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Life Sciences for Philosophers and Philosophy for Life Scientists: What Should We Teach?

This is the final peer-reviewed author's accepted manuscript (postprint) of the following publication:

Published Version:

R. Campaner, G.B. (2020). Life Sciences for Philosophers and Philosophy for Life Scientists: What Should We Teach?. BIOLOGICAL THEORY, 15, 1-11 [10.1007/s13752-019-00333-7].

Availability:

This version is available at: <https://hdl.handle.net/11585/717332> since: 2020-02-14

Published:

DOI: <http://doi.org/10.1007/s13752-019-00333-7>

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This is the final peer-reviewed accepted manuscript of:

Boniolo, G., Campaner, R., *Life Sciences for Philosophers and Philosophy for Life Scientists: What Should We Teach?*. «Biological Theory» 15, 1–11 (2020).

The final published version is available online at:

<https://doi.org/10.1007/s13752-019-00333-7>

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Life sciences for philosophers and philosophy for life scientists.

What should we teach?

Giovanni Boniolo, Raffaella Campaner

[Giovanni Boniolo and Raffaella Campaner have contributed equally to this paper]

1. Introduction

To mark the thirty years of *Biology & Philosophy*, T. Pradeu (2017) wrote an article in which he compares the topics of papers published in the journal with the topics published in PNAS, in order to highlight differences and similarities. The result was a clear mismatch: the fields of biology - but more generally, the life sciences – considered in terms of a philosophical analysis were only a narrow subset of the fields treated by scientists. As a result, Pradeu proposed some reflections that re-opened a very old question concerning the relationships between science and philosophy of science: which role for the latter? It is known that during the contemporary history of philosophy of science many answers have been given to this problem (see the, albeit dated, classics, Losee, 1972; Oldroyd, 1986). Some have sustained that the role of philosophy of science should be simply methodological; others have proposed a clarificatory role; still others have suggested that philosophy should have a proactive role, spurring science towards new goals, or that a closer look should be addressed to science *in practice*, etc.¹ Putting aside a discussion on whether philosophy of science should be a servant of science (an *ancilla scientiarum*) or otherwise, philosophers of science should inquiry where they are coming from and where they are heading to, and, more in general, which should be the right way of collaborating with the scientific disciplines. In this respect, reflections are worth continuing on the point raised by Pradeau concerning the dyscrasia between real science and philosophy of (real?) science, as well as, more generally, the actual interactions between disciplines, the modes of integration between them, and the proper features of interdisciplinary research (see, e.g., Boon and van Baalen, 2019).

We believe that to exhaustively address the concerns raised in Pradeu's work two further aspects need to be tackled. Both of them deal with educational strategies and imply close collaboration between disciplines, i.e. i) the design of proper training for philosophers of the life sciences and ii)

¹ There is a long and classical tradition (Poincaré, Duhem, Campbell, Mach, Boltzmann, Hertz, Enriques, Bernard, Popper, some post-Popperians, etc.) according to which philosophy of science is mainly concerned with methodological/epistemological issues, while the ontological, aesthetics, ethical and political issues are sometimes tackled (see Poincaré on ethics, Popper on politics, etc.) but considered self-contained intersecting disciplines. We do not want to enter this debate here, which surely would deserve an ampler space

the definition of the role to be played by philosophers in the training of both life scientists and clinicians. While teaching philosophy to scientists is a topic already addressed in the debate (see, e.g., Grüne-Yanoff, 2014), we suggest it should be further explored with regard to its role and impact on research in the long run, and intertwined with reflections on education as stemming from within the sciences and with pressing demands for humanities asked by scientists themselves². What clearly emerges, for instance, from a quick survey through PubMed, is the increase, in the last few years, of works concerned with “philosophy of science and medical education” and, more in general, “philosophy of science”³. “Ethics” is surely the object of large focus as well; this last trend has been both wider and lasting for longer, but fundamentally stable in the last few years⁴. Differently, epistemological, methodological and conceptual issues have been proportionally more frequently addressed in recent scientific works. This phenomenon witnesses a lively interest by the scientists themselves in investigating what they are doing and the way in which they are trained, and by the philosophers of science in properly understanding these aspects and getting actively engaged in the debate. If we grant the claim that some philosophical education is to be part of scientific curricula, as suggested in an increasing literature that we mention along the paper, then we must also be ready to design innovative training and to assess its actual impact – in scientific as well as in wider socio-cultural contexts. For an advocacy of the role of philosophy in, for instance, the biomedical curricula not to be rhetorical, but empirically supported, we should be able to prove that some joint training will also be the premise for better research at later career stages, being ready to re-assess whether this is in fact the case in the long run. This interdisciplinary exercise should be evaluated not only per se, but also with respect to the benefits it could provide to the single disciplines involved.

These are the issues we wish to examine in what follows, discussing whether and how training should be re-thought on both sides, the biomedical and the philosophical one, and whether they would be better addressed jointly, rather than from either the perspective of the biomedical curricula or the philosophical ones, as it is often the case, in order to foster a genuine and fruitful dialogue between philosophers and scientists.

Concerning the first issue, i.e., training philosophers of the life sciences, we do not aspire to provide any definitive, final format. Rather, we aim to report a first hand training experiment (run by one of

² See e.g. Quintero (2014); Regh and SmithBattle (2015).

³ From a research on PubMed, it appears that occurrences of “philosophy of science” have constantly increased in the last few years as follows: 2015: 102; 2016: 109; 2017: 117; 2018: 139; 2019 (half year): 82. Joint occurrences of “philosophy of science” and “education” have also shown a slight increase: 2015: 9; 2016: 6; 2017: 12; 2018: 12; 2019 (half year): 7.

⁴ According to PubMed, “ethics” has been directly addressed by many works in the last few years, with a basically constant trend (apart from a decline in 2018). Occurrences in works: 2015: 937; 2016: 943; 2017: 947; 2018: 102; 2019 (half year): 472.

the authors), held in Milan a few years ago. We think it provides a good starting point to reflect upon what a young philosophy of life sciences scholar should be taught to make him/her aware of the frontiers of the research and able to face them philosophically with the right scientific or clinical knowledge. We believe that this sort of training experience could be one possible therapy for the mismatch, highlighted by Pradeu, between what is done in the life sciences domain and what is done in the philosophical domain. Thus, in the first section below (§ 2), we present in a narrative way this training experience so that, on the one hand, it does not fall into oblivion or remain in the private memories of the few who lived it, and, on the other hand, it could be an indication of a possible curriculum for young philosophers of the life sciences and stimulate critical reflections. Some general features of such a training programme might be worth sharing - such as the topics taught, the number of students enrolled, and the educational strategies adopted – and some of its outcomes – such as the number of the published papers and the number of the graduates getting a job in the short run – might help reflecting on the success this educational format can encounter. Differently from other works debating educational programmes and their profiles, the present paper intends to complement theoretical discourses on the merits of interdisciplinary education with evidence regarding its actual consequences in practice. Furthermore, it aims to address philosophical and biomedical curricula jointly, building on the idea that “the future of the relationship between philosophy and medicine depends on the development of a *two-way trade* between them” (Fulford 1991, p. 81, italics added).

Concerning the second issue, i.e. philosophical training for young scientists, we are strong supporters of the need for the humanities, philosophy in particular, in the education of both life scientists and clinicians. Advocacy of the need for teaching philosophy in medical education is by no means new⁵, and continues to be pursued in articulated theoretical terms⁶, suggesting that there is a strong training role that philosophers could and should play in the life sciences. While scientists often become interested in philosophical issues when they are in the later stages of their careers, we believe that a shift of paradigm should be encouraged and that some philosophical tools should be increasingly provided in the earlier phases of their professional life. In order to accomplish this, philosophers will have to adopt a highly informed as well as a respectful attitude, getting to know deeply what the scientific enterprise is like. In other words, as philosophers we should not try to teach young life scientists or medical students what we think relevant from the perspective of our philosophical researches, but rather what they need and what we, discussing with them, agree is necessary to better understand the bases (or the foundations) of their theoretical knowledge and practice. In other terms, *as philosophers we should not teach young life scientists or medical*

⁵ See e.g. Spike (1991).

⁶ See e.g. Andreoletti and Maugeri (2019).

students what we know, but what they actually need. The question to address hence becomes: what do *really* need from the philosophical side? We have tried to answer this question – that we consider central from an educational point of view – starting, as we will show in § 3, from the (sometimes explicit, sometimes implicit) requests coming from the scientific area. Such requests come not only directly from papers on educational matters, but also – as we will recall below – from works addressing methodological and conceptual concerns stemming from within biomedical research.

2. Science for philosophers: the successful Milan experience

In June 2004, one of us (GB) had dealings with the scientific direction of the European School of Molecular Medicine (SEMM), which, in cooperation with the biomedical departments of the University of Milan, ran two PhD programmes: one in molecular oncology, and one in computational biology. SEMM is an educational institution established by the FIRC Institute of Molecular Oncology (IFOM) and European Institute of Oncology (IEO). IFOM is a research institute dedicated to the study of the molecular mechanisms involved in cancer formation and development. It is financially supported mainly by an Italian charity (FIRC) collecting funds for cancer research. The IEO is a comprehensive cancer hospital and research centre engaged in cutting-edge investigations in oncology, ranging from basic to translational level. Both the IFOM and IEO scientists work on a campus (the IFOM-IEO Campus) close to the centre of Milan.⁷ After a period of productive discussions, the scientific direction of SEMM, accepted the project proposed and decided to start an international PhD programme in “Foundations of the Life Sciences and their Ethical Consequences” (FOLSATEC)⁸. This was an extremely important cultural step ahead since it introduced humanistic topics and studies in a genuinely scientific environment. It was the only Italian but also - as far as we know - international humanistic PhD programme to be implemented directly in a biomedical school. It should be noted that this was not a scientific PhD programme with a pinch of humanistic content, but, rather, a PhD programme in philosophy offered by a strictly scientific institution (the SEMM). It was a blow against the idea that there are two irreconcilable cultures and that undergraduate and post-graduate education should keep the two cultures rigorously detached. It was, so to speak, a real example of overcoming the danger described by C.P. Snow in 1959 in his lecture and book “The Two Cultures and the Scientific Revolution”.

⁷ Some numbers of the IFOM-IEO Campus: about 24.000 sqm surface area; 12.000 sqm of laboratories; 600 research work stations; 450 researchers; 35 research groups; 13 technological units.

⁸ G. Testa was appointed as deputy director

The explicit educational aim of FOLSATEC was to create highly skilled scholars in the humanistic disciplines concerned with biomedical research and clinical practice in order i) to ameliorate the conceptual understanding of the philosophical foundations and the ethical implications of biomedical research and clinical practice; ii) to improve patients' quality of life by empowering them and providing humanistic awareness to practitioners. The programme's core target was therefore to train young philosophers of biomedicine and young ethicists. It was also designed in order to make the studies and researches carried out have a strong impact on real biomedical activity, both in terms of the analysis of its foundational issues and of the ethical questions implied. In other words, the basic idea was to contribute to the training of scholars who would have an impact both from the conceptual and the ethical point of view on what now can be labelled as science in practice, in particular biomedicine in practice. In this sense, reflections on the design, structure and implementation of the PhD programme were not only inspired by inter- and trans-disciplinary reflections and educational research principles, but also targeted at improving, in the end, quality of health care.

In order to accomplish such targets – which have both an educational and, through it, also a socio-political value – the PhD programme was planned to provide for the possibility i) to address and analyse in depth a variety of bioethical and societal issues; ii) to explore the philosophical foundations of molecular biomedicine and clinical practice; iii) to refine logical/analytical/philosophical skills to better achieve i) and ii); iv) to be acquainted with lab or clinical practice; v) to conduct genuinely interdisciplinary research that effectively combines scientific and humanistic subjects, interacting with (and observing the work of) top scientists and experienced doctors; vi) to learn how to tackle the practical, cultural and societal-political impacts that biomedicine and its progress can have. These targets were especially pursued by making young researchers directly observe frontier researches and take part into work in the lab. Science in practice was hence not just a theoretical target – conceived as a set of activities to be philosophically analysed – but also a practical one – as meant to ultimately improve patients' conditions.

In 2006, the 4-year PhD programme was launched and lasted until 2015, when it was unfortunately concluded for reasons not pertinent to the present discussion.

Over the years, several philosophers visited, lectured or taught on the programme (e.g., R. Andorno, M. Bedau, M. Bertolaso, W. Callebaut, M. D'Agostino, I. De Beaufort, J. Dupré, B. Fantini, M. Ferraguti, J. Griesemer, J. Harris, G. Hermeren, S. Holm, N. Hoppe, S. Jasanoff, S. Leonelli, N. Levy, M. Mameli, M. Morange, M. Nathan, S. Okasha, A. Plommer, F. Russo, J. Sprenger, D.

Teira, etc.). Some of them left a lasting impression for their humanity, competence and educational capacity on students and on campus life.

The educational curriculum was constructed along two different lines. It was designed first to provide an extremely wide basic preparation and build up a common ground for students from different disciplines. The curriculum then aimed to secure a theoretical and empirical scientific education to students coming from a humanistic background and, vice versa, furnish a philosophical education to students coming from a scientific background. The goal was to achieve a pretty homogeneous background knowledge, with no group being in a privileged position with respect to any others. For this purpose, in the first two years the students received very broad training spanning several different areas also with the aim, as mentioned, to fill either their philosophical or scientific gaps. As mentioned above, one of the most relevant aspects was that the students also had empirical training working with real scientists on genuine frontier scientific problems in real wet or dry labs or on real wards. In this way, the unfortunate situation was avoided of “creating” philosophers who could speak only about fictional examples of fictional science or about science that was not the most up-to-date. We were determined, in other words, to avoid creating armchair philosophers. An essential contribution was given by the scientists of the IFOM-IEO Campus, who published really innovative papers in the most important scientific journals (*Nature*, *Science*, *Cell*, etc.) and spurred the young philosophers to do the same in their fields⁹.

Following this line of thought, in the first two years the students had to attend classes for about 250 hours per year on Bioethics, Biolaw, Computation for Philosophers, Epistemology, Evolutionary biology, Foundations of Ethics and Bioethics, Foundations of Probability and Statistics, General Philosophy of Science, History of Biomedicine, Logic and Rhetoric, Philosophy of the Life Sciences, and STS and the Life Sciences. Moreover, they were also asked to follow (but it would be more honest to say that they were obliged to follow) some classes of the other two PhD programmes, in particular Bioinformatics, Developmental Biology and Animal Models, Fundamental Principles in Molecular Oncology, Genomics and Proteomics, and Scientific Methodology.

⁹ A remarkably large number of papers having among their authors former students of this program have appeared in high-impact journals. We cannot list them all. Let us just recall, e.g., Maugeri and Blasimme (2011); Nardini and Sprenger (2013); Germain, Ratti, Boem (2014); Andreoletti et al. (2016); Sanchini et al. (2016). Various other publications appeared in such journals as: *AJOB Neuroscience*; *Bioethics*; *Biological Theory*; *Biotechnology Journal*; *Cambridge Quarterly of Healthcare Ethics*; *European Journal of Cancer*; *Journal of Assisted Reproduction and Genetics*; *Journal of Medical Ethics*; *Lancet Oncology*; *Medicine, Healthcare, and Philosophy*; *Minds and Machines*; *Multidisciplinary Respiratory Medicine*; *PLOS Biology*; *Public Health Ethics*; *Studies in History and Philosophy of Biology & Biomedical Sciences*; *The American Journal of Bioethics*; *Theoretical Medicine and Bioethics*, ..., as well as in a number of collected volumes.

This rather extensive and varied interdisciplinary basis was intended to form a strong backbone allowing each student to establish her/his own research, but with the awareness also of what was happening in related research fields – most recent discoveries and progresses, need to convey and translate them into practice, most urgent issues, ... Teaching was delivered both *ex cathedra* and, very often, in an extremely interactive way. Students also had to attend real lab activities, one of the specificities of the programme. During the first year, each student, whatever his/her background, had to spend half her/his time in three different wet or dry research labs within the IFOM-IEO Campus to become acquainted with empirical up-to-date biomedical science. During this period s/he also learned the different techniques implemented in the three labs attended. In this way, not only were the students concerned with scientific practice, but they actually “practiced science” themselves. At the end of the first year, each student had to choose a lab at the IFOM-IEO Campus or at the IEO hospital where s/he would spend half their second year. The third and the fourth years were mostly devoted to the specific research chosen by the student.

In addition to this basic theoretical and empirical training, other educational activities were scheduled. In particular, there were i) Student meetings with journal surveys; ii) Research Unit Meetings, iii) Reading Clubs.

In the *Student meetings with journal survey*, each month either second- or third-year students presented their research progress, talking for a specific time as training in time-constrained public speaking. Presentations were followed by a survey of the most relevant papers published that month (each student was tasked with reviewing the most relevant papers appearing in a series of international journals). The *Research Unit Meetings* were monthly meetings of the members of one of three research groups: one on the philosophical foundations of biomedical research and clinical practice; one on the relevant ethical issues, and one on STS topics. During these meetings, papers were read and discussed, and research issues analysed. Finally, there were the *Reading Clubs*, a series of meetings planned and organized by the students in order to read classical philosophical works which could provide relevant hints on metaphysical, ontological and ethical matters. The curriculum designers believed it essential that training in philosophy should include reading the classics. Following this “philosophical prejudice”, it was planned that over the four years of the PhD programme the students had to read and collectively discuss at least: Plato, *Theaetetus*; Aristotle, *Metaphysics*; Aristotle, *Nicomachean Ethics*; Descartes, *Discourse on the Method*; I. Kant, *Groundwork of the Metaphysics of Morals*; I. Kant, *Critique of Pure Reason*; D. Hume, *Treatise of Human Nature*; J.S. Mill, *Utilitarianism*; J. Rawls, *A Theory of Justice*; E. Mach, *Erkenntnis und Irrtum*; H.J. Poincaré, *La science et l'hypothèse*; P. Duhem, *La théorie physique*:

son objet et sa structure; E. Cassirer, *Substanzbegriff und Funktionsbegriff*; K.R. Popper, *Conjectures and Refutations*; W.v.O. Quine, *Ontological Relativity and Other Essays*.¹⁰

Each student was followed by i) a supervisor, chosen from the teaching staff; ii) an external advisor, chosen preferably in Europe and whose expertise was related to the research topic; iii) an internal lab advisor, chosen within IFOM-IEO Campus or at the IEO hospital. In this way, each student was closely supervised and helped by an expert on lab techniques and affairs, by a member of the teaching staff, and by an expert in the topic on which s/he decided to work. Moreover, a number of seminars on several different biomedical and sometimes also humanistic topics were scheduled at the campus each week during the year.

Of course, there were several assessments. In particular, during the second year the student was requested to write a probationary period report, which was evaluated in order to pass to the third year. During the 3rd year, between May and June, the student was invited to hold a public seminar at the campus to show her/his preliminary results and the plan to complete the work in time to discuss the thesis. This seminar was evaluated, as well. In the 3rd year, a first draft of the thesis, even if incomplete, was evaluated by the PhD director and teaching staff. At the end of the fourth year, there was the *Viva Voce Exam*, where the student defended her/his doctorate thesis in front of two examiners, one internal and one belonging to a European scientific or philosophical institution. The international mobility of the students was actively encouraged, spurring them to participate to international meetings to present the results of their researches and inviting them to spend a period abroad at a renowned European institution for about 6 months.

From 2006 and 2014, around 300 individuals applied and around 30 were enrolled (more or less, 50% males and 50% females). Their provenance was international: they came from Italy, Germany, France, UK, Serbia, South Africa, Canada, USA, Brazil, Nigeria, Australia, Lithuania. 24 completed the programme and 23 of them now have either a temporary or a permanent position in academies or in private companies in several countries (France, Germany, China, South Africa, USA, Switzerland, Italy, UK). We take this to show that the Programme was structured such as to grant participants with expertise and skills that could match professional requirements, both within and outside academia.

The students lived in an extremely exciting and lively scientific and cultural environment. They were induced to work and discuss collectively, sharing ideas, writing papers together, exchanging competences, and – of course – friendships, that still continue¹¹.

As mentioned above, there were three research groups: one dealing with philosophical issues, one with ethical issues, and one with STS issues. Over the period in which the programme was active,

¹⁰ Actually, not all of these works were read in their entirety. Chapters and excerpts were properly chosen.

¹¹ There has been also a FOLSATEC marriage and now there is a FOLSATEC child!

about 90 papers written by the students alone or with members of the faculty were published in the most important international journals. This clearly demonstrates how the programme, while paying deep and specific attention to novel training modes, was also meant to introduce students early on to careers as professional researchers, teaching them how to focus on clear deliverables and how to elaborate successful joint research products.

The PhD programme is now virtually extinct, even if something totally different continues under the same label. It was a quite exceptional educational, scientific, and existential adventure, which was made possible by the co-presence of a whole range of extremely favourable circumstances, such as: a particular scientific environment, with great laboratories and facilities available to both scientists and philosophers; specific boundary conditions (especially economic ones); great cultural openness and availability of dedicated and cooperative top senior philosophical scholars, top scientists and clinicians. In other words, educational visions could be very nicely implemented thanks to very favourable material, cultural and socio-economic conditions. Although by no means easy to replicate, this experience offers a clear instance of how the dyscrasia highlighted by Pradeu between the life sciences and philosophy of life sciences could be successfully put right through strategies implemented in educational contexts. It was an experience that would be a pity to forget or not take into consideration since it constitutes an example in the educational history of our discipline, in many respects a litmus test for the pros and cons of philosophy of science as applied in scientific contexts.

3. Philosophy for life sciences training

In the section above we have told a story about an educational programme for philosophers of biomedicine and bioethicists, a programme which – as seen – was strongly scientifically informed, not only since scientific knowledge was provided but mainly because it was realised in a scientific environment to which all participants belonged and in which they all played an active part. First-hand experience of how scientific investigations are *de facto* carried out was no doubt one of the major added values of the programme. Now we want to address the other side of educational programmes across science and the humanities, and show how philosophy might be a necessity and should be included in the educational curricula of young life scientists and clinicians. While the previous example began with the story of FOLSATEC as a possible model for training philosophers of biomedicine and bioethicists, we start now presenting some general reasons why philosophy is necessary for the life sciences and “can support medicine in the effort of maintaining its epistemic authority and credibility in society” (Andreoletti and Maugeri 2019, p. 3). We argue for an educational model in which philosophy and philosophers play a major role. What is interesting from the sketchy

review below of the reasons supporting the idea that philosophy is necessary is that they are not advanced only by philosophers in philosophical journals but largely by life scientists or clinicians in scientific journals¹². And it is exactly to meet this increasing demand for more philosophy - in particular of ethics and philosophy and methodology of science - that we constructed our answer to the question concerning which philosophy a medical student mostly needs in order to become a good scientist or a good physician.

R. Smith, the former editor of *The BMJ*, has vibrantly stated that “healthcare, which is suffering an existential crisis, badly needs the help of philosophers” (Smith 2016). Such a feeling is shared by an increasing number of biomedical scientists and clinicians: all of them are asking for more ethics, more philosophy of science and more methodology of science in the training of the young generations. For example, A. Casadevall, a paradigmatic exemplar of this kind of philosophically-interested scientists, is a strong supporter, at graduate level, of putting “the ‘Ph’ back into ‘PhD’”, i.e., Philosophy into a *Philosophiae Doctor* programme. Philosophy can, in turn, be included in a range of different approaches and specific vantage points. We already mentioned a few of them above and many more could be recalled (see e.g. Casadevall and Fang, 2012; Casadevall, 2015; Prather et al. 2009; Couzin-Frankel, 2013).¹³ Philosophy in turn includes a range of different theoretical proposals, sub-disciplines and vantage points. We should hence be clear on what philosophical approaches might really make a difference to medical education, and should urgently do so.

Why ethics? This is a relatively easy question if considered in the light of the biomedical sciences themselves. On the one hand, there is a need for more integrity among researchers and clinicians, as the reports of scientific fraud and misconduct¹⁴, and the growing number of retractions connected with un-ethical behaviours show¹⁵. On the other hand, the surprising research and advancements, especially in the field of precision medicine and biotechnology, demand new ethical analyses¹⁶. In addition, there is no clearly shared idea of what constitutes a conflict of interest both at the research

¹² See the paper in PNAS written by a group of scientists and philosophers (L. Laplane, P. Mantovani, R. Adolphs, H. Chang, A. Mantovani, M. McFall-Ngai, C. Rovelli and E. Sober): Laplane et al. (2019).

¹³ It worth recalling also Grüne-Yanoff (2014) who provided a detailed analysis of the limits of the standard teaching of the science curriculum, and suggested a few directions in which it should be revised.

¹⁴ There is a huge literature on scientific frauds and misconducts. See, for example, Corbyn,(2012); Edwards and Siddhartha (2017); Yong et al. (2013); Hartgeri (2015); Horbach et al. (2016); Ioannidis (2011).

¹⁵ See e.g. Fang and Casadevall (2011); Steen, Casadevall et al. (2013); Resnik, Wager and Kissling (2015); Wager and Williams (2011). See also: <http://www.the-scientist.com/?articles.view/articleNo/44895/title/The-Top-10-Retractions-of-2015/> and <http://www.the-scientist.com/?articles.view/articleNo/47813/title/Top-10-Retractions-of-2016/>.

¹⁶ Here there is an enormous literature. As an example of contemporary debate, see what is said about He Jiankui's announcement and the first germline-edited babies through CRISPR technique: Cyranoski and Ledford (2018); Cyranoski (2018), and the Editorial on How to respond to CRISPR babies (Nature 564, 5 (2018), doi: 10.1038/d41586-018-07634-0; Cohen (2018).

and clinical level¹⁷. All this requires that a PhD student be exposed to ethical issues. Of course, none of those who ask for more ethics is seeking to transform a life sciences PhD student into an expert ethicist. Rather, s/he should be required to know what ethics is about, and that any of her/his actions (as a future researcher or future clinician) may be ethically valued and can have societal consequences.

Why methodology of science? Speaking with PhD students and biomedical researchers or clinicians, but also reading articles in top journals, epistemological issues arise as to what science and its methods exactly are. In particular, seldom is there an uncontroversial, totally and undoubtedly shared understanding that Galilean science, i.e., our science for at least four centuries, is based on the disclosure of data and empirical procedures, and that it is this disclosure that allows the replicability and the reproducibility of outcomes¹⁸. Without the transparent disclosure of data and empirical procedures, and without replicability and reproducibility of the empirical results, the science we have and we know would no longer exist: a very trivial point too pervasively forgotten,¹⁹ as many warn.²⁰ This is an extremely serious problem, not only for science and scientists,²¹ but for all society, since there is a risk that irreproducible data could be used to propose diagnostic tools and therapeutic treatments to patients. Moreover, without the characteristics just mentioned how could science be separated from other kinds of knowledge, and serious and scientifically validated medical treatments be distinguished from dangerous or absolutely ineffective treatments offered by alternative, not scientific approaches? All these issues – as well as those addressed below with regard to philosophy of science - make clear that the epistemological, methodological and conceptual matters dealt with here actually have also a cultural and political impact, having to do, in a wider sense, with the conception of science and the defence of scientific method, the use of products of scientific investigations in a given social context, therapeutic choices and preventive strategies²². Even in this case, none of those who ask for more methodology of science is asking to transform a life sciences PhD student into an expert of methodology. Rather, it

¹⁷ See, for example, McCoy and Emanuel (2017); Fontanarosa and Bauchner (2017); Thornton (2017); Fineberg (2017); Ginsburg and Levinson (2017).

¹⁸ As is known, replicability concerns the possibility to reobtain the same results with the same experimental set up and procedure by the same researcher in the same lab; reproducibility regards the possibility to reobtain the same results with a different experimental set up and procedure by a different researcher in a different lab.

¹⁹ It is so pervasive that there is also a Wikipedia entry on this: https://en.wikipedia.org/wiki/Replication_crisis

²⁰ Boniolo and Vaccari (2012); Andreoletti (2016); Begley and Ioannidis (2015); Casadevall and Fang (2010); Jarvis and Williams (2016); Freedman and Inglese (2014). See also the special issue of Nature (2017) on Challenges in irreproducible research, Nature; and the manifesto for reproducible results, Munafò et al. (2017); Freedman et al. (2015).

²¹ The irreproducibility of scientific results is such a well perceived issue that we are seeing the birth of new funding agencies exactly devoted to replication of scientific results. See, for example, Baker (2016).

²² See e.g. concerns on drugs (e.g. Andreoletti and Teira 2019)

is asked that s/he knows that there is something called methodology and that her/his daily job in a lab or in a ward is characterised by a specific way of proceeding.

Why philosophy of science? A two-facet answer could be given. On the one hand, a philosophy of science competence could help avoid certain reasoning fallacies, which could jeopardize our way of interpreting scientific results and clinical tests. For example, the fallacy of inferring positive conclusions from negative data, the fallacy of the affirmation of the consequent, the fallacy of the false generalization (Casadevall and Fang, 2012), and the confusion between a statistical correlation and a causal correlation (Velickovic, 2015) are extremely common and easily found in scientific papers. Having a philosophical preparation in correct arguments could improve appropriate reasoning in the research environment, and in the clinic (Bosch, 2018; see also Bartlett and McKinley 2013; Amey, Donald and Teodorezuk 2017; Elizondo-Omaña et al. 2010; Kurzenhäuser and Hoffrage 2002). These kinds of concerns are actually addressed through an increasing range of initiatives, witnessing the large consensus on the importance to put philosophy back into natural sciences. That these are timely and relevant discussions is also shown, for instance, by the growing field of "metascience", which explicitly addresses metatheoretical issues about scientific practice, methodologies, culture and norms influencing science – questioning, for instance, how our statistics, methods, and measurement practices affect our capacity to identify robust findings, whether the distinction between exploratory and confirmatory research matters, what replication is and what its impact and value are, how scientists interpret and treat evidence (see <https://www.metascience2019.org>). All these aspects have to do with our modes of reasoning and interpreting and employing scientific evidence.

If wrong reasoning is made in a lab, at maximum we have a bad research outcome and a bad paper, but if wrong reasoning is made at the patient's bedside, it could endanger that patient's life! And the same could be said on the preventive aspects. Conversely, philosophical competence could provide a correct understanding of the theoretical foundations of probability and statistics. From what we have read over these last years, it seems that there is no clear, univocal and shared idea, for instance, of what a p-value is, what its connection with a confidence interval is, what scientific/clinical relevance is, etc.²³ This, again, could be extremely dangerous both at a diagnostic or therapeutic stage and at a preventive stage, where a wrong interpretation, or use or communication of statistical results could jeopardise, for example, the planning or the success of a screening campaign (see Altenberg, 2015, Ferretti, Linkeviciute, Boniolo, 2017)

²³ Of course, here we cannot avoid quoting Ioannidis (2005), whose impact also on public opinion has been enormous, as the article on *The Economist* of Oct 19th 2013 shows ("How science goes wrong. Scientific research has changed the world. Now it needs to change itself"). For the perception of the problem, see also Nuzzo (2014) .

This lack of philosophical knowledge of the foundations of the two above-mentioned disciplines characterizes not only the research domain but, unfortunately for patients, even the clinical sphere. There are reports showing that sometimes there is incorrect understanding of what a survival rate can tell us, or what the difference between the sensitivity and specificity of a test, or positive and negative predictive values are (Wegwarth, 2012; Loong, 2003). Again, none of those who ask for more philosophy of science is asking to transform a life sciences PhD student into a philosopher of science. Rather, it is asked that s/he knows that there is a proper way of thinking, with its own rules – coded down the millennia – and that there are many conceptual issues under the statistical software s/he is using. Philosophical reflections on the foundations of probability and statistics can complement knowledge of technical tools with some understanding of implicit assumptions, possible interpretations and chosen meanings on notions employed. A philosophically correct understanding of all these aspects is not an intellectual luxury but necessary in order to properly understand the results of a clinical test, an experiment, and a clinical trial.

Thus, what is the most adequate epistemic attitude to ameliorate the situation?

Certainly, it is good and praiseworthy to denounce frauds, misconducts, errors of reasoning, lack of ethical sensibility, ignorance of the basics of the scientific methodology and the philosophical foundations of, for instance, probability and statistics, and modelling. To complain and to denounce is certainly right also in order to warn that we are running the risk of distorting science as we know it, undermining, in the long run, also trust in science and its social role. Denouncing should be accompanied by a more proactive stance, one which is not always conveyed by literature on the topic. Theoretical reflections should be accompanied by constructive engagement with the education of the future generations of biomedical scientists and clinicians, to make sure that the genuine status of science is preserved – as requested by scientists and clinicians themselves – and that we are overall able to make the most out of scientific progress insofar as health conditions are concerned. We should promote changes or adjustments in the usual curricula of the bioscientific programmes and medical schools in order to insert more ethics and more philosophy and methodology of science, i.e., more humanistic subjects which – given our present concerns here – have a direct impact on methodological features of scientific enterprise. A proper training of future researchers and clinicians is the best defence against the awful risk of missing the science we know and trust. This could mean missing reliable scientific findings and failing to make a clear demarcation between science and other, unreliable, forms of knowledge: the only shields against fake science and pseudo-science. Philosophers of science are hence called to take the full responsibility for this educational role, and, to fulfil it, to engage into interactions with scientists not

only on philosophically interesting theoretical issues, but also on practical, contingent, educational matters.

4. Conclusions

Interdisciplinary research projects and teaching activities involving philosophy of science and the biomedical sciences have been increasing in the last few years, as widely witnessed by the expanding literature on the topic, both in science and in philosophy journals. Important centres, research groups and networks devoted to the philosophy of biology and biomedicine operate in a range of institutions worldwide, with a strong focus on actual scientific research and practice.²⁴ While driven by analogous tenets, the training and educational projects described above have been presented as special experiences, requiring a range of favourable conditions, scientific contexts and cooperative relations. We believe that a few of their features might allow to make some significant steps forward in discussing educational issues at the crossroad of philosophy and medicine, addressing them jointly and building bridges between theoretical considerations and educational practices – possibly getting to some shared best practices. In particular, we think three aspects are worth stressing. To start with, educational experiences like FOLSATEC need to be implemented in an environment in which students with a background in philosophy can work side by side with scientists in the labs, thus learning technical aspects of experimental practice in great details. Secondly, implementing a philosophical course for medical students which proves really relevant for medical education needs to: a) be *mandatory* – as opposed to optional – for *all* students in Medicine; b) span over *the whole six years* on the degree in Medicine and Surgery; c) *jointly address* topics in philosophy of science *and* bioethical issues, thus highlighting their close relations and *mutual relevance*; d) involve, during lessons, presentations of *actual cases* by senior colleagues in Medicine, thus showing the strong and direct relevance of *philosophical discourse for clinical practice*. Thirdly, the activities described above are to be conceived within a single, wider

²⁴ To recall just a few, as for research groups see, e.g., the “Theory and Method in Biosciences” research group (University of Sydney); “ImmunoConcEpT” group (University of Bordeaux); the PhiInBioMed network. With respect to teaching, examples are provided both by wide initiatives – as the R3 Graduate Science Initiative “Critically Thinking Science” at Johns Hopkins University (Maryland, USA) led by Gundula Bosch – or by the insertion of specific courses into curricula – as, e.g., the course on “The science and its philosophy”, delivered by the Department of Biology at the University of Lund (Sweden), and mandatory for all PhD students in biology. See also what is done in the Medical Schools of the University of Redlands (CA, USA) by James Krueger and of the University of Alabama (USA) by Ted Poston. Another important educational example, where biological and biomedical aspects are considered together with humanistic aspects, is given by the European Advanced Seminar in the Philosophy of the Life Sciences (EASPLS), which is held each two years (the last two times at the Konrad Lorenz Institute for Evolution and Cognition Research) since 2008.

perspective: a training in which the sciences and philosophical reflections figure jointly is not to be confined to a specific stage of one's education – nor is it just elective – but it is *transversal* to all its various phases (undergraduate, PhD, early career stages) and integrated with them.

Over and above specific features of single projects/initiatives, what general take-home lessons can be drawn from such experiences that might be relevant for a better understanding of present – and future – relations between philosophy of the life sciences and the life sciences themselves?

Reflections can be made at a number of different levels, regarding both scientific and practical issues. On the one hand, we are encouraged to reconsider the mutual role and possible interactions between philosophies and the sciences, not only in terms of theoretical discourses (e.g. on inter-, multi- and trans-disciplinarity), but as enacted in research contexts (e.g. in everyday work in labs).

On the other, any novel approach to higher education and professional training must entail reconsideration of actual educational curricula as well, and on the impact of curricula on professional lives. If we agree on the importance of some scientific training for philosophers and some philosophical training for scientists, then we might also have to question the structure and organization of higher education and early career processes. For instance, would present curricula in philosophy – e.g. Master and/or PhD programmes – allow for the inclusion of scientific training courses, and vice versa?²⁵ Are some curricula in education worldwide more favourable than others in this respect?²⁶ Could some good lessons be drawn by systematically comparing results – e.g. joint works in the sciences and humanities – obtained within different educational and training systems?

A second relevant aspect – which in a sense “builds on” the previous, but concerns also the actual impact of some “mixed” training in the longer run – has to do with early careers. To what extent do the job market or applications for grants and fellowships reward the effort of acquiring some proper tools in both the sciences and the humanities? Is the additional effort required worth it, in terms of access to some job placements and/or research projects? Theoretical reflections on in principle best interactions among disciplines should not ignore practical constraints. At least intuitively, it seems easier to get some knowledge in the opposite field – which, undeniably, requires extra time, energy and commitment²⁷ – if one has already an established position within a scientific community. If philosophical interests in the sciences or scientific interests in the humanities are not to be a sort of “late career addendum”, but, as argued above, part and parcel of standard training, then proper

²⁵ On some features of conventional curricula, see Grüne-Yanoff (2014), § 2.

²⁶ See e.g. the major/minor university system.

²⁷ While strongly supporting the transfer of some scientific knowledge to philosophers and of philosophical, conceptual and methodological tools to scientists, we cannot forget that the enterprise requires strong commitment. Building, for example, a common language and theoretical framework is far from trivial, and often requires selecting the proper degree of simplification – such that, while keeping the core message totally intact, sometimes there is no need to be familiar with all the subtleties that only major experts in the field command.

recognition of some trans-disciplinary work should be warranted from the start. While vast, literature on educational cross-disciplinary scenarios still tends to neglect these aspects, which we believe need to be seriously considered for the debate to get beyond academic discussion and translate into wider scientific, social and cultural impacts.

Boon and van Balen (2019) stress that “not *integration* of theories and disciplinary perspectives is the first task for interdisciplinary collaboration, but clarification of the specificities of the disciplines and of the way in which in a discipline ‘knowledge’ comes about” (p. 23). We agree, and think that this holds for all disciplines. Learning *how* “knowledge comes about” must be a target when approaching a field. Finally, what the examples given above might teach us of the relations between the life sciences and the philosophers of the life sciences is that the engagement of the latter must be measured not only with respect to the topics chosen in research contexts, but also with regard to the roles in educational processes. Actual experiences across disciplines, rather than theoretical, scholarly reflections on interdisciplinarity, might prove more effective in order to have scientifically informed philosophers and philosophically conscious scientists. “Many studies focus on organizational and institutional obstacles to interdisciplinary research, rather than the cognitive and epistemological obstacles” (*ibid.*, p. 8). We believe that: i) the focus should not be just on interdisciplinary results of research per se, but also on the benefit that the exchanges between different disciplines can in the end have *within* each single field involved; ii) rather than being prioritized differently, organizational, institutional, educational, cognitive and epistemological aspects should be addressed *together*, iii) addressing philosophical training for scientists and scientific training for philosophers as two sides of the same coin, and being committed as philosophers with respect to both, is likely to be a very fruitful way to shed light on “how knowledge comes about” in both fields. As a last point, we wish to stress that, as the examples from the scientific literature and teaching activities and projects have shown, only by jointly considering research issues, training initiatives, and institutional and organizational early career conditions can we have a rethinking of the relation between philosophy of science and the life sciences that has an impact on the future fate of both fields.

5. Acknowledgments

We would like to thank T.P. for his useful comments on a previous version of the paper and three anonymous reviewers whose suggestions have helped to improve the paper.

References

- Altenberg L (2015), Statistical Problems in a Paper on Variation In Cancer Risk Among Tissues, and New Discoveries. arXiv:1501.04605
- Amey L1, Donald KJ2, Teodorczuk A (2017) Teaching clinical reasoning to medical students Br J Hosp Med (Lond). 2017 Jul 2;78(7):399-401.
- Andreoletti M (2016) Reproducibility: Hallmark labs with a replicability record. Nature 537: 34
- Andreoletti M et . (2016) Why genes are like lemons, Studies in History and Philosophy of Biol & Biomed Sci, 57: 88-95.
- Andreoletti, M and Maugeri, P (2019) Does medicine need philosophy? Oral Diseases, <https://doi.org/10.1111/odi.13143>
- Andreoletti, M., Teira, D (2019) Rules versus Standards: What are the costs of epistemic norms in drug regulation? Science, Technology, and Human Values, 1-23, <https://doi.org/10.1177/0162243919828070>
- Baker M (2016) Dutch agency launches first grants programme dedicated to replication, Three-year pilot devotes €3 million to verifying other studies Nature News. doi: 10.1038/nature.2016.20287
- Gay S1, Bartlett M, McKinley R. (2013), Teaching clinical reasoning to medical students. Clin Teach.10(5):308-12.
- Begley C.G, Ioannidis J.P (2015) Reproducibility in science: improving the standard for basic and preclinical research. Circ Res. (116): 116-26
- Boniolo G, Vaccari T (2012) Publishing: Alarming shift away from sharing results. Nature 488:157
- Boon M, Van Baalen S (2019) Epistemology for interdisciplinary research – shifting philosophical paradigms of science. Euro Jnl Phil Sci 9:16. <https://doi.org/10.1007/s13194-018-0242-4>
- Bosch G. (2018) Train PhD students to be thinkers not just specialists. Nature, Feb 15; 554 (7692): 277. doi: 10.1038/d41586-018-01853-1
- Bosch G, Casadevall A (2017) Graduate biomedical science education needs a new philosophy. mBio 8:e01539-17. <https://doi.org/10.1128/mBio.01539-17>
- Casadevall A. (2015) Put the “Ph” Back in PhD. <http://magazine.jhsph.edu/2015/summer/forum/rethinking-put-the-ph-back-in-phd/>
- Casadevall A, Fang F.C (2010) Reproducible science. Infect. Immun.78:4972-4975
- Casadevall A, Fang, F.C (2012) Reforming science: Methodological and cultural reforms. Infection and Immunity, 80:891-896
- Cohen J (2018) What now for human genome editing? Science, 7 Dec 18: Vol. 362, Issue 6419, pp. 1090-1092
- Corbyn Z (2012) Misconduct is the main cause of life-sciences retractions. Opaque announcements in journals can hide fraud, study finds. Nature 490: 21

- Couzin-Frankel J (2013) Shaking up science. *Science*, 339: 386-389
- Cyranoski D (2018) First CRISPR babies: six questions that remain. *Nature*, 30 Nov 2018, doi: 10.1038/d41586-018-07607-3
- Cyranoski D, Ledford H (2018) Genome-edited baby claim provokes international outcry, *Nature* 563, 607-608, doi: 10.1038/d41586-018-07545-0
- Edwards M.A, Siddhartha R (2017) Academic research in the 21st century: Maintaining scientific integrity in a climate of perverse incentives and hypercompetition. *Environmental Engineering Science*. 234: 51-61
- Elizondo Omaña R.E. et al. (2010) Teaching skills to promote clinical reasoning in early basic science courses. *Anat Sci Educ*. 2010 Sep-Oct;3(5):267-71.
- Fang F.C, Casadevall A (2011) Retracted science and the retraction index. *Infect. Immun.*79: 3855-3859
- Ferretti G, Linkeviciute A, Boniolo G. (2017) Comprehending and Communicating Statistics in Breast Cancer Screening. Ethical Implications and Potential Solutions. In M. Gadebusch-Bondio, F. Spöring, J.-S. Gordon (eds), *Medical Ethics, Prediction and Prognosis: Interdisciplinary Perspectives*, Routledge, New York 2017, pp. 30-41.
- Fineberg HV (2017) Conflict of interest: Why does it matter? *JAMA* 317(17):1717–1718
- Fontanarosa P, Bauchner H (2017) Conflict of interest and medical journals. *JAMA* 317(17):1768–1771
- Freedman L.P, Cockburn I.M, Simcoe T.S (2015) The economics of reproducibility in preclinical research. *PLoS Biol* 13: e1002165. doi:10.1371/journal.pbio.1002165.
- Freedman L.P, Inglese J (2014) The increasing urgency for standards in basic biologic. *Cancer Res* 74: 4024–4029.
- Fulford, W, (1991) The potential of medicine as a resource for philosophy. *Theoretical Medicine* 12(1): 81-85.
- Germain P-L, Ratti E, Boem F (2014) Junk or functional DNA? ENCODE and the function controversy. *Biology & Philosophy* 29: 807-831.
- Ginsburg S, Levinson W (2017) Is there a conflict of interest? *JAMA* 317(17):1796–1797
- Grüne-Yanoff T (2014) Teaching philosophy of science to scientists: why, what and how. *Euro Jnl Phil Sci* 4:115–134
- Hartgerink C.H (2015) Research misconduct: Speed translation of misconduct reports. *Nature* 522: 419;
- Horbach S.P.J.M, Halfman W (2016) Promoting virtue or punishing fraud: Mapping contrasts in the language of 'scientific integrity. *Sci Eng Ethics*, DOI 10.1007/s11948-016-9858-y

- Ioannidis J.P (2005) Why most published research findings are false. *PLoS Med.* 2:e124
- Ioannidis J.P (2011) An epidemic of false claims. Competition and conflicts of interest distort too many medical findings. *Sci. Am.* 304:16.
- Jarvis M.F, Williams M (2016) Irreproducibility in preclinical biomedical research: Perceptions, uncertainties, and knowledge gaps. *Trends Pharmacol. Sci.* 37:290–302
- Kurzenhäuser S1, Hoffrage U. (2002) Teaching Bayesian reasoning: an evaluation of a classroom tutorial for medical students. *Med Teach.* 2002 Sep;24(5):516-21.
- Laplane L et al. (2019) Why science needs philosophy. *PNAS* 116(10), 3948-3952
- Loong T-W (2003) Understanding sensitivity and specificity with the right side of the brain, *BMJ*, 327:716-719
- Losee J (1972) A historical introduction to the philosophy of science, Oxford University Press, Oxford
- Maugeri P. and Blasimme A (2011) Humanised models of cancer in molecular medicine: the experimental control of disanalogies, *History and Philosophy of the Life Sciences* 33 : 603-622
- McCoy M.S, Emanuel E.J (2017) Why There Are No “Potential” Conflicts of Interest. *JAMA* 317(17):1721–1722
- Munafò M.R et al. (2017) A manifesto for reproducible science. *Nature Human Behaviour* 1: 0021
- Nardini C. and J Sprenger (2013) Bias and Conditioning in Sequential Medical Trials. *Philosophy of Science* 80: 1053-1064
- Normile D (2018) For China, a CRISPR first goes too far. *Science* 07 Dec, Vol. 362, Issue 6419, pp. 1091.
- Nuzzo R (2014) Scientific method: Statistical errors. P values, the 'gold standard' of statistical validity, are not as reliable as many scientists assume. *Nature* 506: 150-152.
- Oldroyd R (1986) The arch of knowledge: An introductory study of the history of the philosophy and methodology of science. Routledge Kegan & Paul: Abingdon
- Pradeu T. (2017) Thirty years of Biology & Philosophy: philosophy of which biology? *Biol Philos* 32(2):149–167
- Prather C. M, Choate D.M, Michel M.J, Crowl T.A (2009) Putting the “Ph” back into “PhD”: framing graduate research in a theoretical context. *Frontiers in Ecology and the Environment* 7: 389–390
- Quintero G. A (2014) Medical education and the healthcare system – why does the curriculum need to be reformed? *BMC Medicine* 2014 **12**:213, <https://doi.org/10.1186/s12916-014-0213-3>

- Rehg, E, SmithBattler L. (2015) On to the 'rough ground': introducing doctoral students to philosophical perspectives on knowledge. *Nurs Philos* 16(2):98-109. doi: 10.1111/nup.12077. Epub 2014 Dec 4.
- Resnik, D.B, Wager E, Kissling, G.E (2015) Retraction policies of top scientific journals ranked by impact factor. *J Med Libr Assoc.* 103: 136-9
- Sanchini S et al. (2016) Research Biobanks: Why Information And Information-Based Consents Are Not Enough, *Bioethics*, 30: 260-271.
- Smith R (2016) Medicine needs for philosophy (<http://blogs.bmj.com/bmj/2016/04/08/richard-smith-medicines-need-for-philosophy/>; April 8, 2016)
- Spike, J (1991) The need for teaching philosophy in medical education. *Theoretical Medicine* 12(4): 359-365.
- Steen R.G, Casadevall A., et al. (2013) Why has the number of scientific retractions increased? *PLoS One* 8: e68397
- Thornton JP (2017) Conflict of interest and legal issues for investigators and authors. *JAMA* 317(17):1761–1762
- Velickovic V (2015) What everyone should know about statistical correlation. A common analytical error hinders biomedical research and misleads the public. *American Scientist* 103(January–February):26-29
- Wager E, Williams P (2011) Why and how do journals retract articles? An analysis of Medline retractions 1988–2008. *J Med Ethics* 37:567—570.
- Wegwarth O.I. et al. (2012) Do physicians understand cancer screening statistics? A national survey of primary care physicians in the United States. *Ann Intern Med* 156:340–349
- Yong E., Ledford H., Van Norden R (2013) Research ethics: 3 ways to blow the whistle. Reporting suspicions of scientific fraud is rarely easy, but some paths are more effective than others. *Nature* 503: 454–457.