Hypotheses and Opinions

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Science as Magic

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Abstract
We draw an analogy between illusionism and scientific research. Based on the conceptual distinction between "external" and "internal life" often used in magic, we discuss how these two worlds also coexist in science, one of them being hardly accessible to both scientists and spectators. The task of the scientist is situated in the context of the spectator of a magic effect, whereas the inner workings of nature are compared to the secret maneuvers of the magician. Such a split and subsequent clash of worlds enables the outcome of the magic trick to produce the so-called "illusion of impossibility", whose consequences we map to the process of scientific discovery, invention and understanding. We illustrate our proposal with three paradigmatic examples from the scientific and magic literature, and end by discussing the limitations of the analogy and its implications for improving the practice of science.

Keywords: *magic, science, illusion of impossibility, cognitive biases, ecological research*

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"The first principle is that you must not fool yourself, and you're the easiest person to fool."
Richard Feynman

Introduction

One of Heraclitus' fragments reads: "Nature loves to hide" (Hadot 2006). This may simply reflect that flowers disappear from trees until spring is back, but at the same time contains the insight that reality is somehow concealed under the appearances, which is what we have access to. Nature seems to have her secrets and keep them. So do magicians. In their performances, we are aware that something important is concealed, at the same time that we often fail to know what that is. And yet, we want to know. Curiosity leads to amusement and amazement, even triggering bewilderment. As the contrast between effect and trick pervades the world of magic, so does the tension between phenomenon and mechanism engross the minds of scientists (especially upon forgoing Goethean science and Husserlian phenomenology). We struggle to avoid appearances and illusion (Rosset 1976, Barfield 1988). Astonished by the spectacle of nature, scientists ask: "what's the trick?!"

Here we draw an analogy between magic and science. We situate the task of the scientist in the context of the spectator of a magic effect. By means of this analogy, one can then emphasize certain aspects of the scientific practice that are seldom explicitly considered, and then turn those challenges into opportunities for science. We argue that extrapolating from illusionism into the process of scientific discovery can improve our study of the inner workings of nature.

What is magic? For our purposes here, let us define magic or illusionism (we use both terms as synonyms) as the art to provoke in the spectator the so-called "illusion of impossibility". This is an illusion that consists of a cognitive dissonance that results from the contradiction between the expectations created by the magician during the presentation of the effect and what the spectator perceives and experiences during the final climax. During a magic show, several effects are usually performed, the structure of which consists of a presentation stage followed by one or several climaxes. At the end of an "impossible" trick, spectators react with various emotions, often a brief surprise followed by admiration, enchantment, and sometimes unease (Camí et al. 2020).

In every magic effect, two different worlds coexist. The first world is what the Spanish magician Arturo de Ascanio called its "external life", which consists of what the audience experiences during the presentation of the effect. The second world is the so-called "internal life", which includes everything that the magician secretly manipulates towards the final climax (Etcheverry 2000). This concept of double or split reality is fundamental to understand how magicians interact with their audience: "To achieve the illusion of impossibility it is necessary for the magician to coherently combine the obvious and patent actions of the "external life", with the concealments, secret maneuvers and the use of various gimmicks and gadgets, that live only in the "internal life" (Camí et al. 2020). This concept of double reality is also central to understand the analogy we are proposing here between illusionism and scientific research.

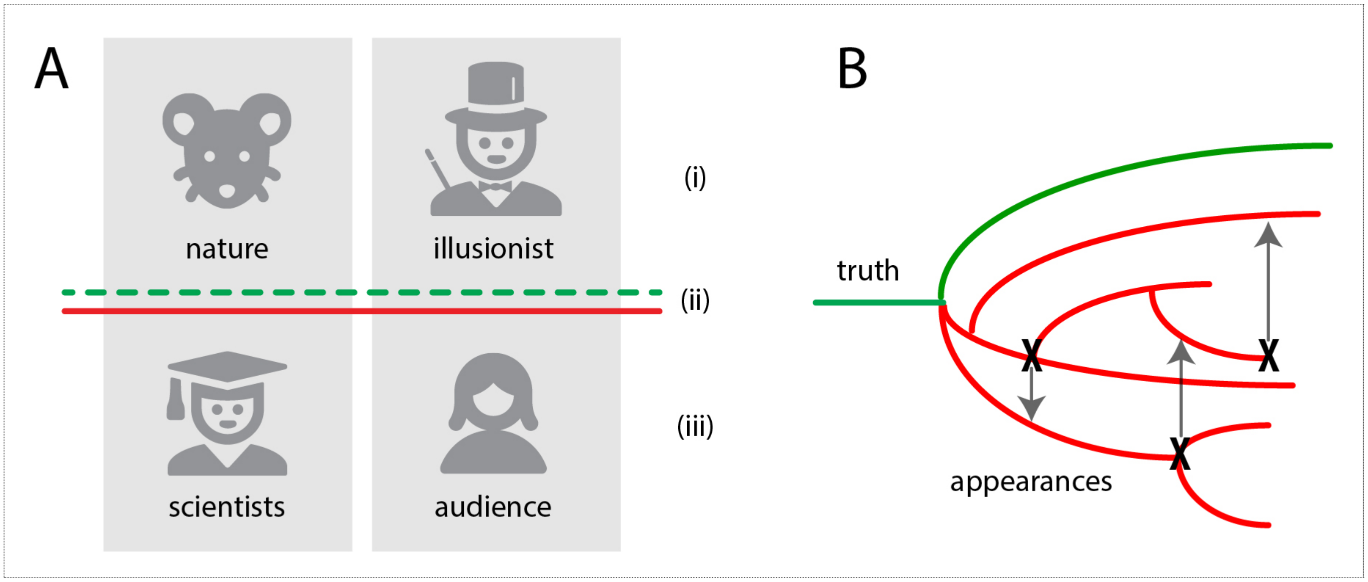

Figure 1: The Science as Magic analogy. (A) Magicians are to their audience what nature is to scientists: (i) both nature and illusionists keep their secrets in a way that (ii) their "internal life" is virtually impenetrable from the "external life" of the spectator/scientist, (iii) who are both astonished and also eager to know the trick. (B) The split between internal and external lives eventually causes the scientist to reject hypotheses, reformulate theories, and even experience a sort of "illusion of impossibility" that may lead to paradigm shifts, in an endless quest for higher quality ignorance.

1. The analogy

In a word, our "Science as Magic" analogy (or SAMA) goes as follows: the magician is to the spectator what nature is to the scientist (Figure 1A). We propose that (i) magicians conceive and carry out their magic effects akin to how nature works, while (ii) spectators of a magic trick fall into a similar cognitive space to that occupied by scientists in their research, so that (iii) the consequences of the "illusion of impossibility" as perceived by the spectators of a magic show are comparable to those provoked by the mysteries and secrets that scientists try to unravel (Figure 1B). Let us unfold these analogies and supplement them with concrete examples.

1.1 Magicians and nature

If no one looks at the magician, there is no magic; if no one looks at nature, there is no science. Magic needs to be performed. In the same way, there is no nature at an instant. Both magic and science are processes. Rather than an appeal to the supernatural, magic can be conceived as the identification of an object of study (Pujol 2015). This is precisely what nature provides. The illusion of impossibility at the outcome of a magic effect is not at odds with the plausibility of the presentation of the effect. As we understand them, magic and science are agnostic to the existence of miracles.

Contrary to what it might seem, magicians never really improvise and, in the face of any unforeseen event, they always manage several exits to save the effect. Magicians conceive, structure and present magic effects with the goal to attain the best possible outcome, never leaving anything of what they say or do to chance. If the circumstances demand so, such as in risky stages, magicians always have ways out and alternative plans that spectators hardly ever notice (Ortiz 1995). Similarly, and acknowledging the difference in timescales, through evolution nature has progressively refined her workings (let us not subscribe to mere mechanism nor to strict finalism). Nature has multiple strategies to course-correct, although we often remain unaware of them. Both in nature and in magic (be it a mouse in a lab or a prestidigitator in a theater), processes take place in real-time and in closed-loop, quickly adapting to the unforeseen.

Magicians are peculiar artists: they make hard things look as easy as possible. So does nature. In the realm of the inert, trajectories comply with the least action principle. In living organisms, optimal is often not good-enough (Loeb 2012). Clever heuristics confer adaptive behavior and improve fitness (Gigerenzer 2007). Interestingly, magic tricks can and do go wrong too. Nature is also capable of error (scientists actually take advantage of it). The study of pathology, for example, illuminates the physiology of the normal (Canguilhem 1991). The study of monsters can reveal a great deal of the structure and function of normal life forms (Alberch 1989). Despite the multiple checkpoints that nature affords (development being a paradigmatic example), nature can abort upon error, but the magician's show must go on.

A magic effect always lives in two worlds. As we have mentioned, magicians present their effects having two parallel worlds in mind (and under control). In the world corresponding to the "external life", sustained by the narrative and non-verbal communication, magicians propose a plot with its own logic and present it with naturality, consistency, timing and rhythm (Etcheverry 2000). All with the sole purpose of avoiding the appearance of any contrasting hints that might drive the audience away from the plot that the magician wants them to follow during the presentation of the effect. Every single act must be thus justified, with the only goal to achieve the "impossible" outcome. Throughout the exposition, the elements of the "external life" are combined with those concealments of the "internal life" in a perfect choreography that makes the secret behind the trick impenetrable for the audience.

In our analogy, we propose that nature does indeed present itself to us compounding two different concurrent realities: one that includes observable effects (always theory-laden, though) and another with supposedly impenetrable content. Baseball players are magicians at catching very difficult balls; they do not compute difficult mathematical equations but run so as to maintain the target along a linear optical trajectory, namely, with optical speed constancy (McBeath et al. 1995). So do dogs when catching Frisbees (Shaffer, 2004). The clash between these split worlds is particularly relevant in the life and mind sciences, since organismic behavior is both intrinsically prescribed by biological needs and also extrinsically describable by mathematical principles, disclosing the tension between scientist-centric and animal-centric perspectives and interests (Gomez-Marin 2019).

As magicians deliberately manipulate certain aspects of the external life so as to achieve the best possible outcome, it might also be that our experimental observations of nature should not be necessarily interpreted in a transparent fashion. Not even when those observations and interpretations are reproducible, as reproducibility does not exclude the impact of the observer's errors and biases (Pashler & Wagenmakers 2010, Staddon 2017, Albright 2017). As in the presentation of a magic trick, what we observe in nature may be modulated by another aspect of reality that is impenetrable to the scientist. One way to penetrate the secret of nature, as in magic, is to pay attention to the contrasting elements, those that do not fit well with our narrative hypotheses.

Negative results, pre-registered experiments (Simons & Holcombe 2014, Simons et al. 2014), outliers, among others, could be doors to the inner workings of nature and, nevertheless, are generally discarded. The invisible world manifests when the visible world fails to close.

Magicians do not perform for the "average spectator". Neither does nature. Magicians pursue a 100% efficacy in their magic outcomes. A statistically significant success on the audience members is worse than suboptimal and unthinkable for them. Magicians are also aware that spectators react with great inter-individual variability (Gea 2018). In order to minimize the potential risks of this diversity, magicians segment the presentation of their effects according to a particular type of audience (as we will see later), and have context into account as a constitutive element of their job.

In our understanding of natural processes, the demands that magicians impose themselves set to us, scientists, a high bar. Making the comparison, we wonder about the acceptability of many scientific results reaching slightly above chance, the reasonability of statistical conventions about significance, or the scarce science done in ecological context. Natural phenomena are differentially affected across populations and contexts (Bar 2004, Blanchard-Fields et al. 2008, Nikolic 2010, Carandini & Heeger, 2012, Louie et al. 2013, Gomis-Pont et al. 2020). For instance, a new medicine may not work the same way in children and adults, or men and women. The obvious is often not necessarily trivial. Moreover, the laboratory is not a substitute for the world; it is just another, often very different, arena (Matusz et al. 2019). The power of reductionism can become a huge limiting factor of the knowledge that we have in reach.

Example 1. "Broken mice"

In several of his well-known effects, the great Italo-Argentine magician Tony Slydini constantly raised and lowered his hands near the edge of the table. Once the spectators got used to this type of movement, they stopped paying attention and thus, the magician could make anything disappear simply by dropping it onto his lap before the surprised and oblivious audience.

Coined by Ascanio (Etcheverry 2000), "conditioned naturalness" is a concept that refers to a kind of very fast conditioning in which one seeks to normalize, always by repetition, something that in any other context would attract attention. Slydini's concealment moves may at first seem strange, unnatural, and even unreal, but before long the audience became familiar with them, embedding them in the natural logic, in the perceived reality of the game and ceased to be aware of them. Slydini had effectively conditioned their naturalness, managing to reduce the contrast of unnatural manipulations. As scientists, like a magician's audience, we learn by repetition and overexposure to naturalize artificial experimental approaches that, at best, offer us a vision (disciplined with abstractions and technological prostheses) of reality that is incomplete (Kayser et al. 2004). A paradigmatic example is offered by the use of laboratory animals.

Scientists know that wild-type laboratory animals are not really wild. Nevertheless, we use them for the many practical advantages they offer. We then publish our studies under the premise, too often implicit, that what we find in the lab applies outside its doors and walls. The artificial has become "natural enough". Nature in the lab has become the rule. We have just got used to it.

In mice, the mammalian organism model *par excellence* in biomedical research, this situation can be particularly crucial. Most of the animals used for research come from a handful of providers, which create a peculiar selective environment where mice live in captivity for generations without predators. Moreover, the young ones are selected for fast reproductive output, sacrificing them before they reach an older age. What could go wrong?

It is known that mice have very long telomeres. The question is whether this is a characteristic of the natural world or one induced by the artificial conditions in which we study nature to decipher its secrets. Work from the laboratory of Carol Greider (Nobel laureate, and the co-discoverer of enzyme telomerase) actually showed that wild-derived inbred mouse strains have short telomeres (Hemann & Greider 2000). Reared for decades, inbred mice used in laboratory studies have telomeres spanning from 30 to 150kb, whereas the telomeres of those "wild" mice tested in Greider's lab were less than 20kb long. Despite no correlation being found between telomere length and lifespan in mice, such a discovery lays out intriguing implications for biology writ large under the so-called "reserve-capacity hypothesis" (Weinstein & Ciszek 2002), which establishes a trade-off between tumor suppression and tissue repair. Leaving aside the fascinating theoretical implications that would bridge evolutionary and molecular biology as pioneered by Weinstein, the concerning practical consequences are that this feature of laboratory mice would make most of the basic results and biomedical applications derived from the study of senescence and tumor formation unreliable, if not dangerous, as one would underestimate tissue damage and overestimate cancer risk in those "mouse models" of human disease (Weinstein & Ciszek 2002). In sum, the answer to the question as to whether normal mice have long telomeres depends on what one means by normal and what one means by mice. As it turns out, for the bulk of the scientific community normal is actually not necessarily natural. And yet, the difference matters as it can profoundly fool us (Figure 2A).

1.2 The illusion of impossibility and the intelligibility of nature

We strive to know the secret of things. The experience that an "impossible" outcome induces on the spectators of a magic trick (independently of the particular cocktail of emotional reactions) compels many of us to ask "how does the magician do it?" Note that spectators willingly attend the show knowing that the artist is going to use tricks in order to carry out the magic effects. In a similar way, the scientific community, astonished by virtually everything that takes place around us, feels the urge to unravel how nature works. As *Homo sapiens*, we have a drive to expand our knowledge (and domination) on nature.

In magic, the same end can be achieved with different means. The world of magic dramatically teaches us that one can achieve the same "impossible" outcome, with the same experience for the audience, but via very different methods and materials (Tarbell 1999). In other words, to reach the same goal, both the magician and nature can use pathways that involve very different systems, materials, and complexity. This is actually how some magicians are able to fool other magicians. In our understanding of nature, knowing its products is not enough; one must figure out the processes that gave rise to them. In evolution and neuroscience, it is well-known that different neural substrates can produce the same behavior and that different behaviors can be produced by the same neural substrates (Lorenz 1974, Sakurai & Katz 2017).

A magical effect is truffled with false clues that make it difficult for us to figure out the secret (Tamariz 2011). Both in magic and in science, we are too often fooled along the way, since things are always less obvious than they appear to be. Spectators have a very difficult time to discover the magician's secrets. Similarly, when studied by scientists, nature is much less transparent than what we think. During the presentation of effects, magicians may use false clues so as to break down our inference on causality relations. In addition, they structure the content and presentation of the effects to minimize that spectators revisit what has really happened (Camì et al. 2020).

Analogously, our observations and inferences about nature are not free from the same obstacles and traps. In the same manner that magic audiences cannot perceive anything without their own heuristics, scientists too fail to face natural phenomena without imposing their own preconceptions, which are based not only on the data of their experiments but also on the context of their hypotheses and previous knowledge. One could argue that both Golgi and Cajal looked through the same microscope at the same histological preparations (although Cajal improved the method), and so they both could see dendritic spines. However, while Cajal thought they were signal, Golgi was convinced they were noise (Yuste 2015). The challenge is to notice all these worlds hidden in plain sight.

Eureka moments in magic can anchor audiences to the wrong solutions. And yet, we have and cherish eureka moments. Despite all the obstacles that the spectator has in the way to figure out what is going on, the impulse to discover what has happened can cause an "aha! moment" that shall be taken as an explanation of the witnessed phenomena (Ortiz 1995). However, very often in magic the spectator may wrongly speculate about the underlying solution. Even worse, after the "aha! moment" the chances are that one abandons reasoning on alternative solutions, the so-called Einstellung effect (Bilalic et al. 2010). In other words, when one believes to have reached a solution, one is more handicapped to think of alternative explanations. We claim that in science one comes across the same problems. While searching for answers to natural phenomena, it is more than possible that we get stuck in the first answers we find which, even if reproducible, may not be the unique or the main solutions to the conundrum. In fact, and despite grand claims for "disruptive research" or "scientific excellence", out-of-the-box thinking is actually discouraged. We all know instances of how such discouragement is materialized (funding environment, publishing games, career building). The scientist is also collective made.

Example 2. "Soups and sparks"

The great Spanish magician Juan Tamariz developed the theory of "false clues" (Tamariz 2011). He thought that, in order to prevent the audience from "rewinding" and trying to assess the logical steps of the magic trick, it would be much more effective if, along the way, the magician created false expectations, perhaps by subtly suggesting solutions to the spectator, that would end up being proved wrong. Taking the audience away from the real method behind the magical effect (which is actually a side-effect of the use of false clues) would enhance the illusion of impossibility at the end of the trick. But, most importantly, would make it impossible for the spectators to reconstruct the logic and thus guess how the trick is done (which, together with creating the "illusion of impossibility", is a great obsession for magicians). False clues would prevent the audience from reaching premature conclusions about the method behind the magic trick. This is important because, whether their deduction be wrong or not, an "aha! moment" would ruin the magical experience; the spectators, believing they have discovered the trick, would cease to be impressed (Ortiz 2015).

Once an idea becomes reasonable in our minds, it is very difficult to consider other alternatives, even if they are actually more viable. It is, again, the most perverse consequence of the afore mentioned Einstellung effect (Bilalic et al. 2010). A sensation of truth is apparently all that matters to generate high confidence in it, as well as positive emotions and increased memorability (Danek et al. 2013). This is as true in magic as it is in science. In fact, in our experiments with nature, false clues do also abound. Although it is not generally possible to prove that a hypothesis is correct (authentication is no proof), we still design most of our experiments and write our grants as if it were; the rebuttal of our starting hypotheses or other alternative viewpoints are often not even considered. But even when reproducible and somewhat backed up by empirical evidence, our working hypotheses can, as false clues, lead us uncritically towards wrong conclusions (Figure 2B). Let us see an example in the field of neuroscience.

Towards the end of the 1930s, the nature of interneuronal communication haunted neuroscientists. Two schools of thought steered the search: one (the most pharmacological one, led by Henry Dale) proposed that synaptic transmission was mediated by messengers of a chemical nature; the other (the most physiological one, led by John Eccles) claimed that communication was direct through a continuous flow of electric charges. The so-called war of the soups and the sparks went on with apparent successes taking place on both fronts.

Eccles showed that the cardiac pacemaker of the cat had a long latency of about 0.1 seconds, and a slow time course of seconds. Led by this "false clue" (stemming in this case from his own reasoning, but in other cases a product of the scientific consensus about the workings of nature), he wrongly concluded that these slow dynamics were the signature of all chemical transmission. Hence, he deduced, synaptic excitation in the central nervous system (with its low latency and fast rate) was too rapid for a chemical process. The electric hypothesis seemed to gain ground. In 1944, an encounter with Karl Popper caused Eccles to reformulate his questions and to radically change his experimental approach (Todman 2008). Then, using as a model an inhibitory synapse, Eccles postulated that, if the chemical hypothesis was correct, the membrane potential of the postsynaptic cell would become more negative when activating the presynaptic neuron. That should not occur if the nature of the communication was electrical. The experiments showed the negative postsynaptic potential and the rest is history (Cobb 2020). The greatest advocate of the electrical hypothesis had just shown that neural communication was chemical in nature. Underperforming big ideas can indeed become entrenched in a community (Joyner et al. 2016).

1.3 Magic spectators and scientists

One of our main tenets is that the scientist is not the magician of nature but its spectator (Figure 1A). We are simultaneously astonished and fooled (Figure 1B).

We love secrets, we simply don't like being fooled or not knowing them (regarding the critique of the logic of "model organisms" in laboratories as general representatives of natural truths, note the irony in the ease with which we tend to speak of "humans" in general). The audience of a magic show (like scientists) know that magic (like nature) has its secrets. As an audience we are naturally impelled to discover what's behind the trick. Likewise, as scientists, we feel the urge to figure out the mechanisms that hide behind each natural phenomenon. The problem is that we are all really easy to fool. But not all spectators are alike, and neither are scientists. Magic is dependent on cultural contexts, previous knowledge and cognitive development (Camí et al. 2020). So is behavior (Gomez-Marin & Ghazanfar 2019). In drawing these analogies, we would like to emphasize only two broad classes of spectators: kids and adults. As it turns out, each of them requires a different modality of magic effects.

Kids require a specific kind of magic that fits their own developmental conditions, and which is distinct from that which conventionally works in adults. Due to their unfolding cognitive processes, children tend to concentrate more on details without great abstractions or a great deal of extra assumptions. This can be a problem during a magic trick conceived to work in adults. For kids, signal can become noise (thus, not showing interest in the trick), and noise can become signal (thus actually discovering the trick). This can easily ruin a professionally performed magic show (see Example 3). Thus magicians tune their effects and the way they present them accordingly. In the analogy with science, we can think of young scientists whose naive and uninhibited curiosity prevents them from prematurely discarding little details that may turn out to be crucial. Without needing to be a genius, their lateral thinking, willingness to try new things, and indifference to ridicule may put them in a privileged position to carry out game-changing discoveries.

The limitations of magic for adults when done in kids actually demonstrate the opportunities available to break into the supposedly impenetrability of the "internal life" of the effect. In science these opportunities also exist, for instance in outlier data, in discarded information, failed experiments, alternative hypotheses, or negative results. In some of such discards one may find the entry point to a wealth of knowledge, as in the case of the so-called "junk DNA" (Pennisi 2012). Adults, but not kids, generally over-determine what they see. As magic for kids remains a challenging endeavor, so is a science of minority reports beyond the community sanctioned interests and habits.

The great majority of magic is thought for adults, namely, grown up people whose cognition follows well-trodden cognitive biases. For instance, magicians have learned to manipulate instinctive decisions by exploiting well established heuristics and cognitive biases characteristic of adults. In fact, magic for adults is the "safest magic", since it comprises the great bulk of efforts, means, history and magic theories. When it comes to science, we can think of this bulk of adult spectators as the majority of professional scientists; a majority that, with time, may over-interpret what they observe, and whose critical thinking may progressively decay, as certain recent crises attest (Head et al. 2015, Ioannidis 2005, Munafò et al. 2017).

Example 3. "Genetic scissors"

About 30 years ago, the professional magician David Williamson invited a 6-year-old boy called Murray to participate in a magic trick during one of his prime-time TV shows. The game, which the magician had rehearsed for months, was based on a classic magic trick involving the use of a carefully crafted special set of cards. What could go wrong? Williamson started laying out the playing cards on the table, claiming that there were three. But Murray stopped him at that instant by pointing out that he could see a fourth card stacked to one of the others (Williamson 2011). The impenetrability of the internal life had been irremediably exposed. The young spectator had defeated the magician. That night was a turning point in Williamson's career; he experienced in his own flesh that there are different types of audiences; different views, such as Murray's, who could see what hundreds of thousands of other people before, mostly adults, did not see (Olson et al. 2015). Magic does not work the same in children.

We see mostly what we expect to see (Figure 2C). Our experiences are shaped by our expectations, which in turn are shaped by evolution as well as by our culture. They also change with age. Naturally uninhibited, children give more importance to details that are considered superfluous information by adults. Unfortunately, curiosity and creativity tend to fade as we grow up.

Just like Murray's fresh look at Williamson's card trick, scientific breakthroughs often emerge from completely unpredictable origins. As scientists, we tend to design our research projects based on the current scientific context and fads. However, it was sheer curiosity what drove a young Francisco Mojica to persevere on the margins of science, without a grant, and with his main papers rejected in top tier journals for years, in his quest to understand a strange microbial DNA repeat sequence that would lead to his discovery of CRI-

SPR (Mojica et al. 2005, 2013). His contribution was a foundational one to its recognition as an adaptive immune system and its biological characterization, that would end up being fundamental to its repurposing for genome engineering, thus transforming biomedical research in unprecedented ways (Lander 2016). As Lander points out: “It is instructive that so many of the Heroes of CRISPR did their seminal work near the very start of their scientific careers (…). With youth often comes a willingness to take risks —on uncharted directions and seemingly obscure questions— and a drive to succeed.” How many discoveries await until we nurture a way of doing science in tune with the limitless curiosity that leads a child to discover that a hardly noticeable card stacked under another is the difference between illusion and reality?

Minority reports can have major consequences. Note that during a magic show everybody applauds even if not so enthusiastic about the magic effect. There is a social component that is even stronger during standing ovations (some jumped from their chairs enthralled, others are forced to do so since they do not want to be left sitting down while the rest is up and clapping). In science, consensus by our peers is a valuable self-correcting mechanism. However, paraphrasing Giordano Bruno, truth does not change because it is, or it is not, believed by a majority of the people, even experts (Sackett 2000). These and other important aspects of the sociology of science need to be dealt with (Lazebnik 2018).

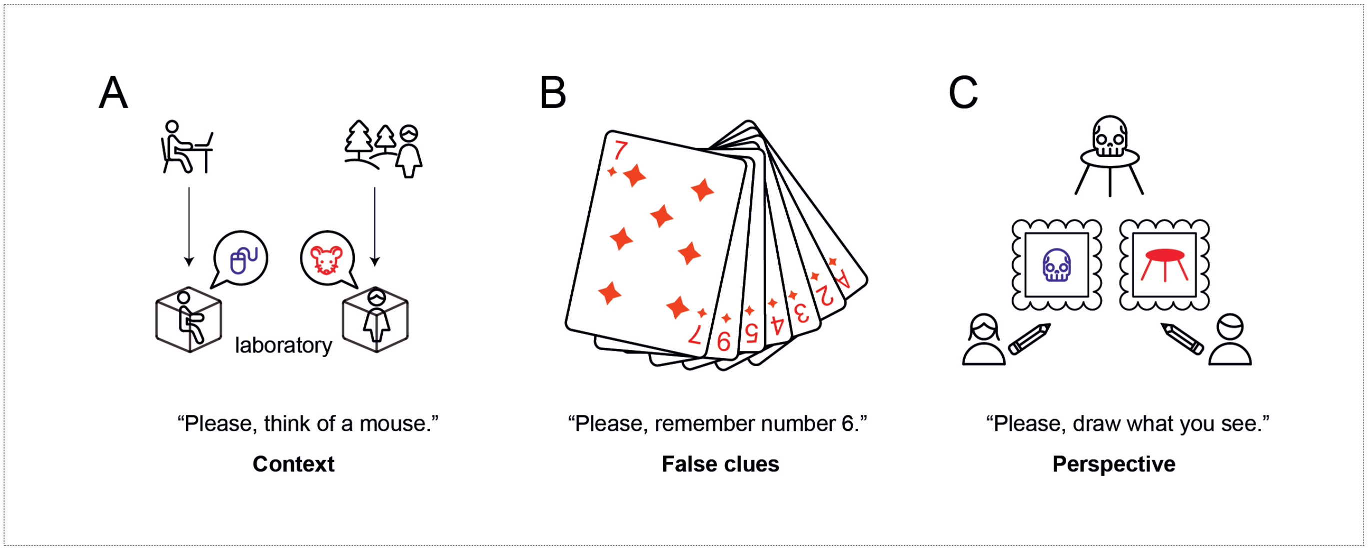

Figure 2: Challenges and opportunities that magic proffers to science. (A) Context is constitutive. While magic succeeds in the real world, reductionist laboratory science insists in getting rid of context, ultimately trumping replicability and generalizability. (B) False clues abound. Magicians purposefully lay them in order to torpedo our post-hoc logical reconstruction of the trick (panel adapted from Edward Marlo effect, Genii Magazine Sept 2008). Despite the fact that science is a self-correcting enterprise, scientists have a hard time realizing their blind spots, false paths, and dead ends. (C) Perspective matters (panel inspired by Edward Steed’s cartoon). Having performed in front of diverse audiences, magicians know that what we see depends on our interests, heuristics and cognitive biases. Thus there is magic for adults and magic for kids, due to their different cognitive developmental stages. However, scientists’ quest for objectivity and tendency for uniformity in their thinking can defeat the purpose.

Concluding remarks

"Science as Magic" is an analogy that presents the scientific quest through the lens of the processes that take place during a magic effect. This is not to be confused with "how magic became science" (Williams 2020), the "science of magic" (Macknik et al 2008; Kuhn et al. 2008) or "magic for science" (Lamont et al. 2010, Camí et al. 2020).

Analogies and metaphors are essential to language and reasoning (Lakoff & Johnson 1980). They allow us to understand one thing or concept by means of another. For instance, when we say that "time is money", we borrow meaning from the structural and functional properties of "money" in order to better grasp those of "time". Here we have highlighted the coherent structure that both magic and science share. In fact, the very existence and necessity of analogies for thinking challenges a theory of mind that assumes that rationality is conscious, dispassionate, linear, logical, disembodied and universal. As magic demonstrates, most of what we perceive or decide is entangled with our emotions, may not take place logically or linearly, strongly depends on the particular context where it takes place and, finally, on ontogenetic factors and cultural background.

Magic actually works thanks to our many cognitive blind spots. The effectiveness of magicians is due to a large body of reproducible techniques and the use of particular materials and methods that have been developed empirically for centuries. These involve many scientific disciplines such as mechanics, electronics, mathematics and, above all, the cognitive sciences. In fact, the efficacy of magic effects is entangled with the magician's capacity to interfere with the attention, perception, memories, decisions, and other cognitive processes of the spectator (Camí et al. 2020). As illustrated by Millikan's example on the measurements of the charge of the electron, it is so easy to fool ourselves (Feynman 1974). Thus, the more we are aware of those biases, the better science we should be able to practice. Any theory of nature is inseparable from a theory of knowledge.

Limitations of the "Science as Magic" analogy

Our analogy, of course, breaks down when overstretched. First, note that the spectator, as opposed to the scientist, does not enjoy the possibility of repetition. And if the magician repeats a certain movement or trick, it certainly is in the service of deception (such as in "conditioned naturalness" or upon "false clues" as discussed above). Second, spectators just watch with their eyes, while scientists use all sort of instruments and abstract symbolic formalisms. Third, the scientist, contrary to the spectator, can perturb the system in order to establish counterfactuals. This is actually the essence of experimental science: to combine observation with manipulation so as to upgrade correlation to causation (however, intervening in their system of study, scientists may also inadvertently affect certain aspects of its internal life, especially if the system is complex, quantum, or a simply living organism). Fourth, scientists can and actually do design their experiments, whereas spectators are just presented with a very carefully designed show from the part of the magician. When spectators are called to participate, they often do not influence what is going to happen (everything is under the magician's control). Fifth, although there is no magic without at least one spectator, there can be nature without science (but probably not the other way around). Finally, magicians bring the spectators to their theater, while we, scientists, rather than meeting nature at her place, have got used to bringing her to our laboratories.

Challenges and opportunities

If we now concentrate on the differences between magicians and scientists, rather than in the similarities between spectators and scientists, we can better appreciate the huge feats that magicians achieve. When applied to science, such challenges become opportunities. Magicians really have skin in the game. First, note that the magician does not target the average spectator, but each and every individual in the audience. A "statistically significant trick" is nothing but a failure. Second, magicians perform *impromptu* magic and succeed in the "real world", while scientists still struggle (Matusz et al. 2018). The street is not a laboratory, and spectators are not inbred mice reared in the house. Quite the contrary to most laboratory practices, rather than pruning context away, magicians deliberately provide it. To put it metaphorically, the absence of a dressing code does not imply that those attending the event will come naked. In fact, each one will bring their own garment. Third, magicians execute very refined protocols (the experimental task, for a scientist) that actually work in real time and in closed loop. In addition, they have a "plan B" and "plan C" for virtually any situation. Robustness is not incompatible with the ability to improvise. Finally, the magician's work is subject-centric and dual in terms of worldviews; the magic effect is effective not only because of the trick they perform hidden in their "internal life", but also because the magic effect overlaps with the spectator's "meaningful environment" (the so-called *Umwelt*). This last point is actually crucial for the life and mind sciences, and for scientific thinking in general. When stuck in a worldview, we can only study those things that fit it, or gamble (Lahti 2015). But when the things we study have their own worldview too (humans, but also mice, flies and even worms), it is necessary that we are willing to commute from third to first person experiences (Gomez-Marin 2019b).

In sum, magicians thrive with real individuals in the real world, conditions that the laboratory-bound, reductionist, and die-hard objective approaches to science fail to deal with.

Outlook

We often conflate what is obvious with what is trivial. But the more obvious a trick is, the more deceptive it can become (the notion that the earth is flat, for instance). One thing is not to know how something happened, and quite another is to believe that what has happened cannot be. Science is the belief in the ignorance of experts. Magic is the art of honest deception (in a way, so is cinema). Excess of credulity is always problematic, but so is its lack. Skepticism is a fundamental element of the magic experience and also of science. So is the enchanted mind. Note that magic spectators are fooled despite knowing in advance that they will be fooled. Scientists should also acknowledge that they will remain ignorant despite their increasing knowledge of the natural world (Firestein 2012). For a magician to suggest or pretend that magic is real is comparable to the scientist's assertion that we now know the truth of the matter. To let the audience know that magic is honest deception is equivalent to the conscious ignorance that preludes every real scientific advance. The will to step into the unknown and to face the mystery are indistinguishable. Granting purpose to nature, we could say that she does not want to fool us as much as to shake us in wonderment. Nature is also that which both magicians and scientists share, both working to simultaneously enchant and disenchant. At the end of the day, the world of magic and the magic quality of our world may not be so far apart as they seem.

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