Learning and Memory Series

104 Six Triggers for Memory and Learning

The end product of learning is information stored in the brain as memory. Yet, most of us are unaware of the mental mechanisms and learning techniques that will contribute so mightily to our success in life. After a career spent researching the problem, the UCLA psychologist and chairman of Amplifire's Science Board, Robert Bjork expressed this dilemma succinctly…

> "Current customs and standard practices in instruction, training, and schooling do not seem to be informed by an understanding of the complex and unintuitive dynamics that characterize human learning and memory. Nor do we, as individuals, seem to understand how to engage fully our remarkable capacity to learn. Instead, we seem guided by a faulty mental model of ourselves as learners that leads us to manage our own learning activities in far from optimal ways." —Robert Bjork, On the Symbiosis of Remembering, Forgetting, and Learning, 2011

Information coming in through our senses is encoded by the brain into the language of neurons. The information is stored in hierarchical and highly associated memory patterns throughout the brain. We retrieve the "trace" of a memory by using cues in the moment of perception to reconstruct details of the original input. And, the trace fades if not strengthened in some manner— by recalling, testing, or repeating the information. Science has revealed much about the optimal conditions for learning and memory, but most of the insights have not been readily adopted by educators.

Sadly, traditional methods deliver simply abysmal results. After a lecture delivered in the classic stand-up format, students will remember only 20% of the material within 24 hours and only 5% after a few weeks. This is a bleak statistic, especially when one considers the fact that all higher order thinking must be built on a solid foundation of easily recalled facts and concepts.

Why is memory fragile? As Bjork and his many colleagues have shown, brains are designed by evolution to forget. Learning that isn't associated strongly with related information or that lacks emotional content is the first to become inaccessible to retrieval. Without employing certain non-intuitive strategies, everyone forgets.

The distinctions that make a difference–triggers, switches, and techniques

For the team at Amplifire, the first part of addressing the challenges of education in the 21st century lay in building a model of learning that considers the components of the brain and the memory it generates in response to learning. We began with the idea that drives all of science—cause and effect. How could we distinguish the truly effective causes of learning out here in the real world, what we call triggers, from the effects within the circuits of the brain itself, what we call switches. After all, we can only reach the brain through the senses—eyes, ears, and touch. To be blunt, the brain then does what it will with the information using processes that are mostly unconscious and unappreciated. In other words, we described hard distinctions between the environmental triggers in the world, from the switches in the brain they affect, and from the techniques that we could write into software.

We must always be aware of this cause and effect distinction between the outside environment, which can be manipulated by teachers or software, and the brain, which then does what it is programmed to do by evolution, culture, and personal history. It might pay attention, be bored, store the information, forget it, or ignore it. Nevertheless, some ways of presenting information are vastly more effective than others at causing learning.

Six triggers for rapid learning and longer retention

Amplifire was built from the articulation of twenty-two triggers that research has shown to switch on learning and memory. The triggers were derived from decades of experiment and observation, some of which led to Nobel Prizes for their discoverers. Here are six that drive the effectiveness of the Amplifire platform.

Confidence and the hyper-correction effect: The feeling of knowing is the emotion of information, and emotion leads to long-term memory.

Adaptive repetition with spacing: Memory is fragile and learning will only stick through multiple encounters at spaced intervals after some forgetting has taken place.

Priming with multiple-choice tests: Questions before actual study increase ease of learning and length of retention.

Retrieval practice with feedback and the testing effect: When learned information is retrieved via testing with feedback, the neural representations of the information become stronger.

Visual cues for memory trace strengthening: Cues present during study will not be present when the information is needed later or as the basis for high-level concepts.

Uncertainty and the dopamine effect: The trigger that causes seeking and curiosity in all animals, humans included. Fire up curiosity, and you have ignited the wick in the candle of learning.

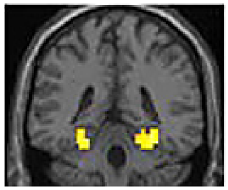
Confidence and the hyper-correction effect

According to Robert Burton, a neuroscientist at UCSF, the feeling of knowing is a core emotion as fundamental to human experience as love, fear, sadness, or hate. Only recently has the feeling of knowing been considered in this context—as the emotion of knowledge. In every-day experience, these feelings show up in phrases like: "I'm not sure," "I'm totally positive," "I haven't a clue." In the Amplifire format, the feeling of knowing is expressed in terms of doubt, certainty, or ignorance.

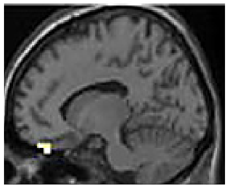
> *"The feeling of knowing and its kindred feelings should be considered as primary as the states of fear and anger... it is time for an examination of the role of the feeling of knowing in shaping our thoughts." —Robert Burton, On Being Certain, 2008*

The deeper evolutionary perspective tells us that the feeling of knowing is of utmost importance because it leads directly to behavior. If you are confident, you act. If you have doubt, you hesitate. If you don't know, you go no further. This is a key link between knowledge, encoded and stored in the brain as memory, and behavior in the physical world. An organism must have a way to gauge the likelihood that knowledge is correct before acting on it. One's level of confidence accomplishes this task.

The neuroscientist John Gabrieli has concluded that parallel processing is occurring in the brain when we access knowledge and judge our confidence in it. One circuit, the parahippocampus, is working on retrieving semantic memories, while another, the ventromedial prefrontal cortex (VMPFC) is processing clues for familiarity (a degree of certainty). The VMPFC may account for the judgments we make about our learning—the mental states we call confidence, doubt, and ignorance.



Parahippocampus

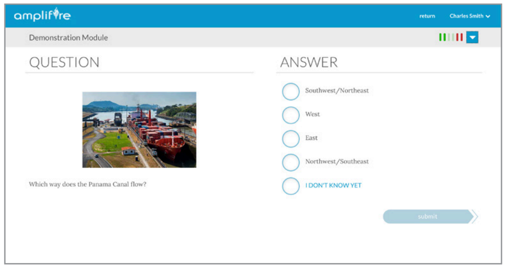


Ventro Medial Prefrontal Cortex

Intuitively, we think that confidently held misinformation should be hard to correct because confidence implies strong memory storage and a robust retrieval pathway. The memory trace of fired and wired neurons that form the representation should be more resistant to change than with other conditions of memory such as doubt and ignorance. In fact, experiments clearly demonstrate that our intuition is wrong in this case. When confidently-held misinformation is corrected, the new information is retrieved and recalled in the future with higher fidelity than information learned by study alone. Researchers call this the hyper-correction effect.

Incorporating Confidence into Learning

Amplifire users learn rapidly because the circuit that stores a memory and the circuit which judges the accuracy of the memory are both active and engaged. As seen in the example here, by allowing users to answer, "I am sure," "I am partially sure" or admit, "I don't know yet," Amplifire brings Burton's feelings of knowing directly into consciousness. No longer is that crucial distinction left to unconscious processes. The emotion of knowledge is directly perceived and considered by the learner, thereby improving the encoding, storage, and recall of memory.



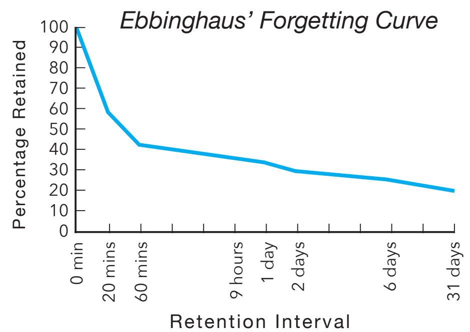
Once Amplifire associates a student's confidence with a their answer, then the system can classify and present which answers are confidently held misinformation. The learner then experiences the effects of hyper-correction—attention, arousal, and a strong desire to eradicate the misinformation.

Furthermore, Amplifire looks at big data sets of user results to determine which questions are most likely to activate the hypercorrection effect. By presenting these questions in the proper ratio with other questions, student engagement, attention, and curiosity are engaged in the early rounds of learning. In other words, Amplifire seasons every module with the proper amount of likely misinformation to trigger this strong feeling that leads to faster learning and longer memory.

> *"The empirical data indicate that high-confidence errors are the easiest, rather than the most difficult, to change."* —Janet Metcalfe

Adaptive Repetition with Spacing

In some of the first experiments in modern psychology, Hermann Ebbinghaus demonstrated that learning is vulnerable to forgetting in two distinct phases as seen below in his forgetting curve. The first is a steep decline in the first hour after learning, followed by a much more gradual decline over days and months. Crucially, he discovered that memory improves through repetition. It flattens out the forgetting curve, especially when learning events are spaced apart in time.



Donald Hebb later postulated how repetition strengthens the synaptic connections between neurons. He famously pointed out that "neurons that fire together, wire together," a process now know as Hebbian Learning or Hebbian Plasticity. Recently, the underlying basis of learning has been identified as a complex cascade of molecular processes that result in protein synthesis based on the genetic code held in DNA. Out of this new protein, structures are built at the synaptic junction between neurons that make them more likely to fire together. The neural patterns that form in this way "represent" information in the world.

Recent work that complicates matters is the ironic finding that retention is enhanced when the material is forgotten and then re-learned. Forgetting in this view means that the information remains stored in memory, but the "memory trace" back to the information has become difficult or impossible to access. A sufficient amount of time must pass for forgetting to take place before re-studying the material.

Spacing studies conducted after 2005 demonstrate the vital necessity of letting sufficient time pass before re-studying if the goal is remembering the material well into the future. Without time between study sessions, the memory of the learning quickly fades.

Incorporating Spacing into Learning

This scientific backdrop is the basis for the incorporation of spacing into Amplifire's learning software. While Amplifire is self-paced, learners do not see all the learning content at once. In fact, the Amplifire format inserts an interval of time between testing and learning. Within Amplifire, learners must answer a question set (typically 6-8 questions) before they can review the learning associated with each of those questions. Time is literally engineered between study sessions.

After learners review their answers for their initial set of questions, they then see a new set of questions. Amplifire's adaptive, iterative learning process (Adaptive RepetitionTM) guides learners though repeated study sessions that are spaced apart by intervals that are personalized to each learner by the algorithms in Amplifire. This personalized spacing allows for hippocampal consolidation to take place. Depending on their level of existing core knowledge prior to entering Amplifire, some learners may finish a module within two or four spaced reviews, while others might take as many as 20 or more reviews. Regardless of the amount of reviews, all learners encounter optimal intervals of spacing within Amplifire, allowing time for the new knowledge to consolidate into long-term memory and heightening their retention of the content.

Additionally, within the Amplifire platform are review and refresher courses. The results of previous learning sessions can be reviewed, and the refresher modules can be taken as a re- study tool.

Spacing is also a key part of the Amplifire protocol over time. Days or weeks later, refresher courses continue to cause retrieval, thereby strengthening the neural patterns of the information and flattening the forgetting curve. Amplifire can prescribe a different forgetting curve to each learner and "push" refreshers at the appropriate time.

> *" The present results show that the timing of learning sessions can have powerful effects on retention..."*
>
> —Cepeda, Rohrer, Wixted, and Pashler in Psychological Science

Priming with multiple-choice tests before study

In 2010, experiments revealed a dramatic effect. Psychologists discovered that testing using multiple-choice prior to study dramatically primes the mind for learning and retention. The test prompts the brain to form the early outline of a hierarchy that will be filled in later with details as learning progresses.

As shown below, not only has the power of priming through testing been demonstrated, but also some potential dangers of multiple-choice tests have been addressed. For example:

- What if the incorrect alternatives on a multiple-choice test are remembered more clearly than the correct information?
- How does pre-testing with multiple choice compare to additional study?
- Research reveals that the brain suppresses old information with the learning of new, related information. So, does testing before studying suppress related information that is not on the test?

In three elegantly crafted experiments, Bjork and Little discovered a host of useful results. First, testing before study is a far better use of time than extending time of study. Even though a majority of answers will be wrong on a pretest, it has beneficial results on the effectiveness of later study. This can be seen in the graphic that shows pretesting as a green bar on the left and extended study time as an orange bar on the far right.

Second, testing before study is better than memorizing facts before study (the two green bars).

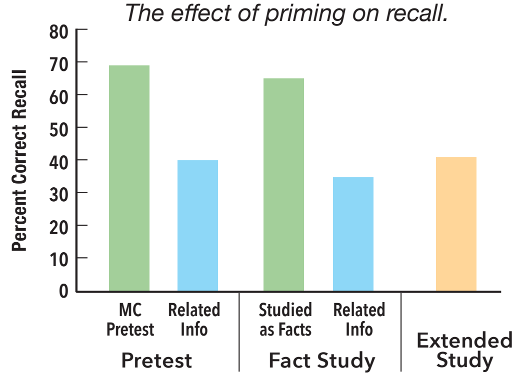
Third, it turns out that multiple-choice pretests improve not only the learning of information on the pretest, but also related information that was not on it (the two blue bars). It is likely that this stems from the fact that students must analyze the alternatives with great care to decide on the correct answer. Even though they have no previous knowledge (since this is a pretest) they still search memory for any related clues and associations that might give them an edge in determining which of the alternatives is correct. This search process leaves them with a memory trace of related information that they will be exposed to again during future study.

Fourth, pretesting does not increase the likelihood of misinformation. This was a concern because it was thought that incorrect alternatives on a multiple-choice test might be mistaken for correct information and later remembered as such. Bjork and Little show that this fear can be laid to rest. Pretesting does not lead to misinformation.

Incorporating Priming into Learning

Amplifire is the most effective application for generating the benefits of priming through testing. Amplifire is designed to begin by assessing a user's current knowledge even though they may never have studied the material. It is made plain to first-time Amplifire users that taking an assessment before study is highly beneficial. Furthermore, the novel answer key gives students the ability to answer with low confidence or honest ignorance—something no other format can offer. The judgements of learning generated by such introspection lead to greater contemplation of the material, focused attention, and associations in the brain's hierarchy of existing knowledge—key elements for rapid learning and long retention.

The effect of priming on recall.



" Even when a multiple-choice pretest takes time away from study, it appears to make subsequent study more effective than other activities that pre-expose students to the information." Little & Bjork

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Retrieval practice with feedback

Sometimes called self-testing, retrieval practice switches on an extraordinary array of brain processes. The wide range of brain activities that result from retrieval goes far in explaining the extraordinarily powerful empirical observation called the "testing effect." Retrieval has been experimentally shown to outperform study as a way to create stronger memory and is one of the core features of Amplifire's design.

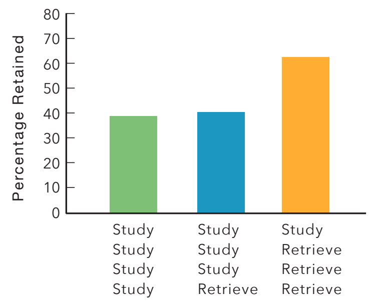
In recent experiments, Roediger and Karpicke found a correlation between testing and learning that was nothing short of astonishing. Students were given a passage containing scientific words and concepts and asked to memorize the general information in one of three ways:

1) Study: The passage was read four times.

2) Single test: The passage was read three times and memory was tested once (retrieval).

3) Repeated test: The passage was read just once and memory was tested on three occasions.

The Power of Retrieval Practice



All three methods proved fairly effective when the final test of memory was performed five minutes after completion. The repeated study method was the winner with 82% retention while the repeated test method came in last with 70% retention.

But, the roles were radically reversed when memory was tested again one week later—much closer to the real time frames of student learning and high-stakes testing. Repeated testing was far more effective at 62% retention while the repeated study came in at only 39%.

These results are simply astonishing, and more so because many education professionals working today would be utterly certain that reading a passage four times would outperform mere testing.

Incorporating Retrieval into Learning

The act of retrieving a memory profoundly affects its own later retrieval—a virtuous circle of learning that Amplifire puts to good use, making it the richest learning format on the planet.

Retrieval is designed into the heart of the system because research shows that self assessment used in a formative manner helps students learn quickly and with greater comprehension and memory. The Amplifire format goes much further than traditional testing systems because of the confidence metric which associates this emotion with knowledge. Confidence engages learners meta-cognitive instincts—they think about their thinking. The testing effect, especially when coupled with confidence, is one of the signature strengths of the platform.

Recent findings show that hard tests, where students get many of the answers wrong, create a long lasting memory of the correct information.

> *"Pupils actually learn better if conditions are arranged so that they have to make errors. Specifically, people remember things better and longer if they are given tests so challenging that they are bound to fail. This phenomenon has obvious applications for education." —Roediger and Finn, reporting in Scientific American Mind, 2010 on a study by Richland, Kornell, and Kao*

The Amplifire algorithm gives students exactly this kind of experience because mastered questions drop out of the iterative process. This keeps the learning just difficult enough to maintain focus. Boredom, the ultimate enemy of learning and memory, is held at bay.

> *"Memory research has revealed that a test which requires a learner to retrieve some piece of information can directly strengthen the memory representation of this information." —Harold Pashler, Education Researcher Magazine*

Cues for memory trace strengthening

Everyone experiences moments when a cue in the environment stimulates the retrieval of a related memory. For example, the smell of pine trees might conjure up recollections of summer camp twenty years ago. Cues in the present call forth related experiences from the past. This happens because memory is a network of associated nodes of information. The experience of the moment being encoded in working memory, like a song or a smell, activates and retrieves an associated memory trace—the pathway back to the information stored in long-term memory. This kind of memory activation is called context dependent memory.

Three kinds of cues that affect learning are, 1) the environment 2) the word structure of sentences, and 3) visual images associated with the study material.

Robert Bjork demonstrated the surprising power of cues. In one experiment, subjects in either of two rooms were given 80 words to study and remember. The rooms differed in location, color, size, and smell. Subjects who were tested in the same room could remember 49 words on average, while subjects tested in the different room remembered just 35 words. Context dependence improved memory by 40%.

Cues can be helpful while learning, but in many cases those same cues will not be present when the information is needed, for example, on the job or during a test. Importantly, this applies to high level concepts as well. Cues won't be present when higher-order conceptual thinking is constructed from lower order facts and definitions.

Bjork, et al, went on to discover that changing the context can enhance memory because it causes forgetting between study session. As the Bjorks have shown over a lifetime of work, some forgetting is necessary between study session if additional study is going to have an effect on the strength of the memory trace leading to the stored information. Taking away memory cues creates a desirable difficulty that enhances the memory of the information.

Incorporating Cues into Learning

To foster memory trace strengthening, Amplifire uses methods within it's delivery system that minimize context dependence. Cues are bundled with content at the beginning of study to aid with initial learning, but are unbundled as the student progresses over time.

The refresher module helps to forget graphical cues.
The refresher modules are designed so that photographs, videos, charts, graphs, and other visual cues are automatically stripped away. This forces students to abandon those reminders and to deal only with the ideas that form higher level thinking. The odds improve that concepts and theories will transfer and mesh with other disciplines in an integrated, consilient picture of the world.

Shadow questions allow for higher order thinking.
Shadow questions are conceptually similar to each other, but they are constructed using different words, syntax, and grammar. They allow for higher order learning by encouraging a demonstration of knowledge about the underlying concepts, while not allowing students to simply memorize the questions.

Amplifire's software is built so that shadow questions can be embedded into modules that the system will serve up according to the algorithm and the learner's progression through the material.

Shadow questions overwrite word structure and grammar cues.
Students often don't really learn the material deeply. Instead, and unbeknownst to them, they unconsciously remember the structure of sentences—a cue that triggers the correct answer. Again, the real world does not ask questions in the same grammatical format and neither does Amplifire. Shadow questions ask for the same information, but are constructed using different words and styling, thereby aiding in concept formation and transfer to other knowledge domains.

> *"When instruction occurs under conditions that are constrained and predictable, learning tends to become contextualized. Material is easily retrieved in that context, but the learning does not support later performance if tested at a delay, in a different context, or both."*
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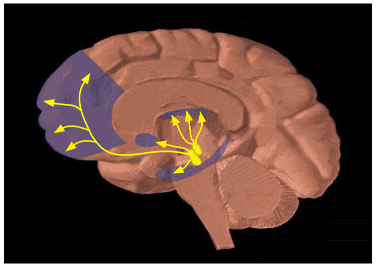
> *—Bjork and Bjork, Making Things Hard on Yourself, But in a Good Way, 2009*

Uncertainty and Motivation

You can lead a horse to water, but you can't make it drink. A truer aphorism can't be found within education. Learners often have every imaginable form of modern technology at their fingertips, but without motivation, information can't be turned into knowledge stored in a brain.

The brain system that mediates motivation is the circuit that distributes the neurotransmitter dopamine. Discovered accidentally in the 1950s during electrical stimulation experiments, researchers found that laboratory rats would press a lever incessantly to get shots of dopamine directly administered into their brains. And, they would do this to the exclusion of food, even when starving. Dopamine became quickly known as the neurotransmitter of pleasure and its circuit, the pleasure pathway.



Dopamine production and pathways.

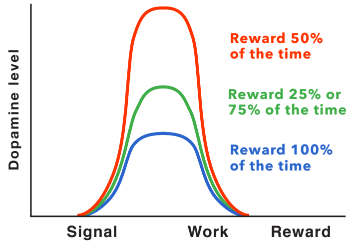
It turns out that this original equation (dopamine = pleasure) did not capture the underlying processes very well. First of all, as can be readily seen in the illustration, the prefrontal cortex (the locus of working memory and conscious awareness) is connected to a major source of dopamine. This arrangement gives dopamine the power to focus a creature's attention on active goals while disregarding less interesting ones. This pathway is nearly identical in all mammals. In a way, dopamine decides what is "interesting." Consequently, attention is highly influenced by dopamine levels which affect the inhibition and excitation processes that control activity in the PFC system—the seat of the executive function and consciousness.

Dopamine is maximally present during the anticipatory stage while a creature is seeking reward, and less so during the experience of reward. It is not involved in the pleasurable activity per se. What it does is more important. It heightens anticipation and drives a creature to seek out things in the environment. Seeking, anticipation, and curiosity are intimately related and we can use these terms with some interchangeability. Seeking behavior is deeply fundamental to all animals and Jaak Panksepp, its primary investigator, has called the dopamine network that causes it "the granddaddy of motivational systems."

Researchers now think that the seeking system mediates "wanting" while other brain systems are in charge of "liking." Panskepp and other researchers have found that dopamine drives the seeking-wanting processes, which are accompanied by elevated arousal levels. Opioid receptors, on the other hand, are responsible for liking—the pleasurable feelings associated with shelter, food, sex, and companions once they are procured—exactly the opposite of arousal. Taken together, the two form a dual feedback circuit whose purpose is to initiate aroused seeking behavior (wanting) followed by satiation (liking) once the desired thing has been obtained.

Readily seen in the graph are a set of fascinating experimental results with lab animals conditioned to expect a reward. First, notice that dopamine production goes up in the brain when a signal indicates that a behavior will produce a reward (blue curve). This is anticipation. In lab animals, this might be a bell indicating that pushing a lever will release a bit of food. In humans, it might be the sight of Mcdonald's arches or the thought of a date with a romantic interest. Notice that dopamine falls off after the work is performed—the reward is given, the hamburger is consumed, the date is underway.

Dopamine is about anticipation of reward. Uncertainty magnifies its production.



Now, here's something unexpected. Dopamine levels skyrocket whenever the reward has a 50% likelihood of occurring (red curve). As Robert Sapolsky notes, "You have introduced the word 'maybe' into the equation and that is reinforcing like nothing else on earth."

Further proof that uncertainty is arousing comes from the observation that dopamine levels fall from this peak when the reward is given either 25% or 75% of the time (green curve). This is because the reward is becoming more predictable at 25% and 75% and, as we now know, dopamine is all about anticipation of the reward, not the reward itself. Predictability reduces dopamine levels and attention fades.

" The fact that curiosity increases with uncertainty suggest that a small amount of knowledge can pique curiosity and prime the hunger for knowledge." —*Camerer, Kang, et al, Psychological Science, 2009*

Incorporating Uncertainty into Learning

Amplifire takes advantage of uncertainty, anticipation, and the dopamine system in unique ways.

First, is the idea that questions create far more uncertainty than answers. An answer, in terms of dopamine, is like a reward. As we have seen, rewards turn off seeking. Consequently, curiosity, attention, and seeking fall off. Questions, on the other hand, are fraught with uncertainty and stimulate dopamine production and the seeking system. Socrates is well known for his emphasis on the power of questions to motivate thought and concept formation.

Second, the Amplifire assessment format creates added uncertainty because the questions and their order of presentation are unknown to the learner. Questions drop out while new ones appear and their order is always changing so that learners are kept purposefully off balance.

Third, Amplifire's confidence measure drives learners to anticipate some unexpected and surprising aspect of their stored knowledge. Their confidence surprises them when they should have been doubtful. Their misinformation is a shock when they had perceived its opposite—mastery. This uncertain anticipation of a surprising result keeps their attention focused on seeking new information, including the hunt for their own misinformation.

Fourth is the observation that knowing a correct answer with confidence is a reward. Researchers (and the graph on the previous page) have shown that rewards should be given, on average, about 50% of the time. A 50% reward schedule causes uncertainty and triggers maximal dopamine levels. The result is curiosity, attention, and seeking. With those brain circuits switched on, students learn faster and they remember information longer.

> *"These same systems (dopamine) give us the impulse to become actively engaged with the world and to extract meaning from our various circumstances." —Jaak Panskepp, Affective Neuroscience*

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