

## How 'Inside Out' Explains The Science Of Memory

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*The five emotions of Inside Out (Image: Disney/Pixar)*

*Inside Out* is not just Pixar's [best film](#) since *Toy Story 3*, it's also the smartest. Mostly set inside the mind of 11-year-old Riley as she moves to a new town, the movie uses colorful characters to illustrate how emotions influence our memories.

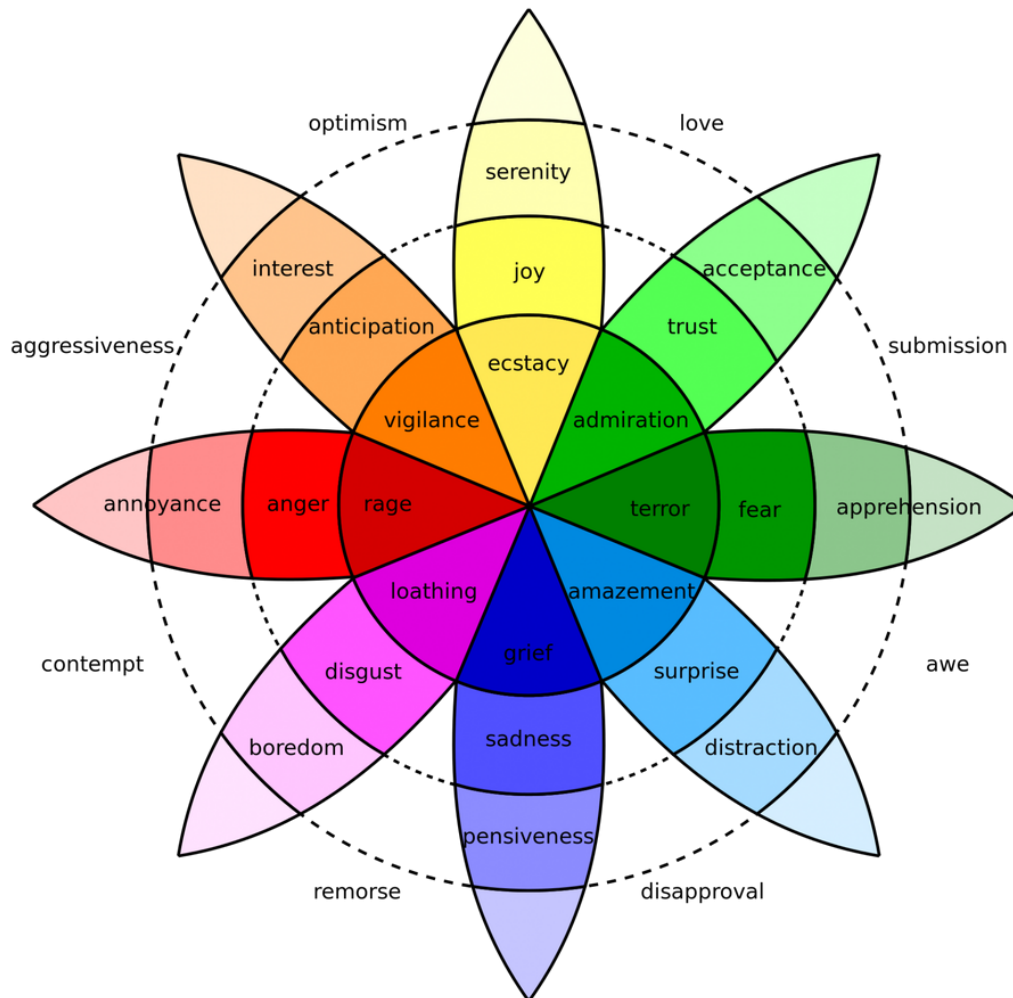
We humans have two main memory systems: implicit and explicit.

Implicit memory includes unconscious processes like emotional and skeletal responses, learning skills and habits, plus reflex actions.

Explicit memory stores facts and events, and recalling that information requires conscious awareness. The two systems can be separate, which is why you might retain an implicit fear of clowns after forgetting the explicit experience that originally triggered your coulrophobia. The two memory systems can also be connected when events have emotional significance – the focus of Pixar's film.

### **Outward emotions**

*Inside Out* depicts five emotions as characters with distinct personalities: Joy, Fear, Disgust, Anger and Sadness. These are inspired by the work of American psychologist Robert Plutchik, who proposed that we have [eight basic emotions](#), which can be arranged on a wheel with pairs of opposites: joy and sadness, anger and fear, trust and disgust, anticipation and surprise.



*Robert Plutchik's wheel of emotions (Image: Wikipedia)*

Plutchik called this idea a 'psycho-evolutionary synthesis' because it's based on Charles Darwin's theory that an animal's outward **expressions reflect emotions** that help them survive. As stated at the start of *Inside Out*, fear stops you from putting yourself in danger, for example, while disgust prevents you from poisoning yourself. Although the film's major characters are Joy and Sadness, the most vital emotion in nature is fear.

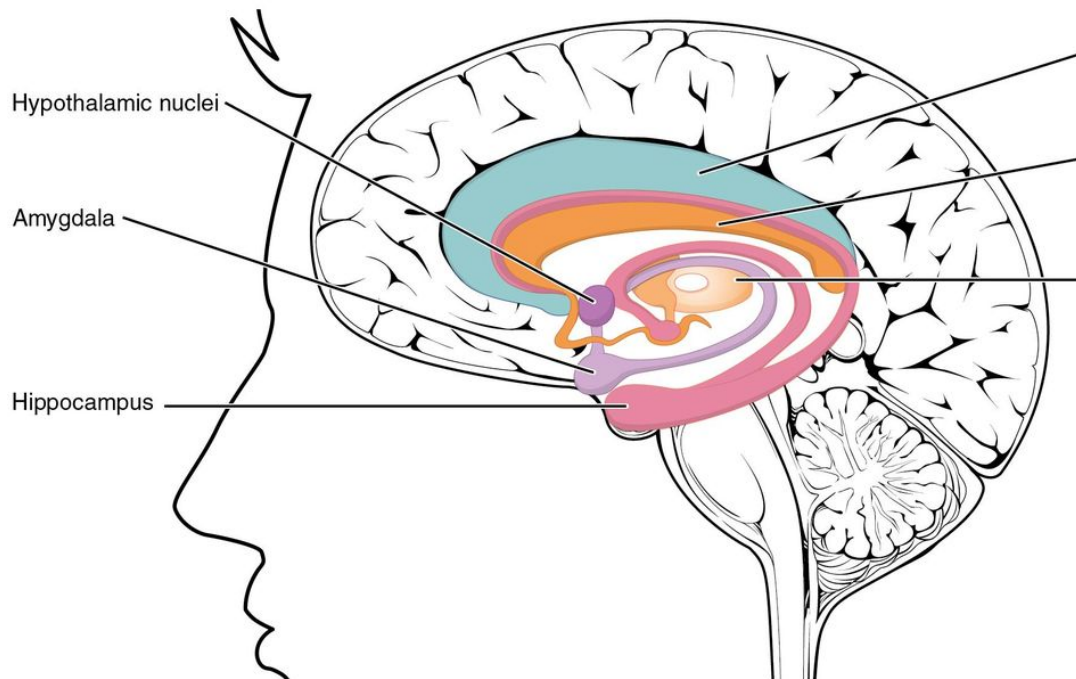
Having emotions is driven by natural selection: if an animal isn't able to recognise a potential threat, it risks being killed.

Learning and memory helps animals respond quickly to situations that resemble past experiences, which improves its chances of survival. Attaching emotions to an event gives that explicit memory some context, and also makes it stronger. As Riley's imaginary friend Bing Bong says, "When Riley doesn't care about memories, they fade."

In *Inside Out*, each memory is a glowing orb whose colours match the movie's five emotions: yellow for joy, blue for sadness, red for anger, purple for fear, and green for disgust. Memories aren't limited to a single emotion, as shown at the end of the film when most of Riley's memory orbs aren't uniform, but become marbles filled with multicoloured swirls of emotions. For example, while not named in the movie, combining joy and sadness (blue and yellow) creates sentimental feelings for the past, or nostalgia (Greek for 'ache for home').

### **Inside the brain**

So how do memories and emotions become connected? The process begins with stress hormones released by adrenal glands, which ultimately activate the amygdala, a pair of tonsil-sized areas in each brain hemisphere. The amygdala is located above a pair of seahorse-shaped structures called the hippocampus, which is roughly equivalent to *Inside Out*'s aptly-named 'Headquarters'. The five emotions personify the amygdala, and attach emotional significance to a new memory by pressing a big button on the control console in Headquarters, which is akin to nerve cells (neurons) in the amygdala sending signals to the hippocampus.



Memory has two lifespans: working (or 'short-term') and long-term. Working memory keeps knowledge in mind for cognitive functions like learning and reasoning, enabling us to compare and contrast information. Long-term memory is needed when the brain is presented with more information than it can handle, such as when you're asked to memorise 10 words at once.

Long-term storage of facts and events (explicit memory) depends on the hippocampus, as proven by the case of 'HM', who suffered from epileptic seizures. In their [famous 1957 study](#), surgeon William Scoville and neuroscientist Brenda Milner removed a small part of HM's brain, the hippocampus and surrounding areas within the medial temporal lobe. The procedure cured HM of epilepsy, but also left the patient with anterograde amnesia – the inability to form new long-term memories.



The memory orbs of *Inside Out* are sent through vacuum tubes down to 'Long Term', a library of endless shelves that hold Riley's memories. From above, Long Term looks like the cerebral cortex, folded outer layers that make a mammal's brain to resemble a walnut. Jellybean-like characters known as 'Mind Workers' pick memories off a shelf and throw them into the 'Memory Dump', a deep chasm where the unwanted orbs go dull and the information they carry – such as old phone numbers and piano lessons – is soon forgotten.

### **Scattered storage**

In the movie, an individual memory is a single orb. But in the brain, each memory doesn't exist in a specific location, but as a branching network of neurons. More precisely, each memory is stored or 'encoded' as a pattern of synapses, as the tiny gaps between brain cells. (An adult brain has 86 billion neurons, each with about a thousand synapses.) The pattern of nerve impulses across the cerebral cortex creates the physical trace of a memory, what scientists call an 'engram'.

Sleep is an important process for learning and storing memories. The brain's hypothalamus – located above the amygdala – controls the switch between being awake or asleep. In *Inside Out*, Riley enters REM (rapid-eye movement) sleep the second she closes her eyes. In reality, we fall into non-REM first, then alternate between REM and non-REM over 4-5 sleep cycles during the night.

REM sleep often includes dreaming, and [one theory for why we dream](#) is that the sensations and emotions we experience are a side-effect of random firing of impulses during the strengthening and pruning of the connections between neuron branches. Our brain tries to make sense of our thoughts by stitching them together into a logical story. In Pixar's film, Riley's mind has a studio called 'Dream Production' that creates movies based on her past experiences. This often creates a disjointed narrative. As Fear shouts while watching a dream, "Boo! Pick a plot line!"

### **Unreliable recall**

Your memory isn't as reliable as you might think. Research by American psychologist Elizabeth Loftus has shown that our minds can be manipulated via a 'misinformation effect' that implants false memories. In a 1974 study, Loftus showed participants a video of a car crash, then told them to recall the accident. After being asked a leading question or changing one minor detail, like using the word 'smashed' instead of 'hit', people would estimate that vehicles had travelled at faster speeds, and remembered seeing broken glass – even though it wasn't there. This highlights the dangers of relying on eyewitness testimony alone during criminal trials.



In *Inside Out*, recall occurs when memory orbs from Long Term are sent back up to Headquarters, where a projector shines light through the orb so a past event is replayed on a screen in front of the control console. Although this is the most common way to show the past in the medium of moving pictures, it perpetuates the myth that individual memories are recorded as linear film sequences that we can rewind or fast-forward.

But in the brain, each memory actually consists of scattered information – synaptic connections between neurons – that only leave a physical trace during storage or recall. Every time a memory is accessed, its bits are pieced back together. And so instead of retrieval, it's more accurate to describe recall as 'recollection'. The process of converting information in working memory to long-term is known as 'consolidation', and scientists have found that recall can sometimes cause memories to be reconsolidated. This means there's potential for a memory to become modified by synapses that weren't part of its original physical trace.



*Inside Out* also shows that the association between explicit events and implicit emotions isn't permanent, as illustrated whenever the character Sadness changes a memory orb's colour from yellow (joy) to blue. Researchers are testing ways to exploit reconsolidation to improve mental health. Drugs like propranolol (a beta blocker that interferes with molecules that help form and maintain memories) can be given while someone relives a bad experience to cut synaptic connections between an event and its associated emotions. This could reduce the emotional impact of flashbacks that soldiers experience in post-traumatic stress disorder (PTSD), for example.

The unreliable nature of human memory is illustrated at the end of *Inside Out*, when Joy realises that one of Riley's happiest moments followed an unhappy event, after her team lost a big hockey game. Clearly, the moral of the story is that emotions – even negative ones like sadness – are necessary for dealing with life's ups and downs.

Pixar's movie is also a triumph for science education. It's not perfect (there's no biological basis for a 'Core Memory' or the 'Islands of Personality', for instance) but it's still a very clever film. Analogy is a powerful tool that helps people understand complex concepts in an intuitive way, without jargon, and *Inside Out* has managed to teach a generation of kids – and adults – how memory works.