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Overcoming obstacles to creativity in science

Superando obstáculos à criatividade na ciência

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Abstract

Creativity is a crucial issue in science. Scientific research should not be restricted to the logical development and application of known ideas, but should promote new ideas to expand knowledge beyond the existing frontiers. Stimulating scientific creativity means not only giving a boost to creative thinking, but also taking into account the factors that put a brake on creativity. This article is devoted to factors that keep scientific creativity in check and how we could address them. We analyze several obstacles lying inside and outside the researcher's mind. The most important obstacles inside the researcher's mind are epistemological obstacles and cognitive bias (confirmation bias). While the most important obstacle outside are the social norms, *i.e.* the pressure for the scientific community and, sometimes, the whole society, to conform to the dominant scientific model. We conclude with some proposals to overcome these obstacles.

Keywords: Abduction; Cognitive bias; Creativity; Epistemological obstacle; Normal science.

Resumo

A criatividade é uma questão crucial na ciência. Sua pesquisa científica não deve se restringir ao desenvolvimento e aplicação lógica de ideias já conhecidas, mas deve promover novas ideias para expandir o conhecimento além das fronteiras existentes. Estimular a criatividade científica significa não apenas estimular o pensamento criativo, mas também levar em conta os fatores que dificultam a criatividade. Este artigo é dedicado aos fatores que mantêm a criatividade científica sob controle e como podemos resolvê-los. Analisamos diversos obstáculos dentro e fora da mente do pesquisador. Os obstáculos mais importantes dentro da mente do pesquisador são os obstáculos epistemológicos e o viés cognitivo (viés de confirmação). Enquanto o obstáculo externo mais importante é composto pelas normas sociais, ou seja, a pressão por parte da comunidade científica e, por vezes, por parte de toda a sociedade, para se adequar ao modelo científico dominante. Concluímos com algumas propostas sobre como superar esses obstáculos.

Palavras-chave: *Abdução; Vieses cognitivos; Criatividade; Obstáculo epistemológico; Ciência normal.*

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Creativity is a crucial issue in science (Grégoire, 2016). The goal of science is extending our knowledge based on testable observations and logical reasoning. Scientific research should not be restricted to the logical development and application of known ideas, but should promote new ideas to expand knowledge beyond the existing frontiers. Stimulating scientific creativity means not only giving a boost to creative thinking, but also taking into account the factors that put a brake on creativity. This article is devoted to the factors that keep scientific creativity in check and how we could address them.

What is creative scientific reasoning?

Where do new ideas come from? What kind of reasoning produces new ideas? The American philosopher Charles Peirce (1839-1914) provided an important contribution to this question. Peirce[2] made an essential distinction between three kinds of inferences based on deductive, inductive, or abductive reasoning.

Deduction is reasoning from one or more premises to reach a logically certain conclusion. For example, "all men are mortal and I am a man, therefore I am mortal". The conclusion must be true if the premises are true and unambiguous, and the rules of logic are respected. In this case, the argument is valid and sound. Induction is the derivation of a general principle from specific observations. For example, "the ravens I observe are black; therefore I can expect that all ravens are black". Inductive reasoning is inherently uncertain and only probable. It is possible that the conclusion is false, even if all of the premises are true. Even if I only observed black ravens, a white raven could exist somewhere in the world. In this case, my conclusion that all ravens are black would be wrong. According to the probability of the conclusion, induction is considered as weak or strong. Abduction is inferring a condition from the observation of its consequence. For example, "the grass is wet this morning, and I infer it was raining during the night". Abductive reasoning is inherently uncertain because of multiple possible explanations for an observed consequence. The grass could be wet because the automatic system of watering started during the night or because a water pipe crossing the garden was broken. Therefore, abduction is guessing. We usually select the most probable and simple hypothesis among several hypotheses. Peirce (cited by Sebeok, 1982, p.38) claimed that "facts cannot be explained by a hypothesis more extraordinary than the fact themselves; and of various hypotheses the least extraordinary must be adopted". This principle is similar to Ockham's razor, which was proposed by William of Ockham (1287-1347): "Entities are not to be multiplied without necessity". Following this law of parsimony, the simplest and most economical explanation should always be selected.

According to Peirce, scientific creativity resulted mainly from abductive reasoning. It is a creative insight into how to solve "some surprising phenomenon, some experience which either disappoints an expectation, or breaks in upon some habits of expectation" (Peirce, 1908/2011, p.368). This first stage of the scientific inquiry relies on imagination, but also on logic in order to construct new hypotheses of which the consequences will be later explored using deductive reasoning.

Deductive reasoning is not really creative, since it only draws out the consequences of original hypotheses coming from abductive reasoning. Niels Bohr expressed the same idea in his famous quotation: "No, no, you're not thinking; you are just being logical" (Frisch, 1980, p.95). In general, inductive reasoning is not either creative, since it draws general principles from the observation of particular cases (Hamad, 2007). However, the induction of principles is not always obvious and straightforward. If the initially induced principles prove to be inappropriate, we have to be flexible

[2] All the information about the philosophy of Peirce comes from the selected papers of Peirce edited by Justus Buchler in "*Philosophical writings of Peirce*" (2011).

and explore other options. Divergent thinking and fluency, which are characteristic of a creative mind are then required to find the more appropriates principles (Vartanian, Martindale, & Kwiatkowski, 2003).

On the other hand, abductive reasoning is essentially creative since it is guessing and risk taking. As guessing is more frequently wrong than right, researchers prefer building projects on deductive or inductive reasoning than on abductive reasoning. A research project based on deduction from a well-known theory is less risky than a project based on an original theoretical framework, and can be more easily approved and financed.

As a consequence, a lot of research projects are not very creative, following the rules of the dominant theories.

Obstacles to abductive reasoning

To understand such a tendency and to rely more heavily on deductive reasoning, we have to understand the obstacles to abductive reasoning. These obstacles lie inside and outside the researcher's mind. The most important obstacles inside the researcher's mind are epistemological obstacles and cognitive bias (*e.g.*, confirmation bias). While the most important obstacle outside are the social norms, *i.e.* the pressure for the scientific community and, sometimes, the whole society, to conform to the dominant scientific model, which is called "normal science" by Kuhn (1962) in his famous book The Structure of Scientific Revolutions. Scientific norms are too often supported by the current assessment system of scientific projects and productions, *i.e.* the peer review procedure.

Epistemological obstacle

The French philosopher Gaston Bachelard (1884-1962) introduced the concept of "epistemological obstacle", which is knowledge coming from previous experiences and theories preventing the acquisition of new scientific knowledge. Bachelard (1938, p.14) observed that: "When it moves to scientific culture, the mind is never young. It may even be very old, since it is as old as its prejudices. Coming to science means spiritually rejuvenating, accepting a sudden transformation that contradicts the past". A historical example of an epistemological obstacle is the discovery of snow on the mount Kilimanjaro, which is located in the Central Africa. In 1848, Johannes Rebmann, a German missionary was the first European to observe snow on the summit of Kilimanjaro. This observation contradicted his own previous belief that snow could not exist close to the equator. Rebmann published his discovery in 1849, but the Royal Geographical Society of London held that snow could not occur in such latitudes and considered Rebmann's observation to be hallucination related to malaria. The Royal Geographical Society only recognized the observation was correct in 1862 after the Kilimanjaro expedition of Baron Carl von der Decken, who received the Society's Gold Medal for this discovery.

The observation of epistemological obstacles is also very common during the child's development of scientific knowledge.

For example, when children learn the sequence of natural numbers, they observe that the largest numbers are also the longest ones, *i.e.* with more digits (*e.g.* $5 < 15 < 115$). But when they discover the rational numbers, such a general rule is no longer true. A number with two digits can be larger than a number with four digits (*e.g.* $0.5 > 0.255$). Because of their representation of natural numbers, children used to give a wrong answer when they have to select the larger between two rational numbers, choosing the number with the most digits (Desmet, Grégoire, & Mussolin, 2010). For example, they select 0.255 instead of 0.5. To give the correct answer, they have to reorganize their knowledge about numbers and consider natural numbers as a special case of a larger set of numbers.

Cognitive bias

Cognitive biases have been extensively studied by social psychologist (Kida, 2006). It is a

systematic deviation from rationality in judgment, which leads to incorrect statements. No researcher is immune to cognitive bias, which can be an obstacle to his/her creativity. Among the types of cognitive bias, confirmation bias is a common error in inductive reasoning. Instead of taking into account all the observed events, we only select the information that confirms our initial hypothesis, while the alternative hypotheses are not considered.

An example of confirmation bias is the non-observation of the planet Neptune before the mid-19th century. This planet is known to have been mathematically predicted by the French astronomer Le Verrier in June 1846, before being directly observed by Galle the same year, the night of September 23. In retrospect, it turned out that Neptune had been observed many times before, but not recognized. Galileo 1613, Lalande, 1795 and Herschel, 1830 recorded an observation at the same position, but failed to recognize it as a planet. Galileo considered it was a fixed star, while planets are in motion within the solar system. He noted something unusual about this star, but did not draw the conclusion that it was a planet because he considered its motion was too slow and it appeared too small. Galileo had in mind a list of attributes of a planet. As the brightness and the speed of Neptune were lower than the usual characteristics of the other planets, he discarded this information, which did not confirm his initial representation of a planet.

Normal science and scientific norms

While cognitive bias is a shortcoming of our own judgment, scientific norms stimulate pressures from the scientific community to think in a specific way. However, the two concepts are interrelated. When scientific norms are internalized, they underlie several cognitive biases.

In his influential book, "The structure of scientific revolutions", Kuhn (1962) introduced the concept of scientific paradigm, which is "universally recognized scientific achievements that, for a time, provide model problems and solutions for a community of practitioners" (p.viii). The dominant paradigm defines "normal science" during a period of time. The dominant paradigm specifies: (1) the kind of questions that are supposed to be probed, (3) what predictions can be made, (4) how an experiment should be conducted, (5) how the results of scientific investigations should be interpreted, etc. Normal science can be fruitful, providing solutions for a restricted set of problems defined within the dominant paradigm.

However, as it is mainly based on deductive reasoning, creativity within normal science is limited. Normal science can even be very normative, restricting new inquiries, observations, or interpretations, creating resistance to new scientific discoveries. As Kuhn emphasized (1962, p.24): "No part of the aim of normal science is to call forth new sorts of phenomena; indeed those that will not fit the box are often not seen at all. Nor do scientists normally aim to invent new theories, and they are often intolerant of those invented by others. Instead, normal scientific research is directed to the articulation of those phenomena and theories that the paradigm already supplies". Within a dominant paradigm, researchers tend to be very conservative. A good example is given by the declaration of Lord Kelvin at the British Association for the Advancement of Science in 1900: "There is nothing new to be discovered in physics now. All that remains is more and more precise measurement". Five years later, in 1905, Einstein published four articles in the journal "Annalen der Physik," which founded modern physics and deeply modified our perception of space, time, mass, and energy. Among them, the paper "On the Electrodynamics of Moving Bodies" introduced the Special Theory of Relativity.

Scientific creation often needs what Kuhn call a "paradigm shift," which is very well expressed by Niels Bohr in his famous quotation: "Electricity was not invented by trying to improve the candle." Reversible figures are another illustration of a paradigm shift. It is a new interpretation of the same stimuli. The rabbit-duck illusion is a well-known example of an ambiguous image, which can be seen as a duck or a rabbit according to our viewpoint on the same drawing (Figure 1).

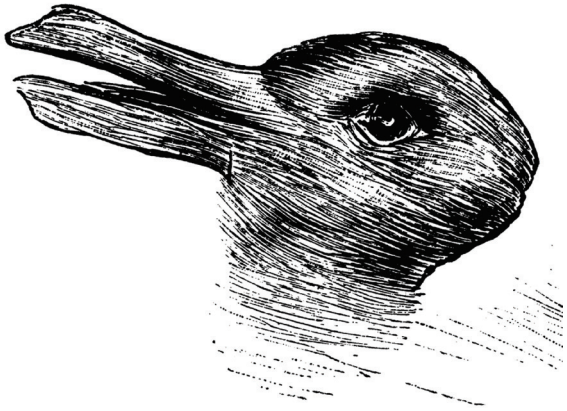


Figure 1. The rabbit-duck figure.

A paradigm shift appears in response to the accumulation of critical anomalies, *i.e.* observations that cannot be correctly explained within the dominant paradigm. For example, for 200 years, the Newtonian mechanic was the dominant paradigm for explaining a large set of phenomena. During this period, more and more observations did not fit Newton's law of motion and universal gravitation. Einstein's Special Theory of Relativity is a paradigm shift, which provides an explanation of the phenomena that could not be correctly explained by Newton's theory. For Kuhn, a new theory should be accepted if it is:

- Accurate (the theory fits the observations);

- Consistent (internally and with other theories);

- Broad in scope;

- Simple (the theory respects Ockham's razor principle);

- Fruitful (the theory helps to disclose new phenomena, new applications, relations, etc.).

Paradigm shift is not always a smooth process because of the inability of the scientific community to see beyond the current model of thinking. The Galileo affair is a well-known example of a strong conflict between the old and the new models.

In 1610, Galileo described surprising observations made with a new telescope, confirming Copernicus's heliocentric theory. In 1616, the Inquisition declared that heliocentrism was heretical since the earth was then seen as the center of the universe according to Aristotle's geocentric model, which was consistent with the Bible narrative.

Another dramatic example was the discovery by Ignaz Semmelweis, in 1847, a Hungarian physician, that the mortality rate due to puerperal fever could be drastically cut by the use of hand disinfection in obstetric clinics. Despite various publications of results showing that hand washing reduced mortality rates to below 1%, Semmelweis's observations conflicted with the medical opinions of the time. Several colleagues were even offended at the suggestion that gentlemen should wash their hands. As a consequence, the medical community rejected Semmelweis's observations and recommendations, to womankind's greatest detriment. Semmelweis's ideas earned widespread acceptance only years after his death when Louis Pasteur confirmed the germ theory, in 1864.

Here is a last example, in the field of mathematics, of resistance from normal science to a paradigm shift. Today, we consider that negative numbers are real numbers, which are less than zero. But the existence of negative numbers provoked heated debate in the 18th and 19th centuries. For a long period of time, numbers were identified to natural numbers, which are positive integers used for counting and ordering. Around 1800, mathematicians wondered if terms as "-2" also represented numbers. Euler, 1766 considered that negative numbers are real numbers, while Carnot, 1801 claimed that numbers are only positive since they relate to real quantities. After long and bitter discussions, Buss, 1804 and Förstemann, 1817 expressed strong arguments refuting Carnot's representation of numbers. A crucial distinction should be made between the minus sign used for numbers and for the subtraction operation. Another distinction should be made between quantities and numbers. Numbers are arithmetical concepts, but quantities are not. In the mathematical field, there is no objection to creating real numbers less than zero and written with a minus sign in front.

Creativity in the scientific activities

In the model of scientific revolutions proposed by Kuhn, theory is at the center. It doesn't

imply that scientific creativity should be restricted to theories.

Scientific creativity could occur in three components of the scientific activity, which have a circular and bidirectional relationship: new instruments/methods, new empirical observations, and new theories (Figure 2).

Here is an example of a new observation based on a creative experiment stimulating a new theory. In 1820, during a lecture, the Danish physicist Hans C. Ørsted observed that a compass needle deflected from magnetic north when an electric current was switched on and off. This was the first scientific observation of a relationship between electricity and magnetism. The same year, in France, André-Marie Ampère, 1820 developed the first theory to explain this observation. And in 1865, James C. Maxwell published a paper (*A Dynamical Theory of the Electromagnetic Field*) where he presented the so-called Maxwell's equations linking electricity and magnetism, which formulated the classical theory of electromagnetic radiation.

A nice example of how the creation of a new instrument stimulates new observations is the invention in 1800 by Alessandro Volta of the voltaic pile. This pile is the early electric battery, which produced a steady electric current. Before this invention, only static electricity was produced rubbing two nonconductive objects. The voltaic pile opened a new field of observations. The same year, Carlisle and Nicholson used the voltaic pile to discover electrolysis by passing an electric current through water, decomposing it into its constituent elements of hydrogen and oxygen. A few years later, using this new method, the Cornish chemist Davy isolated for the first time several substances as calcium, strontium, barium and magnesium.

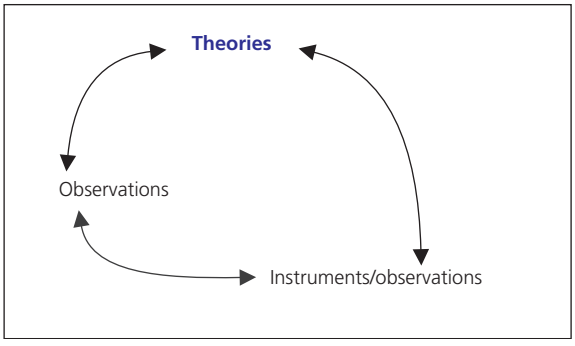


Figure 2. Interrelationship between theories, empirical observations, and instruments/methods.

These two examples show creativity occurring in an observation and in an instrument making. Why did Ørsted move an electric current close to a compass needle? He had no previous theories for doing so.

He was only curious, exploring a new field without intellectual censorship. Why did Volta used plates of zinc and copper, with sulfuric acid mixed with saltwater as the electrolyte to create the voltaic pile? He had some ideas coming from previous observations and experiments. But he was also creative exploring new ways without taboo. Ørsted and Volta did not make their discovery only using deductive reasoning or inductive reasoning. The role of abductive reasoning was crucial to open new territories to scientific exploration.

Scientific norms and peer review

Peer review is considered as essential for assessing scientific quality and is currently the standard procedure for selecting papers that should be published in renowned scientific journals and awarding research grants and fellowships. Therefore impact of peer review on scientific production is considerable. In 1968, Merton published an influential article where he analyzed how scientists judge the scientific accomplishment of their colleagues. Based on the testimony of a large sample of scientists, including several Nobel laureates, he observed that the reward system of

[3] "*For those who have, more will be given and they will have an abundance*: *but those who have nothing, even what they have will be taken*" – Gospel of Matthew.

science and the allocation of scientific resources were rarely neutral and fair. Merton (1968, p.58) called Matthew Effect[3], "the accruing of greater increments of recognition for particular scientific contributions to scientists of considerable repute and the withholding of such recognition from scientists who have not yet made their mark". He emphasized the impact of the Matthew effect in the scientific communication system. If a scientist is well known his/her papers will be easily published and will attract a larger readership than an unknown scientist, independently of the quality of his/her scientific contribution.

According to Merton, the Matthew Effect could have positive consequences since it increases the scientist's self-assurance, pushing him/her to conduct research on risky problems. On the other hand, the Matthew Effect can have adverse effect on innovative scientific ideas. The most well-known scientists could spend a lot of energy defending normal science against innovative ideas questioning a scientific paradigm for which they devoted their life as a researcher. Because of their dominant position, they can be very strong obstacles to a paradigm shift.

A lot of examples can be found in the history of science of virulent opposition from scientists of very high repute to new ideas coming from more creative colleagues.

The Matthew Effect can also have an adverse side effect on peer review. There is a conservative bias toward established ideas. In the case of an innovative paper, reviewers have more to lose from not indicating weaknesses than they have to gain from supporting innovation. They face an inner debate between the protection of their personal reputation and their support for creativity in science (Luukkonen, 2012). When an innovative paper is submitted by an unknown researcher, reviewers will have a tendency to reject it. Blind review is not a sufficient answer to this problem, because editors often do a first selection of papers knowing their authors. Moreover, reviewers often guess who are the authors based on the references mentioned in the paper.

Empirical data confirms the impact of conservative criteria used by reviewers, such as researchers' track records and apparent feasibility of the proposals. Companario and Acedo (2007) contacted 132 researchers who authored highly cited articles. Only 33.5% told they had no problems with the referees. Twenty-five percent had their paper rejected before being later accepted by another journal. The most common causes of problems were skepticism, ignorance, and incomprehension of referees and editors[4]. In some cases, extreme reactions were even reported (*e.g.*, "I stopped being invited to conferences and people stopped talking to me"). In another article, Campanario (2009) reviewed the resistance encountered by 24 future Nobel Laureates from scientific journal editors or referees to publish manuscripts dealing with discoveries that later would earn them the Nobel Prize. Often, the obstacles these innovative researchers had to face in order to be published and recognized by the scientific community were incredibly high. The provocative Max Plank's quotation (1949, p. 33) reflects the obstacles these creative scientists had to deal with: "A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it".

Conclusion

To move a car, we have to accelerate, but we first have to remove our foot from the brake. Developing and stimulating scientific creativity is an important goal, but it will remain insufficient if we do not work to overcome the obstacles to creativity. We have seen that the first obstacles are inside the researcher's mind. Therefore, we should first work

[4] Example cited by Campanario and Acedo (2007, p.738): *"My fellow Physical Organic chemists thought I had gone mad by shifting my focus away from experimental work, and I suffered over a decade of peer rejection until my crusade (along with a few others) to convince chemists of the virtues and advantages of computational chemistry by personal example finally succeeded"* (P. Schleyer).

at this level. Researchers should learn to question their initial knowledge related to their initial experiences and the dominant scientific models they have learned. Scientific education should spend more time on questioning initial notions and on history of science, especially its conflicting aspects. Researchers should also be aware of judgmental bias and learn to identify their own cognitive bias.

Creative scientists should enjoy taking risks. Such behavior is not easy because their scientific environment too often has an aversion to risk. Researchers know that a paper presenting a study based on a known theory and using a classical method will have more chance of being published than a paper based on an original theory or using a new method, which is mastered by few people. Therefore, they avoid risk taking and prefer to stay on the rails of normal science. Scientific education should increase the value of risk and serendipity. Students and young researchers should be stimulated to explore, having the possibility to go in a wrong direction and make mistakes. They should have the opportunity to investigate alternative pathways and to be surprised.

Because of its potential adverse impact on scientific creativity, the peer reviewing procedure needs to be improved. An alternative system seems unrealistic because of the millions of papers and projects submitted each year. A selection is needed and should be done by the scientific community. Blind review by other scientists is sometimes inappropriate, but no better method has been proposed. Instead of looking for an alternative method, it would be more efficient to work on a better definition of what are good papers and good research projects. We should also work on a better definition of what is creative science (*i.e.* advances in theory, methods, instrumentation, empirical phenomena) to provide criteria to enhance the value of creativity in scientific assessment. Relevance and novelty should be the core criteria for selecting papers and research projects.

References

Bachelard, G. (1938). *La formation de l'esprit scientifique*. Paris: Vrin.

Campanario, J. M. (2009). Rejecting and resisting Nobel class discoveries: Accounts by Nobel Laureates. *Scientometrics*, *81*(2), 549-565.

Campanario, J. M., & Acedo, E. (2007). Rejecting highly cited papers: The views of scientists who encounter resistance to their discoveries from other scientists. *Journal of the American Society for Information Science and Technology, 58*(5), 734-743.

Desmet, L., Grégoire, J., & Mussolin, C. (2010). Developmental changes in comparison of decimal fractions. *Learning and Instruction, 20*(6), 521-532.

Frisch, O. R. (1980). *What little I remember* (p.95). Cambridge: Cambridge University Press.

Grégoire, J. (2016). Understanding creativity in mathematics for improving mathematical education. *Journal of Cognitive Education and Psychology, 15*(1), 24-36.

Hamad, S. (2007). Creativity: Method or magic? In H. Chen & B. Stemmer, *Consciousness and cognition*. London: Academic Press.

Kida, T. E. (2006). Don't believe everything you think: *The 6 basic mistakes we make in thinking*. Amherst: Prometheus Books.

Kuhn, T. S. (1962). *The structure of scientific revolutions* (p.24). Chicago: University of Chicago Press.

Luukkonen, T. (2012). Conservatism and risk-taking in peer review: Emerging ERC practices. *Research Evaluation, 21*(1), 48-60.

Merton, R. K. (1968). The Matthew effect in science. *Science, 159*(3810), 56-63.

Peirce, C. S. (2011). *Philosophical writings of Peirce* (p.368). New York: Dover Publications. (Original work published in 1908).

Planck, M. (1949). *Scientific autobiography and other papers* (pp.33-34). Westport: Greenwood Press.

Sebeok, T. A. (1982). You know my method: A juxtaposition of Charles S. Peirce and Sherlock Holmes. In T. A. Sebeok. *The play of musement*. Bloomington: Indiana University Press.

Vartanian, O., Martindale, C., & Kwiatkowski, J. (2003). Creativity and inductive reasoning: The relationship between divergent thinking and performance on Wason's 246 task. *Quarterly Journal of Experimental Psychology, 56*(4), 641-656.

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