of Rice University, (Texas, US) offered useful suggestions. A previous version

of this work with a different title appears as a preprint as "Saltelli, Andrea, How to Teach Research Integrity? (February 21, 2023). Available at SSRN: https://ssrn.com/abstract=4365779 or http://dx.doi.org/10.2139/ssrn.4365779".

Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes on contributor

Andrea Saltelli (https://orcid.org/0000-0003-4222-6975) is presently academic counsellor at UPF-Barcelona School of Management, visiting researcher at the University of Bergen, Centre for the Study of the Sciences and the Humanities, and associate researcher at Institute for Cognitive Sciences and Technologies of the Italian National Research Council (CNR). His papers tackle sensitivity analysis and auditing, statistical and mathematical modelling, the rational of evidence-based policy, the crisis of science, sociology and ethics of quantification, the post-truth debate and the role of science in processes of regulatory capture, see www.andreasaltelli.eu.

ORCID

Andrea Saltelli http://orcid.org/0000-0003-4222-6975

References

ALLEA - All European Academies. (2017). *The European Code of Conduct for Research Integrity*. https://allea.org/code-of-conduct/

Anderson, M. S., Martinson, B. C., & De Vries, R. (2007). Normative dissonance in science: Results from a national survey of U.S. scientists. *Journal of Empirical Research on Human Research Ethics*, *2*(4), 3–14. https://doi.org/10.1525/jer.2007.2.4.3

Bacon, F. (1627). *Magnalia naturae, praecipue quoad usus humanos*. https://archive.org/details/worksfrancisbaco05bacoiala

Begley, C. G., & Ioannidis, J. P. A. (2015). Reproducibility in science: Improving the standard for basic and preclinical research. *Circulation Research*, *116*(1), 116–126. https://doi.org/10.1161/CIRCRESAHA.114.303819

Boltanski, L., & Thévenot, L. (2006). *On justification: Economies of worth*. in C. Porter Trans.(1st, pp. Princeton University Press). https://doi.org/10.1515/9781400827145.

Brecht, B. (1943/2013). *The life of galileo* (M. Ravenhill, Trans., Reprint ed.). Bloomsbury Methuen Drama.

Bruno, I., Didier, E., & Prévieux, J. (2014). *Statactivisme. Comment lutter avec des nombres*. Édition La Découverte.

Buranyi, S. (2017, June 27). Is the staggeringly profitable business of scientific publishing bad for science? *The Guardian*.

Conner, C. D. (2005). *A people's history of science: Miners, midwives, and low Mechanicks*. Bold Type Books.

Cornford, F. M. (1908). *Microcosmographia academica: Being a guide for the young academic politician*. Andesite Press.

Crowe, B. L. (1969). The tragedy of the commons revisited. *Science: Advanced Materials and Devices*, *166*(3909), 1103–1107. https://doi.org/10.1126/science.166.3909.1103

David, P. A. (2008). The historical origins of "open science": An essay on patronage, reputation and common agency contracting in the scientific revolution. *Capitalism and Society*, *3*(2), Article 5. https://doi.org/10.2202/1932-0213.1040

Davies, P. J., & Hersh, R. (1986). *Descartes' dream: The world according to mathematics (dover science books) - Harvard book store*. Penguin Books. https://www.harvard.com/book/descartes_dream_the_world_according_to_mathematics_dover_science_books/

de Solla Price, D. J. (1963). *Little science, big science*. Columbia University Press. https://books.google.es/books?id=MWQPAQAAMAAJ

DiFiore, M., Kuc Czarnecka, M., Lo Piano, S., Puy, A., & Saltelli, A. (2022). The challenge of quantification: An interdisciplinary reading. *Minerva*, *61*(1), 53–70. https://doi.org/10.1007/s11024-022-09481-w

DORA. (2013). *San Francisco Declaration on Research Assessment*. https://sfdora.org/

Edwards, M. A., & Roy, S. (2017). Academic research in the 21st century: Maintaining scientific integrity in a climate of perverse incentives and hypercompetition. *Environmental Engineering Science*, *34*(1), 51–61. https://doi.org/10.1089/ees.2016.0223

Else, H. (2022). Paper-mill detector put to the test in push to stamp out fake science. *Nature*, *612* (7940), 386–387. https://doi.org/10.1038/d41586-022-04245-8

Else, H. (2023). Alzheimer's drug saga prompts journal to scrutinize whistle-blowers. *Nature*, *613* (7945), 618–618. https://doi.org/10.1038/d41586-023-00062-9

Erasmus University Rotterdam. (2020). *Dilemma Game*. https://www.eur.nl/en/about-eur/policy-and-regulations/integrity/research-integrity/dilemma-game

Fanelli, D., & Scalas, E. (2010). "Positive" results increase down the hierarchy of the sciences. *PLoS ONE*, *5*(4), e10068. https://doi.org/10.1371/journal.pone.0010068

Fecher, B., & Friesike, S. (2014). Open science: One term, five schools of thought. In S. Bartling & S. Friesike (Eds.), *Opening science* (pp. 17–47). Springer International Publishing.

Feyerabend, P. (1975). *Against method*. Verso.

Feynman, R. (1974). *Cargo Cult Science*. https://calteches.library.caltech.edu/51/2/CargoCult.htm

Foucart, S., Horel, S., & Laurens, S. (2020). *Les gardiens de la raison. Enquête sur la désinformation scientifique. Éditions La Découverte*. https://editionsladecouverte.fr/catalogue/index-Les_gardiens_de_la_raison-9782348046155.html

Goldacre, B. (2012). *Bad pharma: How drug companies mislead doctors and harm patients*. Fourth Estate.

Graeber, D. (2014, January 8). Of flying cars and the declining rate of profit. *The Baffler*. https://thebaffler.com/salvos/of-flying-cars-and-the-declining-rate-of-profit

Han, B.-C. (2017). *Psychopolitics: Neoliberalism and new technologies of power*. (E. Butler, Trans.). Verso.

Han, B.-C. (2022). *Infocracy: Digitization and the crisis of democracy* (1st ed, Trans., D. Steuer.). Polity.

Harris, R. F. (2017). *Rigor mortis: How sloppy science creates worthless cures, crushes hope, and wastes billions*. Basic Books.

Hessen, B. (1931). The social and economic roots of Newton's Principia. In N. I. Bukharin (Ed.), *Science at the crossroads*. Routledge. https://archive.org/stream/in.ernet.dli.2015.51669/2015.51669.Science-At-The-Cross-Roads-1931_djvu.txt

Ioannidis, J. P. A. (2016). Evidence-based medicine has been hijacked: A report to David sackett. *Journal of Clinical Epidemiology*, *73*, 82–86. https://doi.org/10.1016/j.jclinepi.2016.02.012

Ioannidis, J. P. A., Califf, R., Platt, R., Selby, J., Greenberg, D., & Neumann, P. (2016). Why most clinical research is not useful. *PLOS Medicine*, *13*(6), e1002049. https://doi.org/10.1371/journal.pmed.1002049

Ioannidis, J. P. A., Fanelli, D., Dunne, D. D., Goodman, S. N., Chalmers, I., Al-Shahi, S. R., Chan, A., & Glasziou, P. (2015). Meta-research: Evaluation and improvement of research methods and practices. *PLOS Biology*, *13*(10), e1002264. https://doi.org/10.1371/journal.pbio.1002264

Jasanoff, S., & Kim, S.-H. (2015). *Dreamscapes of modernity: Sociotechnical imaginaries and the fabrication of power*. The University of Chicago Press. https://www.press.uchicago.edu/ucp/books/book/chicago/D/bo20836025.html, https://doi.org/10.7208/chicago/9780226276663.001.0001

Kerr, N. L. (1998). Harking: Hypothesizing after the results are known. *Personality and Social Psychology Review*, *2*(3), 196–217. https://doi.org/10.1207/s15327957pspr0203_4

Kozlov, M. (2023, January). 'Disruptive' science has declined — and no one knows why. *Nature*, *613* (7943), 225. https://doi.org/10.1038/d41586-022-04577-5

Kuhn, T. (1962). *The structure of scientific revolutions*. University of Chicago Press.

"la Caixa" Foundation. (2023). Doctoral INPhINIT fellowships. https://lacaixafoundation.org/en/doctoral-inphinit-fellowships-incoming-call

Lenardic, A., Seales, J., & Levander, A. (2022). The rise of the academic science humble brag. *Matter*, *5* (3), 766–767. https://doi.org/10.1016/j.matt.2022.02.003

Mayer, J. (2017). *Dark money: The hidden history of the billionaires behind the rise of the radical right*. Anchor.

Mennicken, A., & Espeland, W. N. (2019). What's new with numbers? Sociological approaches to the study of quantification. *Annual Review of Sociology*, *45*(1), 223–245. https://doi.org/10.1146/annurev-soc-073117-041343

Mennicken, A., & Salais, R. (Eds.) (2022). *The new politics of numbers: Utopia, evidence and democracy*. Palgrave Macmillan. https://doi.org/10.1007/978-3-030-78201-6

Merton, R. (1973). *The sociology of science: Theoretical and empirical investigations*. University of Chicago Press., Ed.

Mirowski, P. (2011). *Science-mart, privatizing American science*. Harvard University Press.

Mirowski, P. (2018). The future(s) of open science. *Social Studies of Science*, *48*(2), 171–203. https://doi.org/10.1177/0306312718772086

Mirowski, P. (2020, April). Democracy, expertise and the post-truth era: An inquiry into the contemporary politics of STS. *Academia.Eu* .https://www.academia.edu/42682483/Democracy_Expertise_and_the_Post_Truth_Era_An_Inquiry_into_the_Contemporary_Politics_of_STS

Mitroff, I. I. (1974). Norms and counter-norms in a select group of the apollo moon scientists: A case study of the ambivalence of scientists. *American Sociological Review*, *39*(4), 579. https://doi.org/10.2307/2094423

Mittelman, J. H. (2017). *Implausible dream*. Princeton University Press. https://press.princeton.edu/books/hardcover/9780691165189/implausible-dream

Moher, D., Bouter, L., Kleinert, S., Glasziou, P., Sham, M. H., Barbour, V., Coriat, A.-M., Foeger, N., & Dirnagl, U. (2020). The Hong Kong Principles for assessing researchers: Fostering research integrity. *PLOS Biology*, *18*(7), e3000737. https://doi.org/10.1371/journal.pbio.3000737

Monbiot, G. (2018, September 13). Scientific publishing is a rip-off. We fund the research – it should be free. *The Guardian*. https://www.theguardian.com/commentisfree/2018/sep/13/scientific-publishing-rip-off-taxpayers-fund-research

Morgan, M. S. (2012). *The world in the model: How economists work and think* (New ed.), Cambridge University Press. https://doi.org/10.1017/CBO9781139026185

Munafò, M. R., Nosek, B. A., Bishop, D. V. M., Button, K. S., Chambers, C. D., Percie du Sert, N., Simonsohn, U., Wagenmakers, E., Ware, J. J., & Ioannidis, J. P. A. (2017). A manifesto for reproducible science. *Nature Human Behaviour*, *1*(January), 1–9. https://doi.org/10.1038/s41562-016-0021

Open Science Collaboration. (2015). Estimating the reproducibility of psychological science. *Science: Advanced Materials and Devices*, *349*(6251), aac4716–aac4716. https://doi.org/10.1126/science.aac4716

Osterloh, M., & Frey, B. S. (2020). How to avoid borrowed plumes in academia. *Research Policy*, *49*(1), 103831. https://doi.org/10.1016/J.RESPOL.2019.103831

Pardo-Guerra, J. P. (2022). *The quantified scholar: How research evaluations transformed the British social sciences*. Columbia University Press. https://www.amazon.com/Quantified-Scholar-Research-Evaluations-Transformed/dp/0231197810/ref=sr_1_1?crid=3AYTUEPDH9H64&keywords=pardo+quantified+scholar&qid=1685366346&s=books&sprefix=pardo+quantified+scholar+%2Cstripbooks-intl-ship%2C449&sr=1-1

Pereira, Â. G., & Funtowicz, S., Pereira, A. G., Funtowicz, S. (2015). *Science, philosophy and sustainability: The end of the Cartesian dream*. Routledge. https://doi.org/10.4324/9781315757902

Pinker, S. (2018). *Enlightenment now: The case for reason, science, humanism, and progress*. Random House.

Pluckrose, H., Lindsay, J., & Boghossian, P. (2018). Academic grievance studies and the corruption of scholarship. *Areomagazine*. https://areomagazine.com/2018/10/02/academic-grievance-studies-and-the-corruption-of-scholarship/

Polanyi, M., Ziman, J., & Fuller, S. (1962). The republic of science: Its political and economic theory. *Minerva*, *1*(1), 54–73. https://doi.org/10.1007/BF01101453

Pooley, J. (2020, February 21). Read-and-Publish Open Access deals are heightening global inequalities in access to publication. *Impact of Social Sciences*. https://blogs.lse.ac.uk/impactofsocialsciences/2020/02/21/read-and-publish-open-access-deals-are-heightening-global-inequalities-in-access-to-publication/

Popp Berman, E., & Hirschman, D. (2018). The sociology of quantification: Where are we now? *Contemporary Sociology*, *47*(3), 257–266. https://doi.org/10.1177/0094306118767649

Postman, N. (1992). *Technopoly, the surrender of culture to technology*. Vintage Books, Random House.

Pritchard, M. S. (2005). Teaching research ethics and working together. *Science and Engineering Ethics*, *11*(3), 367–371. https://doi.org/10.1007/s11948-005-0005-4

Ravetz, J. R. (1971). *Scientific knowledge and its social problems*. Oxford University Press.

Rogers, A. (2019). How rich donors like Epstein (and others) undermine science. *Wired*. https://www.wired.com/story/the-problem-with-rich-people-funding-science/

Ruben, A. (2017). Another tenure-track scientist bites the dust. *Sciencemag*. https://doi.org/10.1126/science.caredit.a1700056

Sachs, G. A., & Siegler, M. (1993). Teaching scientific integrity and the responsible conduct of research. *Academic Medicine: Journal of the Association of American Medical Colleges*, *68*(12), 871–875. https://doi.org/10.1097/00001888-199312000-00001

Salais, R. (2022). La donnée n'est pas un donné": Statistics, quantification and democratic choice. In A. Mennicken & R. Salais (Eds.), *The new politics of numbers: Utopia, evidence and democracy* (pp. 379–415). Palgrave Macmillan.

Saltelli, A., Bammer, G., Bruno, I., Charters, E., DiFiore, M., Didier, E., Nelson Espeland, W., Kay, J., Lo Piano, S., Mayo, D., Pielke, R., Jr., Portaluri, T., Porter, T. M., Puy, A., Rafols, I., Ravetz, J. R., Reinert, E. S., Sarewitz, D., Stark, P. B. . . . Vineis, P. (2020). Five ways to ensure that models serve society: A manifesto. *Nature*, *582*(7813), 482–484. https://doi.org/10.1038/d41586-020-01812-9

Saltelli, A., & Boulanger, P.-M. (2019). Technoscience, policy and the new media. Nexus or vortex?. *Futures*, *115*, 102491. https://doi.org/10.1016/j.futures.2019.102491

Saltelli, A., Dankel, D. J., DiFiore, M., Holland, N., & Pigeon, M. (2022). Science, the endless frontier of regulatory capture. *Futures*, *135*(102860), 102860. https://doi.org/10.1016/j.futures.2021.102860

Saltelli, A., & DiFiore, M. (2020). From sociology of quantification to ethics of quantification. *Humanities and Social Sciences Communications*, *7*(1). Article 1. https://doi.org/10.1057/s41599-020-00557-0.

Saltelli, A., & DiFiore, M. (Eds.). (2023). *The politics of modelling. Numbers between science and policy*. Oxford University Press.

Saltelli, A., & Funtowicz, S. (2017). What is science's crisis really about?. *Futures*, *91*, 5–11. https://doi.org/10.1016/j.futures.2017.05.010

Saltelli, A., & Reinert, E. (2023). Physiocracy, guillotines, and antisemitism?' Did economics emulate the wrong enlightenment?. In I. Kvangraven & E. S. Reinert (Eds.), *A modern guide to uneven economic development* (pp. 200–217). Elgar.

Saltelli, A., Theben, A., & Scandurra, R. (2022). Smashing the glasshouse. Diminishing the prestige of measures of higher education. *SocArXiv*. https://doi.org/10.31235/osf.io/fu5r4

Ščepanović, R., Labib, K., Buljan, I., Tijdink, J., & Marušić, A. (2021). Practices for research integrity promotion in research performing organisations and research funding organisations: A scoping review. *Science and Engineering Ethics*, *27*(1), 4. https://doi.org/10.1007/s11948-021-00281-1

Schrag, B. (2005). Teaching research ethics: Can web-based instruction satisfy appropriate pedagogical objectives? *Science and Engineering Ethics*, *11*(3), 347–366. https://doi.org/10.1007/s11948-005-0004-5

Shapin, S. (2008). *The scientific life: A moral history of a late modern vocation*. University of Chicago Press.

Shapin, S. (2016). Invisible science. *The Hedgehog Review*, *18*(3), Fall 2016.

Shen, C., & Björk, B.-C. (2015). 'Predatory' open access: A longitudinal study of article volumes and market characteristics. *BMC Medicine*, *13*(1), 230. https://doi.org/10.1186/s12916-015-0469-2

Singh Chawla, D. (2021, February 8). Hundreds of 'predatory' journals indexed on leading scholarly database. *Nature*. https://doi.org/10.1038/d41586-021-00239-0

Smaldino, P. E., & McElreath, R. (2016). The natural selection of bad science. *Royal Society Open Science*, *3*(160384), 160384. https://doi.org/10.1098/rsos.160384

Sponholz, G. (2000). Teaching scientific integrity and research ethics. *Forensic Science International*, *113*(1), 511–514. https://doi.org/10.1016/S0379-0738(00)00267-X

Stark, P. B., & Saltelli, A. (2018). Cargo-cult statistics and scientific crisis. *Significance*, *15*(4), 40–43. https://doi.org/10.1111/j.1740-9713.2018.01174.x

Stirling, A. (2023). Against misleading technocratic precision in research evaluation and wider policy – A response to Franzoni and Stephan (2023), 'uncertainty and risk-taking in science'. *Research Policy*, *52*(3), 104709. https://doi.org/10.1016/j.respol.2022.104709

Sumner, P., Vivian-Griffiths, S., Boivin, J., Williams, A., Venetis, C. A., Davies, A., Ogden, J., Whelan, L., Hughes, B., Dalton, B., Boy, F., & Chambers, C. D. (2014). The association between exaggeration in health related science news and academic press releases: Retrospective observational study. *BMJ*, *349*(dec097), g7015. https://doi.org/10.1136/bmj.g7015

Supiot, A. (2017). *Governance by numbers: The making of a legal model of allegiance*. Hart Publishing.

Szilard, L. (1948). *The Mark Gable Foundation (Later published in The voice of the dolphins: And other stories, 1991)*. https://library.ucsd.edu/dc/object/bb33804055

Toulmin, S. (1992). *Cosmopolis: The hidden agenda of modernity*. University of Chicago Press.

University of Bergen. (2023). *MNF990: Theory of science and ethics at the Faculty of Mathematics and Natural Sciences*. https://www.uib.no/en/svt/21463/mnf990-theory-science-and-ethics-faculty-mathematics-and-natural-sciences

Van Noorden, R. (2013). Brazilian citation scheme outed. *Nature*, *500*(7464), 510–511. https://doi.org/10.1038/500510a

Van Noorden, R. (2020). Highly cited researcher banned from journal board for citation abuse. *Nature*, *578*(7794), 200–201. https://doi.org/10.1038/d41586-020-00335-7

Various Authors. (1996). *The Sokal Hoax: A forum*. Lingua Franca. http://linguafranca.mirror.theinfo.org/9607/tsh.html

Watzlawick, P., Weakland, J. H., & Fisch, R. (2011). *Change: Principles of problem formation and problem resolution* (Reprint ed.). W. W. Norton & Company.

Weber, M. (1946). Science as a vocation. In H. H Gerth & Wright Mills, C. (Eds.), *From Max Weber: Essays in sociology* (pp. 129–156). Oxford University Press. http://anthropos-lab.net/wp/wp-content/uploads/2011/12/Weber-Science-as-a-Vocation.pdf

Zilsel, E. (2003). D. Raven, W. Krohn, & R. S. Cohen (Eds.), *The social origins of modern science*. Kluwer Academic Publishers. https://books.google.es/books/about/The_Social_Origins_of_Modern_Science.html?id=HZSOwdruoMkC&redir_esc=y

Zuboff, S. (2019). *The age of surveillance capitalism: The fight for a human future at the new frontier of power*. PublicAffairs.