Deep down, you are a scientist

Yael Niv, Princeton University

You may not know it, but deep down you are a scientist. To be precise, your brain is a scientist, and a good one, too! The kind of scientist that makes clear hypotheses, gathers data from several sources, and then reaches a well-founded conclusion.

Although we are not aware of the scientific experimentation occurring in our brain on a momentary basis, the scientific process is fundamental to how our brain works. This process involves three key components. First: *hypotheses*. Our brain makes hypotheses, or predictions, all the time. Every movement that we make involves predicting [1] – where will my arm end up if I engage this muscle, how heavy is the cup of coffee that I am planning to grasp and bring to my mouth, etc. A stark example is the familiar experience of going up the stairs in the dark (or while reading email on your phone) and almost falling because you expected, predicted, that there would be one more stair. We could have simply lifted our legs and decided whether there is a stair or not based on sensory feedback (do I feel a hard surface or not?), but anyone who has traveled up a flight of stairs in pitch dark knows that this is extremely slow and attention-demanding. Our normal stair-climbing is quick and effortless thanks to accurate predictions.

This is also how we learn from experience: we don't just wait for things to happen in order to learn, but rather we make a prediction about what will happen, and learn only if our prediction is wrong [2,3]. Every time you cross the street, you predict whether the approaching car will make it to the crosswalk before you make it to the other side of the street. This is not a simple prediction: it relies on inferring from visual input what is the distance and speed of the car, as well as having a good idea of how fast you walk and how wide the street is. Nevertheless, young kids can master this complex inference and prediction. If you have taught young kids to cross the street, you may have noticed, however, that they are much more cautious than (most) adults. This is because they have yet to refine their model of speed of cars and how long it takes to cross a street. They will do this through trial-and-error by observing differences between their predictions and reality: every time they cross the street, although they will have crossed successfully, as their brain had predicted, their brain will automatically register small discrepancies between prediction and reality: "that car is still very far from me, even though I am close to the other sidewalk". They will learn to adjust their predictions accordingly, and over time, will cross the street more like an adult.

We know, from over a century of research about learning from experience with the world, that animals, from snails and bees [4] to monkeys and humans [5], all learn by making predictions and then comparing these predictions to reality as it unfolds. This is called "error-driven learning" – you don't just learn from what happens, you specifically learn from your mistakes in predicting what will happen.

The second component of good scientific work is gathering data – testing your hypothesis by comparing it to evidence. As neuroscientists, we can gather data to test our theories about how the brain works from several sources: behavior, invasive recordings of the activity of single cells in the brain, non-invasive imaging of overall activity in large areas of the brain, etc. Because each type of measurement gives only partial information about how the brain works, to make solid conclusions we are taught to combine information from several sources – as many as possible. You can call this corroborating evidence, and it is not only the mainstay of scientific discovery, but also important in fields ranging from journalism to art history (you would not make conclusions about an artist's style only from one painting, or even only from paintings of that artist, without comparison to other contemporaries).

Our brain does this automatically: it optimally combines information from several sources in order to understand the world [6]. These sources are our senses. Have you ever felt that you can hear what someone is saying better when you have a line of sight to their face? That is because your brain is combining vision (yes, you can lip-read!) and sound to interpret the speech [7], and this is most important when there are distractors around (like other people talking, or some background noise). Another example is hammering a nail into the wall. We intuitively know that the best way to avoid hitting our thumb (or the wall) is by having it be our thumb (not someone else's!) holding the nail. Why is that? If someone else held the nail, we would surely avoid pain to ourselves. Yet, we are not as confident aiming the hammer if we are not holding the nail, because vision (seeing where the nail is) is not enough. We also use the sense of proprioception – our internal knowledge, based on sensors in our joints, of where our limbs are in 3D space. By holding the nail ourselves, we can combine proprioception and vision to accurately aim.

Finally, after making precise, well-founded predictions, and gathering data from all available sources, a scientist must interpret the empirical observations. So does the brain – the world is inherently ambiguous, allowing multiple interpretations of our perceptual input at any point in time. Imagine passing by your kitchen at night and seeing light coming from the window. Is this the light inside the room reflecting back from the glass pane, or a burglar outside shining a flashlight into your house? Unbeknownst to you, to interpret the sensory information, your brain will optimally combine your prior beliefs about each of these events (burglars are rare; the windows often reflect light) with the likelihood of the sensory information under each interpretation (at what angle is the light reflected? Is this the same angle you have witnessed many times? that is, how likely is it that you would perceive this exact scene if it were a reflection, versus if it were a burglar?), to arrive at a split-second decision [8,9].

It is important to realize that our perceived reality is subjective, interpreted, rather than an objective image of the world out there, as in some cases this interpretation can break down. For instance, in schizophrenia, meaningless events and distractors can take on out-sized meaning in subjective interpretation, leading to hallucinations, delusions and paranoia (that faint sound is not just steam in the radiator, but rather someone trying to convey a message to me, or aliens spying on my actions). Our memories are similarly a reflection of our own interpretations, rather than a true record of events. This holds implications for the reliability of memory in witness testimony, or in an argument with your partner [10].

In essence, our brain is always striving to understand the "truth", exactly what is out there. But our perception, far from a simple recording of objective reality, is rather an attempt to divine the causal structures that underlie our sensory inputs – what is the simplest "theory" that would explain what we hear, see, smell, etc. As many perceptual illusions attest to, we don't really see the world as it is, but rather, what we perceive is an interpretation, the best story we can tell that would make sense of all the data so far. Just like a scientist.

<u>Footnotes & references</u>

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