OPINION

The forgotten half of scientific thinking

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Although thinking is the core business of scientists, we rarely ponder how it thrives best; this is ironic, as there is abundant scientific insight to draw upon. For example, it is now known that thinking has two complementary modes: roughly, association versus reasoning (1). We systematically underestimate the role of the first (1), and the way our institutions, meetings, and teaching are organized heavily reflects this imbalance. By contrast, many of the greatest scientists systematically nurtured a balanced dual-thinking process. We should follow their example and reform scientific practice and education to catalyze the unusual combinations of knowledge that often turn out to have the highest impact (2).

Although the precise physiological basis of the two aspects of cognition is not yet resolved, it has become clear that the complementary mode to rationality is the "associative machine" in our brain. The capacity to make remote associations is linked to creativity (1). This capacity varies between persons, but also depends on our state of mind. For example, ideas may come while falling asleep, peeling potatoes, or walking. In fact, Charles Darwin had a special "thinking path" close to his house where he used to stroll twice a day to promote his thought. Recent experimental work confirms that our capacity to make novel associations is boosted by rapid eye-movement sleep (3) and by undemanding activities that allow the mind to wander (4). This finding suggests that it may be good in a daily routine to alternate our cognitive work with naps or activities conducive to mind wandering.

However, to let the associative machine come up with useful new ideas it needs to have good elements to connect. Darwin's walks could generate his groundbreaking insights only because his mind was loaded with a rich array of life-long observations and ideas, which raises the questions: How can we best provide our minds with elements that might combine into crucial novel insights?

A study of 17 million scientific articles recently showed that the highest impacts often come from work that is well-grounded in a field of research but at the same time involves an unusual link to another field (2). Why are such influential links so unusual? How can we feed the associative machine in our brain with potential elements for such unexpected links? This is a tantalizing problem, because if the connection should be unexpected one cannot plan for it. Should we just allow curiosity to guide us on a random walk and collect elements for our associative machine on the way? Perhaps we should. As Nobel Laureate Kenneth Arrow, known for his many revolutionary contributions to economics, phrased his attitude in a conversation we had: "It is so far from anything I do, I *must* be interested." The idea that such a broad interest can be productive fits with the finding that winners of the world's top science prizes had, without exception, internalized a lot of scientific diversity (5).

However, if novelty arises from diversity, why does institutionally planned interdisciplinarity so rarely generate the sparks we hope for? Why do unplanned, random encounters seem to be more productive in this respect? This seems frustratingly uncontrollable, but unusual encounters can be promoted too. Small interdisciplinary institutes, such as the South American Institute for Resilience and Sustainability Studies, Santa Fe, and Janelia Farm, may have the best cards for that, although on a traditional campus simply creating irresistible informal places with nice food or free coffee may already catalyze a lot of unplanned cross-disciplinary encounters (5).

It may feel uneasy to count on the unplanned, and risky to pursue remote associations, but this is calculated risk. When I was discussing these ideas with Kenneth Arrow, he stated: "If you are not wrong two-thirds of your time, you are not doing very well." He added, "if you are wrong you had better find out yourself, not only because it is more pleasant, but also because it helps you to learn." Indeed, solid scientific skills are needed to weed out right from wrong. However, our current teaching and routines are focused almost exclusively on those skills, whereas the best science tends to come from a balanced mix of rationality and adventurous association. Why is half of that mix so hidden? If we know unexpected associations are important, and we know how they can be facilitated, why not act accordingly?

The idea that taking walks, reading things unrelated to your research, and hanging out with strangers in a campus pub should be considered part of the serious process of thinking, but might well meet with skepticism in practice. Should we really set time and space apart for things that distract us from our jobs? Yes we should, because many of the breakthroughs in science were made by people who were distracted.

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1 Kahneman D (2011) *Thinking, Fast and Slow* (Farrar, Straus and Giroux, New York), p 512.
2 Uzzi B, Mukherjee S, Stringer M, Jones B (2013) Atypical combinations and scientific impact. *Science* 342(6157):468–472.
3 Cai DJ, Mednick SA, Harrison EM, Kanady JC, Mednick SC (2009) REM, not incubation, improves creativity by priming associative networks. *Proc Natl Acad Sci USA* 106(25):10130–10134.
4 Baird B, et al. (2012) Inspired by distraction: Mind wandering facilitates creative incubation. *Psychol Sci* 23(10):1117–1122.
5 Whitfield J (2008) An indifference to boundaries. *Nature* 451(7181):872–873.

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