

# What We're Learning About Learning (and what we need to forget)

*The least effective teaching methods are some of the ones most commonly practiced.*

by Joan Straumanis

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## Introduction

We begin with a paradox: On the one hand, *not nearly enough* is known about exactly how learning takes place in the brain, although exciting new results are emerging thanks to improved brain imaging and a greater focus on neuroscience by government and universities. But this research is just beginning, and a much larger investment and effort are needed to answer even the most basic questions. On the other hand, *more than enough* is already known to motivate and drive educational reform for years to come. This article is a report from the front lines of both research on learning and the implementation of that research. The information should prove of use to anyone—faculty, administrators, researchers—concerned with how best to improve formal or informal teaching and learning, help people remember complex instructions, or change unhealthy habits and practices.

## NSF Decides to Weigh In

Soon after the turn of this century, the National Science Foundation (NSF) decided to make the sort of major investment in the science of learning that had hitherto been reserved mostly for the traditional natural sciences, engineering, and mathematics. The funding mechanism

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involved cooperative agreements with newly created interdisciplinary multi-university centers, each receiving multimillion dollar annual awards for a maximum period of 10 years. The six centers eventually funded<sup>1</sup> have matured into influential and sophisticated collaborations generating important science, some of which will be described in what follows. The author of this article was an NSF program director who helped to manage the Science of Learning Centers program.

### Robust Learning

Researchers at the Pittsburgh Science of Learning Center (PSLC) developed a useful starting point for any discussion of scientific evidence-based learning research: a definition of what should count as success in teaching and learning (LearnLab—Pittsburgh Science of Learning Center 2008). They characterize successful learning as “robust” and measure the degree of robustness according to three criteria: (1) long-term retention, (2) effective preparation for further or deeper learning and application, and (3) effective transfer of knowledge or skills to novel situations.

These criteria suggest the need for further refinement and research. For example, how long is “long-term”? The learning researcher will want to discover how much learning is retained—not just until the next test but for months or even years after the lessons are over. What schedule of practice best ensures long retention? Might the spacing of reminders or lessons determine how long the material will be usefully remembered? It turns out that it does and that the interval between practice sessions is correlated quite well with the length of retention (Cepeda et al. 2008; Pavlik and Anderson 2008). Other things being equal, longer intervals lead to longer retention, which is one reason why cramming the night before a test leads to poor long-term learning.

### The assessment of learning is more than the testing of recall.

Defining robust learning in this multi-dimensional way is a reminder that learning is more than simple recall, and the assessment of learning is more than the testing of recall. At its best, education builds sophistication as well as knowledge. That is why robust learning is defined to

include such sophisticated skills as the ability to build further knowledge on one's own and the capacity to transfer knowledge and skills to new domains related in increasingly complex ways to what was originally learned.

### Clearing Away the Myths

It is common today to hear the call for “brain-based education,” an indication that the public is both interested in and eager for more scientific information about the brain. Further, teachers and parents seem willing to translate research findings into practical steps that might enhance learning—if only they had access to accurate information and workable advice about how to adapt research results so as to enhance teaching and learning effectiveness.

Unfortunately, due in part to careless reporting in the popular media, certain ideas have gained currency even though they are poorly supported by research. One of the most widely believed of these—an article of faith in many elementary schools—is that individual differences among learners require individualized teaching techniques. One hears that because some people are “visual learners,” “auditory learners,” or “kinesthetic learners,” a variety of teaching methods, each directed toward particular learners, are required if all students are to learn. Variety is actually a good idea because it reinforces learning for everyone, but not for the reason given, because of differences in learning styles. Research has shown that while such differences in learning preference or aptitude exist, they are very small—more than zero, but not enough to warrant much attention, especially in comparison with the attention that should be paid to the techniques that we know increase robust learning by much larger amounts for *everyone* (McKeachie 1995).

This notion of learning styles is easily confused with another popular idea, proposed by Howard Gardner, that people have “multiple intelligences” (Gardner and Hatch 1989). For example, a person might have great skill at sensing and interpreting the feelings of others (“emotional” intelligence) while being a clumsy dancer (lacking “musical” and/or “kinesthetic” intelligence). Such differences in ability might well exist, and some of them might be correlated with some learning styles, but they are conceptually different. In the one case, it is about how one learns best; in the other, about where one's greatest talents lie. If both the idea of divergent learning styles and the theory of multiple intelligences were correct and important for teaching and learning, then one might have to consider teaching to each

intelligence in a different way for each style of learner! Fortunately, this degree of individualization is not at all necessary in order to achieve excellent learning and retention.

Another myth with even less scientific grounding is the view that some people are left-brained (the allegedly conventional, analytical types) while others are right-brained (the creative and artistic people, according to some of those who so label themselves). But in fact, except for those with grievous brain trauma, everyone uses *both* sides of the brain, and the two sides are richly interconnected.

The misconception that people are right- or left-brained in the same way that most people are right- or left-handed may have arisen through studies of brain trauma or from brain imaging studies that track oxygen uptake in various brain regions. When an injury at point A results in cognitive or mental deficit B, it may seem reasonable to assume that the capacity for B is localized in the brain at A. This is a bit like cutting the electrical cord to your television near the plug and when the picture goes out assuming that the cord is the part of the system that generates the picture. Theorists call this error a functional localization fallacy. Also, it may stand to reason that if a certain part of the brain is involved in a task, then more activity would be correlated with more expertise. This too is false. In fact, the brains of experts take up less oxygen and therefore show less, not more, activity than the brains of novices. This makes sense because tasks are *easier* for the expert; they use less energy and therefore less oxygen. Actually, individual differences in both the *degree* and *location* of brain activity are influenced by experience and training. For example, creating and analyzing music activates mostly the left brains of professional musicians, while in beginners the right hemispheres show more activity. But that does not make the professionals “left-brained” and the learners “right-brained.” For most people, the part of the brain that shows activity depends on history and circumstance; people’s brains are more similar than different in these respects.

## Inefficient and Efficient Learning

Decades of good research demonstrate that, judged by the criteria for robust learning, the *least effective* teaching methods are some of the ones most commonly practiced in schools, colleges, and universities: passive reading and passive listening to explanations and lectures (Middendorf and Kalish 1996). The culprit here is passivity; interrupting a lecture to insert a short peer-to-peer discussion or a

three-minute writing break causes learning to spike upward. (A simple device is to ask students to write—or better still, tell one another—the main point that the instructor has just made.) The attention span of someone passively listening is likely to be short—reportedly less than 15 minutes for a typical adult student. However, the usual length of a college lecture class is 50 to 90 minutes, a very inefficient use of student time and teacher energy.

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Three factors perpetuate this state of affairs: (1) most teachers teach as they were taught; (2) more likely than not, those who went on to become professors were relatively better than others at learning through passive methods when they were students; and (3) many instructors concentrate on *coverage* of the material over *retention* of the material—that is, teaching over learning. Moreover, despite study after study demonstrating the low effectiveness of lectures, modern technology is being used to deliver more lectures to more students in ever more remote locations. And despite what is known about the shortcomings of learning by passive reading, more and more students spend their learning time looking at not just books and articles, but at computer screens and PowerPoint slides.

Interestingly, a teaching technique at the far opposite end of the passive-active continuum, the much-touted method known as “discovery learning,” proves also to be relatively ineffective. According to its proponents, free exploration is supposed to result in higher-quality, longer-lasting results. But research has shown that although this technique can be motivating, it does not efficiently promote robust learning. More deliberate intervention by a teacher and more structuring of the environment or the lesson seems to be required for optimal learning (Dean and Kuhn 2007).

What then does the research tell us about the most efficient and effective teaching and learning? These are the conditions that have thus far proven to be best for ensuring that *robust* learning takes place:

- *Enlist the brain’s motivational and reward systems; compete effectively with other rewards.* Extrinsic rewards such as prizes and bribes may actually work to some degree, but most effective is to make the

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learning environment and the lessons themselves intrinsically rewarding—interesting, exciting, socially engaging, even entertaining—as well as productive of confidence, self-worth, and pride in self-education. Difficult as it may be to accomplish, the rewards of educational activity should compete effectively with Facebook, video games, and other rewarding and omnipresent distractions.

- *Provide plenty of social interaction.* In classic studies, researchers at the University of Washington demonstrated that babies easily learn language from human instructors, but they learn little or nothing if those same lessons are delivered via audio or video technologies, despite the fact that the children find them attractive (Kuhl 2007, 2011). This and other research at the LIFE Center reveals the potent role played by social interaction for learners of all ages in many contexts—but what counts as “social” may differ at different ages. Thus, while babies seem to learn little or nothing from video, learning in older children is enhanced by interactive electronic games and social communication with computer avatars (especially “teachable agents”—avatars taught by the human learner) in virtual environments such as Second Life (Chin et al. 2010; Segedy, Kinnebrew, and Biswas 2012). At this time, it is not clear to scientists whether the contribution to learning from social interaction is at its heart a case of motivation and reward—the pleasure of being social—or whether something else is operating. Experiments with “social robots,” in which elements of social interaction are systematically manipulated (human appearance, gaze following, emotional mirroring, timing of responses, etc.), may reveal exactly which features of a social situation best promote learning (Meltzoff et al. 2009).
- *Use multimodal forms of input.* If you studied a foreign language in high school and have not used it since, how much do you remember as an adult? For many people the answer is that they remember the songs. This is an example of multimodal learning: the cognitive content is linked to a melody, enlisting more than one part of the brain and ideally including the pleasure-loving hippocampus, central to motivation. The neural systems reinforce one another, contributing to learning. It is not just that melody may serve memory as a mnemonic device. Laboratory experiments have shown that if

music is played during learning, then that same music can improve performance during recall—and it does not have to be Mozart; the music that you like best works best. And not only music but other kinds of input modalities—for example, odors—may work in the same way, triggering recall.

- *Manage sleep to consolidate memory.* Laboratory trials prove that sleep is a learning aid. In simple experiments, sleeping for a full night or even napping between a lesson and a recall test has a positive effect on memory. Although the precise roles of sleep and dreaming in learning are not well understood, empirical studies are unanimous in showing that adequate sleep seems to consolidate memories of all kinds, a powerful effect. And different kinds of learning seem to be reinforced by different phases of sleep: factual knowledge by some phases, kinesthetic learning by others.
- *Manage the timing of practice and reinforcement.* Other things being equal, does it matter when a learner receives hints or other assistance while working out a problem? Yes, it does—help given too soon is ineffective, as is help given too late; this is called the assistance dilemma (Koedinger and Alevan 2007). Learning performance plotted against the timing of assistance turns out to produce an inverted U-shaped curve. For each task—perhaps for each task for each person—there appears to be a sweet spot, a time when assistance does the most good in enhancing robust learning. Similarly, the timing of reinforcement or review relates directly to the length of recall: the farther apart reinforcement sessions are spaced, the longer the learning lasts.
- *Ensure engagement—active learning.* The phrase “active learning” has become a kind of shibboleth for educational reformers, and indeed the research support is strong for many variants of it. Because the research has been so uniformly positive, it may by now be safe to generalize: actively engaging learners promotes all kinds of learning. The documented benefits of small classes may well be attributable to increased opportunity for interaction. (But small classes are no guarantee of engagement: When I was dean at Kenyon College, a certain professor had to be informed that only one student had signed up for his class, and hence he could not use his accustomed classroom but would be expected to teach the student

in his office. He reluctantly agreed to the arrangement, adding, “But I will require a lecturer!”) Small classes are of course expensive, as is equipment (“clickers,” intelligent digital devices, swivel chairs) or special architecture (breakout rooms) that fosters interaction, but research demonstrates that simple and less expensive techniques can also work—even for learners in large groups. Each of the following techniques is likely to be more effective than passive learning, and using a variety of such methods alternately or in combination is likely to be most effective of all:

- ◆ short writing breaks during lectures, labs, or other activities
- ◆ peer explanation and self-explanation (requiring all learners to repeat what they have learned in their own words)
- ◆ problem solving—especially using worked examples or specimen solutions
- ◆ discussion or problem solving with others in teams or pairs (“buddy system”)
- ◆ “guided inquiry”—structured lesson delivery in which the material to be learned is divided into graduated increments and presented by means of carefully designed problems to be solved collectively by small groups of students<sup>2</sup>

A kind of useful synthesis of much of this research, confirmed primarily in the context of STEM (science, technology, engineering, and mathematics) learning in high schools and colleges but likely to be applicable in many settings, is that

*expert explanation* is less effective than *peer explanation*, which is less effective than *self-explanation*, which is less effective than *teaching another*, whether that other is a fellow learner or a computer-generated avatar!

When I present these findings as a workshop, I try to ensure that the recommended learning techniques are *demonstrated* as well as *described*. For example, to engage audiences in ways that best promote memory, participants are asked to write down everything they hear that seems new, debatable, surprising, or likely to be especially useful in their own practice. They are then paired up and during specific points of the presentation are asked to discuss these notes with their partners. At the conclusion of the workshop, they are invited to list and share the items they most want to remember—and research tells us that these

simple active learning techniques ensure that these will indeed be the things they are most likely to remember.

Such techniques could work not only in classrooms, but also in everyday learning contexts. For example, health

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practitioners might ask patients to repeat instructions back to them, or better still, to explain them to another patient—or best of all, to explain them to a long-term peer partner with whom they can periodically review new understandings and health habits. An exciting use of technology to reinforce this sort of learning would involve enrolling a patient struggling to manage a chronic illness in a virtual world where an avatar under the patient’s control would need, for example, to change its behavior to lose weight or manage diabetes.

## Translation of Research to Educational Practice

This article began with the premise that enough is already known about effective learning to drive reform efforts; indeed, this has been true for at least three decades. Too few of the advances in knowledge brought about by exciting new research are finding their way into classrooms and homes. In fact, it sometimes seems that the more we know, the wider the chasm between research and reform. As expensive as it is to support research in learning, the dissemination of this knowledge, and especially its implementation, is far more expensive. Yet if we know what helps children and adults learn more efficiently and effectively, what helps them to improve themselves, their communities, and the country, then isn’t that investment justified? Ignaz Semmelweis, a 19th-century Hungarian obstetrician, discovered empirically that by washing his hands between patients, he could sharply cut the number of deaths from childbed fever (Wikipedia 2012). But he could not persuade his colleagues to wash their hands, condemning many women to die of preventable illness. We too know quite a lot about what works in education, but we are like Semmelweis: we seem unable to convince our colleagues in education to wash their hands. Every child who does not learn to read, every college student

who drops out, every patient who misunderstands or forgets a doctor's orders, adds to the national tragedy of preventable ignorance. 📖

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## Notes

1. The NSF Science of Learning Centers:
  - CELEST (Center of Excellence for Learning in Education, Science, and Technology) at Boston University; lead partners Massachusetts Institute of Technology and Brandeis University; pursuing interconnected computational modeling and experimental research in cognitive neuroscience (<http://celest.bu.edu>).
  - LIFE (Center for Learning in Informal and Formal Environments) at the University of Washington, Seattle; lead partners Stanford University and SRI International; focusing on discovering the role of social factors in learning throughout the life span ([www.LIFE-SLC.org](http://www.LIFE-SLC.org)).
  - PSLC (Pittsburgh Science of Learning Center) at Carnegie Mellon University; lead partners University of Pittsburgh and Carnegie Learning; conducting in vivo classroom research using intelligent tutors to collect minute-by-minute data on student learning behavior to discover the conditions that lead to "robust" learning ([www.learnlab.org](http://www.learnlab.org)).
  - SILC (Spatial Intelligence and Learning Center) at Temple University; lead partners Northwestern University and University of Chicago; exploring the nature of spatial cognition and its importance to learning in the STEM (science, technology, engineering, and mathematics) disciplines (<http://spatiallearning.org>).
  - TDLC (Temporal Dynamics of Learning Center) at the University of California, San Diego; lead partners Brown, Rutgers, Vanderbilt, and other universities; elucidating the role of time and timing in learning at multiple levels from brain function to the classroom (<http://TDLC.ucsd.edu>).
  - VL2 (Visual Language and Visual Learning Center) at Gallaudet University in Washington, DC; lead partners Georgetown University, Rochester Institute of Technology, and Universities of California, Davis, Illinois, and New Mexico; researching how language and literacy are learned visually, particularly by deaf learners (<http://VL2.gallaudet.edu>).
2. For well-validated models in undergraduate chemistry, see Process Oriented Guided Inquiry Learning (POGIL) at <http://pogil.org>.

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## Further Readings

These readings are offered to demonstrate the range of research and instructional materials available in support of active learning pedagogies. Together they form a core resource library for the educational innovator.

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