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Ten tips for young scientists on how not to think about science

Diez consejos para jóvenes científicos sobre cómo no pensar sobre ciencia

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RESUMEN

Llegar a una definición adecuada sobre qué es la ciencia ha constituido un tema central de la filosofía de la ciencia durante mucho tiempo. Además, varios actores del público en general (incluidas las autoridades, los financiadores, y los docentes/profesores de ciencias) tienen muchos conceptos erróneos y mitos sobre cómo funciona la ciencia y qué hacen los científicos. Este ensayo ofrece una serie de consejos a jóvenes científicos sobre cómo lidiar o contrarrestar tales conceptos erróneos y, en general, sobre cómo no pensar en ciencia. Muchos de estos conceptos erróneos tienen fuertes efectos negativos sobre cómo se piensa, enseña, y financia la ciencia. A través del desarrollo de este ensayo llegué a la conclusión de que varios aspectos sobre el funcionamiento de la ciencia y el método científico, deben ser evaluados y enseñados de manera diferente. Es necesario dar la bienvenida a los cambios de paradigma, evitar los delirios racionalistas, comprender la plétora de métodos científicos que existen y, sobre todo, enfatizar cuán importante es la introspección en la actividad científica. Como consecuencia de esta forma de pensar e introspección, se deben promover cambios en el comportamiento cotidiano: acentuar la cooperación y la creación de redes científicas globales, enfatizar la importancia de un trato y comportamiento más cálido e inclusivo dentro y entre los grupos de investigación, estar abierto en términos de horarios e ideas, y construir un equilibrio más saludable entre el trabajo y la vida diaria.

Palabras clave: Humor, Aprendizaje, Recurso didáctico.

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ABSTRACT

Arriving to a proper definition on what is science has constituted a main issue of the philosophy of science for a long time. Besides, several actors in the general public (including authorities, funders, and science teachers/professors) have a lot of misconceptions and myths about how science works and what scientists do. This assay offers a series of tips to young scientist on how to deal or counteract such misconceptions, and overall on how not to think about science. Many of these misconceptions have strong negative effects on how science is thought, taught, and financed. Through the development of this assay I came to the conclusion that several aspects on the functioning of science and the scientific method, should be evaluated and taught differently. It is necessary to embrace paradigm shifts, avoid rationalist delusions, understand the plethora of scientific methods that exist, and especially, emphasize how important introspection is on the scientific activity. As a consequence of this way of thinking and introspecting, changes in everyday behavior should be promoted: embrace cooperation and global scientific networking, emphasize the importance of a warmer and more inclusive treatment and behavior within and among research groups, be open in terms of schedules and ideas, and build a healthier work-life balance.

Keywords: : creativity, networking, science myths, scientific method, stoicism.

INTRODUCTION

As soon as science and scientific knowledge appeared, there were and are intense debates on defining what science is -and what it is not. Defining what science is has been a central issue of the philosophy of science and its specific disciplines for more than a century. Also, there are misconstrued public perceptions and myths from the public and authorities on what scientists do. Sadly, many of these misconceptions have strong negative effects on how science is thought, taught, and financed. Thus, although the debate on a definition of science and issues within is more than important, it is also important to define what science is not. Or specifically, how (not) to think about science.

I am aware that speaking in the negative is uncommon, but necessary, and always a step towards a definition, in order to combat the many myths that surround scientific activity. This also is an exercise coming from discussions and debates with researchers at different stages and with different yet reconciled and broad perspectives, reflecting the spirit of open academic discussion. In this sense, these tips take inspiration from the Ten Simple Rules article series of the PLOS Computational Biology journal (Dashnow et al., 2014; Bourne et al., 2018). Hence, these tips include some that are more philosophical and introspective, while others are more practical and related to the everyday life of a scientist.

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DEVELOPMENT

Tip 1: Science continuously changes, mistakes and paradigm shifts are expected

In his short story "On Exactitude in Science" (Borges, 1998), Jorge Luis Borges imagines an Empire where the cartographers are so obsessed with creating an exact map of it, that they ended up crafting a map as big as the Empire itself. For following generations, the map was useless and ended up being ripped apart. This is a basic and fundamental feature of the scientific activity that should be celebrated: science is uncertain to some point, it is an approximation to reality, and paradigm shifts are expected (Kuhn, 1962; Okasha, 2016). Although, sometimes it is difficult to have objective criteria to evaluate such shifts, as noted by Paul Feyerabend (Hoyningen-Huene, 1995). Still, celebrate these uncertainties and even mistakes, as they signal that knowledge is advancing or at least that you should take another path. Even when your own hypotheses, ideas, and/or theories are rejected, you should also celebrate this. And even when someone proves you wrong -either by arguments or experiments, you should never take it personally, even if sometimes the counterpart makes it personal. Celebrate your mistakes. In many cases, when experiment fail to support experiments, this leads to new experimental designs and/or new questions, which often also leads to new facts being discovered.

Sometimes the general public and especially the press, do not understand that some uncertainty is healthy, that mistakes happen, and that such is the way science works, in a self-correcting way. That is a message that every scientist should make clear, and that should be taught to kids from an early age, so adults do not get offended when corrected. For scientists, the language used and the supporting evidence should be of paramount importance when communicating complex ideas to the public, hopefully in a simple way. For example, during the still-present COVID-19 global pandemic, risky levels of misinformation (Rosenberg et al., 2020) and science skepticism (Rutjens et al., 2021) are being observed, because, among other reasons, newer and changing knowledge about the virus and vaccines (and other protective measures) is being generated at unprecedented rates. Most people are not used to such changes. A basic grasp on how science works would counteract misinformation and science skepticism.

Tip 2: Science is a human activity, therefore reason may not always prevail

Despite sometimes being presented in an idealistically objective framework, science is a fundamentally human activity, and therefore, flawed. Reason and intuition have a complex interaction in the mind, even for scientists. For Haidt (2012), "the mind is divided, like a rider on an elephant, and the rider's job is to serve the elephant", where intuition is the elephant, and strategic reasoning the rider. Six areas of experimental research support this notion (Haidt, 2012): i. The brain makes constant and instantaneous moral, social, and psychological judgments; ii. Social and political judgment highly depend of fast intuitive flashes; iii. Corporal states (like flavors and smells) sometimes affect our moral judgments; iv. Psychopaths reason but do not feel; v. Babies feel but do not reason; and vi. In the brain, affective reactions are in the right place at the right time (Haidt, 2012). All this has been shown irrespective of the education level (Haidt, 2012). Thus, and contrary to what many philosophers have argued (from Plato to Kant), the "rational caste" (philosophers and scientists -who should rule, according to them) is not exempt from the strong role that intuitions and feelings play in the mind. Furthermore, research has shown that even moral philosophers -those who analyze ethics through reason- are no different from the rest of society (Haidt, 2012). They do not return more books (Schwitzgebel, 2009), are equally negatively critiquing of colleagues (Schwitzgebel & Rust, 2009), do not vote more (Schwitzgebel & Rust, 2010), are equally cordial during conferences (Schwitzgebel et al., 2012), and do not answer more students' emails (Schwitzgebel & Rust, 2014), compared to academics from another areas. They are also equally vegetarian, in contact with their mothers, associated to academic societies, they equally donate blood, organs, and money, and they are equally honest when answering questionnaires (Schwitzgebel & Rust, 2014). Thus, not even the people using reason to study ethics seem to be more ethical (Haidt, 2012).

So, if not even the most prepared minds are exempt of such instant and intuitive moral, social, and psychological judgments, why insist that reason dominates the mind? And why think scientists are exempt? The above-mentioned evidence suggest that most action in our minds happens in the elephant -the intuitions, which activate immediately through perception. But the elephant itself is not stupid nor a tyrant, and with time, a good rider learns to anticipate the elephant's actions.

This does not imply we should abandon reason. The fact that each individual scientist is not totally reasonable and not exempt from strong intuition and quick judgments, does not mean that science is not reasonable but rather a "social construct" or a "modern myth" (Berger & Luckmann, 1966). The cognitive relativism of postmodernism should be strongly and permanently denounced (Sokal & Bricmont, 1997). But also, such denouncement should not lead to the extreme to think that science and reason alone should be the only moral guides for human behavior (Harris, 2010). The mechanism of evolution through natural selection proposed by Darwin and Wallace, is a scientific fact supported by contemporaries of them as different as the eugenicist Sir Francis Galton and the Russian anarchist Pyotr Alexeyevich Kropotkin. Both of them (as Darwin and Wallace themselves) had highly different political views -and therefore different intuitions and moral, social, and psychological judgments, but the truthiness of natural selection is so strong, they supported it.

Tip 3: There is not one scientific method

With his quest on determining what science is and what it is not -the problem of demarcation, the Austrian philosopher Karl Popper had, and continues to have, a strong influence on how science is perceived and taught. For Popper (1934, 1980), science should always use deductive inferences. In practice, though, that is not how science works (Okasha, 2016): the cause of Down syndrome (three copies of chromosome 21) and Newton's universal gravitation principle have been inductively inferred. All chromosomes of all persons with Down syndrome and all gravitational attractions from all bodies in the Universe should be measured for both phenomena to be deductively inferred. And even there, for Popper, the cause for both phenomena cannot be concluded, rather just falsified. In practice, no one is looking to not-affirm or falsify her

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(or others) hypotheses, but to prove them. As David Hume argued, there is no rational way to justify the use of inductive inferences (Okasha, 2016), but we use them all the time in everyday life, even in science. Many different inductive inferences, with variation in time and in space (ie. replication of experiments), and coming from people with different moral views and judgments (see Tip 2), will lead to an approximation of the truth (see Tip 1).

Unfortunately, science as a solely deductive activity is how it is mostly taught and, in some cases, financed, even if does not correspond to how it is practiced. Hansson (2006) analyzed 70 highly cited Nature articles, applying the five demarcation questions/criteria that Popper suggested to define what science is and is not (Popper, 1963, 1980), related to the types, number, and characteristics of the hypotheses tested. Just two out of the 70 articles met such criteria. It would be laughable to suggest that the other 68 articles do not constitute science. Likewise, it would not be responsible to say that areas like modeling, paleontology, naturalistic exploration, and many others that do not meet Popper's criteria, are not science. This leads to the inevitable conclusion that there is not one scientific method applicable to all areas of research, but rather different methods of doing science. There are particular philosophical problems and ways of doing science within physics, chemistry, biology, and their specific areas.

Tip 4: No scientist is an island

Research (and ancient philosophy) shows that human nature is a balance between cooperation and competition (Turchin, 2010; Moorad, 2013; Richerson et al., 2016); sadly, the dominant economic theories and systems over the last century have emphasized the latter. Such a competitive way of thinking has affected how science is thought, taught, and financed. This leads to an extremely competitive environment for scholarships, grants, jobs, publishing, and prestige. And while ideas do need to compete, and scholarship/grant/job applications and publications should be thoroughly and carefully evaluated, an extremely competitive environment is not a healthy one. Such an environment has adverse effects on resource sharing, research integrity, and creativity (Fang & Casadevall, 2015), and increases the inequality of funding among researchers (Bol et al., 2018). It is also possible that such competitiveness leads to demographically underrepresented early career scientists, who innovate at a higher level, being less recognized and earning fewer academic positions (Hofstra et al., 2020).

The best ideas should prevail while at the same time creating a cooperative and collaborative research environment (within and between departments, universities, and/or internationally), where precisely the processes of collaboration, networking, and mentoring, and all the enjoyment that they entail (when done correctly), are the most fun part of doing science, even more so that the end result (publications, grants obtained, prestige, etc.). Investing time in your own research helps to build a strong curriculum vitae and a career, but investing time in students, in outreaching the general public, in building collaborations, networks, and academic communities (things seen by some as not as important as your own research), benefits many careers, increasing the reach of your area, and ultimately generating more knowledge that you could on your own.

You can cooperate far outside the limits of your institution and country. Recently, the formation of collaborative scientific networks has gained relevance by integrating researchers with common interests, from national to global scales (Richter et al., 2018). These networks allow constant communication, with less formality (and costs) than in traditional scientific societies, and also with well-defined objectives, while hopefully avoiding "helicopter science" – the practice of researchers from developed countries collecting samples, analyzing data, and publishing results from the Global South with little or no involvement of local collaborators (Minasny et al., 2020; Haelewaters et al., 2021). These networks allow assessing research questions with dozens or hundreds of researchers from all over the planet, as it is increasingly required in various scientific areas, for example like soil ecology (Bueno et al., 2017; Maestre & Eisenhauer, 2019). Founding, leading, and/or collaborating in research networks is more and more important.

Tip 5: Prestige and productivity is not all that matters

Criteria such as productivity (number and quality of articles and projects), match of interests, prestige of the university, and quality of life in the country, are important when choosing a place to study a graduate program or to establish yourself as an early career researcher. However, equally important criteria - albeit sometimes ignored- are the kindness and warmness of principal investigators (PIs) and their teams (Maestre, 2019), and a compatibility in work ethics. This is only known through previous interactions (for example during conferences), or by asking third parties. It is always possible that a not-so-productive PI provides more emotional support and a warmer treatment, and in general that there is a greater personality and work ethics compatibility. This will contribute more to forming free, independent, and happy researchers, than environments where productivity may be higher but the treatment is less warm and stress is prevalent (Maestre, 2019).

A warmer treatment implies avoiding extreme power dynamics in academy, which can have very negative effects (Park, 1992). Instead, horizontality should be promoted. Practices where students and early career researchers end up fulfilling secretarial or laboratory technician tasks should be avoided. Promoting work horizontality implies greater trust and a delegation of labor such as project management, supervision and co-supervision of bachelor and graduate thesis, classes, etc. This also implies a change in behavior and language, where excessive reverence, and distant and too-cordial treatment can be very counterproductive in trust building.

Diversity, equity, and inclusion also matters (Chaudhary & Berhe, 2020). It is important to feel included and being treated equally amidst a diverse group of individuals, so that you too carry that inclusion sense forward as you are responsible for groups of researchers rather than to just yourself. We owe that much to our fellow scientists.

Tip 6: Do not be affected by things not under your control

In other words, be stoic. Stoicism is a Hellenistic philosophy school based on logic, monism, and naturalistic ethics. In this system of thought, the path to eudaimonia (nowadays this can

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be translated as "self-actualization"), ataraxia (a state of robust equanimity), and areté (virtue) is achieved by living in and accepting the present, by not being controlled by the desire of pleasure or by fearing pain, by using reason to understand and improve the world, and by working together with others and treating them in a fair and just way (Pigliucci & Lopez, 2019). For stoics, living according to nature means using reason to improve social living, which sounds fundamentally scientific. We are in control of our own emotions, actions, and especially reactions to things happening in the world, but we should not be affected by things not under our own control. These include some health issues, property, reputation, and all other external things. If external things represent obstacles, they constitute growth opportunities. According to stoics, in order to make the most of life we should be aware that time is limited but we often fill it by worrying unnecessarily and with distractions that need to be ignored. Destructive and bad emotions should be avoided as they represent errors of judgment (Pigliucci & Lopez, 2019).

Some advice from stoicism can be applied for working in science: i. Train and take control of your attention, of your focus; ii. In the morning, start first with your most dreaded, challenging, stressful, and even boring tasks; iii. Focus on things, actions, and ideas under your control. If the end-results are not what you expected, do not be disappointed as you tried your best, and that is what matters. In stoicism, the focus is trying your best rather than getting a determined result, so you are never truly dissatisfied; iv. Always make progress, focusing on the small things in the present, not in the big picture of an uncertain future; and v. Simply, do not waste time, practice to become a good time manager and, again, avoid distractions. Overall, accept unexpected results, failure of experiments, rejections of project proposals and articles, and unless those failures are caused by an unjust treatment, repeat experiments and re-write your publications and project proposals. This would be a proper, stoic behavior after such failures, which should not affect you -or at least not that much. Failure can be the best teacher.

Tip 7: Creativity and interests should not be scheduled, restricted, and over-specialized

Traditional schedules do not work in science, since creativity does not have a schedule. Ideas come and go. Thus, besides some activities (periodic personal and team meetings, classes, laboratory, etc.), each researcher should adjust their own schedules at their convenience (Maestre, 2019). In this way, hopefully time management skills are learnt. A list of pending tasks per week eventually leads to the pressure of deadlines being more internal than external, which together with focused daily work and not wasting time, is a stoic way of work (Pigliucci & Lopez, 2019) (see Tip 6).

Do not restrict creativity. Starting with the bachelor thesis (or even before) there should be spaces for students to contribute their own ideas, which can always be debated, corrected, or improved. These spaces should increase in later stages, even when there are already research projects underway with well-defined objectives and methods. At any stage, it is vital to develop original ideas and encourage others to do the same. Negotiation, time, and trust building lead to this freedom of time and ideas, forming independent researchers.

Avoid over-specialization. Graduate students and early career researchers should not be an exact copy of their current or past supervisors -or of their peers, and there should be differences and complementarity in research interests, techniques, and/or abilities. Over-specialization can lead to not surviving in the academic environment when the area of expertise loses popularity or its paradigms shift -which can result in certain areas, hypotheses, and/or methods receiving less funding. Over-specialization can also lead to monopoly, monotony, isolation, to not being able to critically evaluate other fields, and even to tribalism (Casadevall & Fang, 2015). Having multiple interests -or being able to easily switch topics, opens up multiple possibilities, also outside academia. Research has shown that nowadays scientists switch more frequently between topics than a century ago, and that highly-productive, early career scientists switch topics less than highly-productive researchers at later stages (Zeng et al., 2019). To easily switch topics, it is important to constantly learn new things, even at middle or late career stages. Also, under this interdisciplinary perspective, the distinction between 'basic' and 'applied' science becomes diffuse (Douglas, 2014).

Tip 8: Science is not about unfinished work

Or it should not be. Although it is common and expected to find many researchers having multiple projects and writing multiple articles at the same time, all of them should be finished. It is normal that during the initial stages of the academic career, results and manuscripts to be published accumulate, or that some manuscripts were rejected and must be improved and re-submitted. There is a moral responsibility to publish such manuscripts, as it took a lot of effort (and public funds in most cases) to obtain them. Also, of course, these publications benefit the curriculum vitae. Ideally, a good bachelor thesis should be published in a well-recognized journal. In graduate studies, it is recommended to publish additional results and reviews or meta-analyses to the results of the thesis -not necessarily with the same supervisor or topic. These may arise from additional projects or from courses taken. Although, it is clear that not all experimental results are worthy of publication. Finally, although the focus of publications should be articles indexed in Web of Science and/or Scopus, other types of publications, such as preprints, articles indexed elsewhere, science outreach articles, op-ed articles (Goh & Bourne, 2020), technical reports, book chapters, among others, contribute to reaching other audiences, which is always good and increasingly recognized as being important.

Tip 9: Science and research are important, but not everything

Building a research career based on publications and grants is quite important, but it is not everything a scientist should do. As soon as possible, bachelor students should begin to build their teaching resume, for example as teaching or laboratory assistants. This should be increased for graduate students and postdocs, who should be invited to be collaborators or guest professors, and when possible or appropriate, responsible professors. Also, outreaching your own research (and that of others) is essential when doing science today, as it could inspire others to choose a scientific career (Laursen et al., 2012). This is a social and moral responsibility towards the public, the biggest science funder, and it also improves the ability to communicate complex ideas in simpler terms. Advertising your own

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research might also lead to it being more cited (McClain & Neeley, 2014). Finally, scientists should be more involved in policy matters, regarding not only the regulation of research and science funding, but also in the specific areas of their expertise.

Work-life balance issues are constantly discussed in academia. Research has shown a negative relationship between perceived work-life balance satisfaction and the intention to leave academia (in Malaysia; Noor, 2011), and a positive relationship between science work and personal life enhancement and job satisfaction (in Oman; Agha et al., 2017). Thus, work (including scientific work) should be viewed as one component (but not everything) of life satisfaction, a view that requires high emotional intelligence (Koubova & Buchko, 2013). The stoic work recommendation of not wasting time and focusing on things that matter the most (see Tip 6), not only applies to work itself, but to life in general. Friends, partners, family, hobbies, leisure, proper rest and sleeping hours, holidays, politics, cultural activities, pets, etc, all of them also matter and all of them also require time and focus. The positive effects of hobbies (crafts, art, sports) on mental health and work-life balance are well recognized (Takeda et al., 2015). In science, finding time and hobbies where the mind can rest from academic matters is critical. This can counteract the dissatisfaction caused by overworking, something sadly common in academia (Jacobs & Winslow, 2004).

Tip 10: Do not automate the scientific practice, introspect

The speed at which a scientific career passes leaves little to no time to reflect on it. Sometimes it seems to be an automatic process, with steps and ways of doing science that you "need" to follow, without further analysis or questioning. What kind of scientist do I want to be? Why should I only focus on my thesis or project, or publish articles only indexed in Web of Science and/or Scopus, or work solely with my supervisor or PI? Can I build my own way of doing science? A healthy introspection implies asking many personal and more general aspects about the way of doing science, and about the way of moving forward in the academic career. Numerous journals of science philosophy and sociology are a clear example of such introspection, but sadly, it seems that many scientists are not aware of them. Finally, it is clear that scientists should also be interested in the sociology, history, and philosophy of their area(s) of study and research community.

CONCLUSIONS

This assay represent a mixture of tips based on both philosophical underpinnings and everyday life aimed to improve the quality and practice of science, and how it is thought about and taught. Specifically, I think that some aspects on how science and the scientific method work, should be thoroughly re-examined and in some cases taught differently. Embracing paradigm shifts, avoiding rationalist delusions, understanding that there are multiple scientific methods, and especially, introspecting about one's scientific activity, should be common thinking and practices for scientists. As an almost inevitable consequence of this way of philosophizing about science, changes in everyday activities and behaviors are expected. Such changes include putting more attention on cooperation and global networking, to a warmer and more inclusive treatment within and among research teams, to an openness in terms of schedules and ideas, and to building a healthier work-life balance, among others.

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Desde 2020 es el Editor en Jefe del International Mycorrhiza Society Newsletter. Además, pertenece al Consejo Editorial de las revistas: Agro Sur, Frontiers (sección: Evolutionary and Genomic Microbiology), y Journal of Sustainable Agriculture and Environment. Es el presidente y fundador de la South American Mycorrhizal Research Network, una red científica con casi 300 integrantes de 45 países. Es miembro fundador de la Global Soil Biodiversity Observation Network (Soil BON), y pertenece a la Junta Directiva de la International Mycorrhiza Society. Además, es Investigador Asociado de la Society for the Protection of Underground Networks (SPUN) y Asesor Científico del FungiFest – Festival de los Hongos de Valdivia.

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Sus líneas de investigación son: i. Biodiversidad y funciones ecosistémicas del suelo; ii. Micorrizas: biodiversidad, funciones, y aplicaciones; iii. Biogeoquímica terrestre.