# Connecting the dots between engagement and learning

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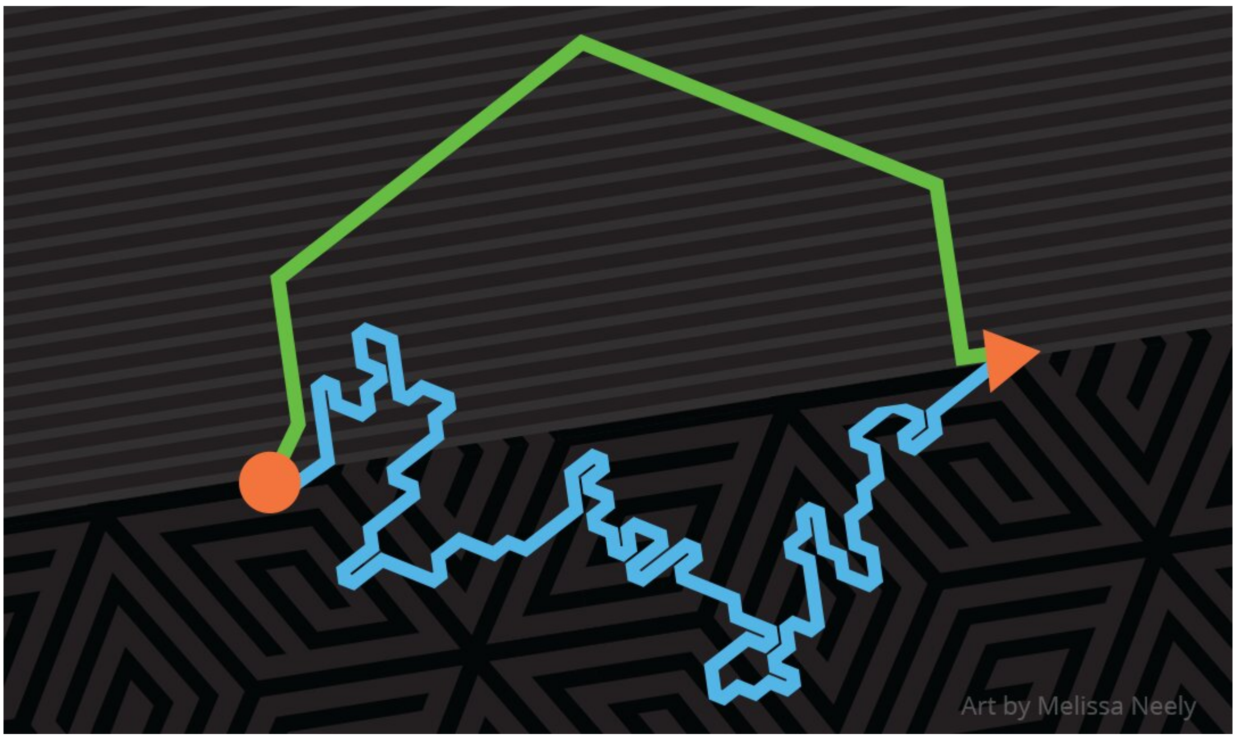


Learning is shaped by abrupt changes in neural engagement. Credit: Melissa Neely

We've all heard the adage, "If at first you don't succeed, try, try again," but new research from Carnegie Mellon University and the University of Pittsburgh finds that it isn't all about repetition. Rather, internal states like engagement can also have an impact on learning.

The collaborative research, published in *Nature Neuroscience*, examined how changes in internal states, such as arousal, attention, motivation, and engagement can affect the learning process using brain-computer interface (BCI) technology. Findings suggest that changes in internal states can systematically influence how behavior improves with learning, thus paving the way for more effective methods to teach people skills quickly, and to a higher level of proficiency.

Internal states are known to modulate brain-wide neural activity, and studies continue to explore their impact on motor control, sensory processing, and cognition. However, the specific interaction between internal states and learning is not well understood.

"Intuitively, we know that neural activity changes as we're learning different things, because our behavior gets better with practice," explains Jay Hennig, a graduate student in neural computation and machine learning at Carnegie Mellon. "However, what we're finding is that it's not just about getting better. All of the things that go on alongside of learning, such as one's level of attention or state of arousal, play a significant role."

Using a BCI learning paradigm, the researchers observed how neural activity changed, and the degree to which these changes were influenced by shifts in internal states, as subjects performed tasks by moving a cursor on a computer screen using only patterns of neural activity.

As the study unfolded, the team began to notice occasional large, abrupt fluctuations in neural population activity within the motor cortex. At first, they did not understand why this was happening, but over time, they came to realize that the fluctuations happened whenever the subject was surprised with a change in the task. (Changes ranged from brief pauses to perturbations of the BCI mapping.) At these moments, the subjects' pupils dilated, suggesting that the abrupt fluctuation was the neural manifestation of an internal state, engagement.

"We weren't looking for this particular effect in the neural data," says Steve Chase, an associate professor of biomedical engineering at Carnegie Mellon and the Neuroscience Institute. "The pupil diameter was tightly correlated with the engagement signal that we saw in the neural activity, and it seems to have a massive effect in the motor cortex."

Ultimately, the research suggests that subjects' level of engagement or attention can make things easier or harder to learn, depending on the context.

"You might have imagined that the brain would be set up with a clear segregation of functions, like motor areas to motor control, and emotional areas to emotional control, and sensory areas to sensory representation," says Aaron Batista, professor of bioengineering at the University of Pittsburgh. "What we're finding is a serendipitous kind of intrusion of an internal state into a motor area. It could be that we can harness that signal to improve learning."

The group's work is ongoing and done in collaboration with the Center for Neural Basis of Cognition, a cross-university research and educational program between Carnegie Mellon and the University of Pittsburgh that leverages each institution's strengths to investigate the cognitive and neural mechanisms that give rise to biological intelligence and behavior.

"One of the unique parts of our collaboration is how integrated we all have been throughout the entire project, from experimental design, to experimental conduction, to data analyses, and adopting; we're all involved in all parts of that," says Byron Yu, professor of biomedical engineering and electrical and computer engineering at Carnegie Mellon.

"The findings here might one day help people learn everyday skills, such as math or dance, more quickly and to a higher level of proficiency."

**More information:** Jay A. Hennig et al. Learning is shaped by abrupt changes in neural engagement, *Nature Neuroscience* (2021). DOI: 10.1038/s41593-021-00822-8

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