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SYMPOSIUM

The Science of Learning: Breaking News

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Abstract

We begin with a paradox. On 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 effort and investment are needed to answer even the most basic questions. On the other hand, *more than enough* is already known about what best promotes learning to motivate and drive educational reform for years to come. This is a report from the front lines of both research and educational implementation. This information should prove of use to anyone—teachers, students, parents, patients, and health practitioners—who is concerned about how best to improve formal or informal teaching and learning, to help people remember complex instructions, or to change unhealthy habits and practices.

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National Science Foundation Decides to Weigh In

Soon after the turn of the 21st century, the National Science Foundation decided to make the type of major investment in the science of learning that had hitherto been reserved mostly for the traditional natural sciences. The funding mechanism would be through cooperative agreements with newly created interdisciplinary, multi-university centers, each receiving awards of up to $5 million per year for a maximum period of 10 years. During the 2-year period of 2004–2006, the six centers currently in operation were launched, although in most cases, the funding has not reached the levels anticipated in the initial solicitations. Nonetheless, the six centers have matured into influential and sophisticated collaborations, generating important science. These are the six centers, their lead partners, and their Web sites (where links and references to the latest research findings and publications may be found):

- CELEST (A Center of Excellence for Learning Education, Science, and Technology) at Boston University; lead partners, Massachusetts Institute of Technology and Brandeis; pursuing interconnected computational modeling and experimental research in cognitive neuroscience; http://celest.bu.edu.
- LIFE (Learning in Informal and Formal Environments) at the University of Washington; lead partners, Stanford University and SRI International; focused on discovering the role of social factors in learning throughout the lifespan; http://www.LIFE-SLC.org.

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- PSLC (Pittsburgh Science of Learning Center) at Carnegie Mellon University; lead partners, University of Pittsburgh and Carnegie Learning; *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; 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) at Gallaudet University; lead partners, Georgetown, Rochester Institute of Technology, and the University of California (Davis), the University of Illinois, and the University of New Mexico; researching how language and literacy are learned visually, particularly by the deaf; http://VL2.gallaudet.edu.

Robust Learning

The Pittsburgh Science of Learning Center has 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.[1] They characterize such learning as "robust" and measure the degree of robustness along three dimensions: (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.

Each of these criteria lends itself to different techniques for assessment. For example, how long is "long-term"? Though such considerations might not be practical in all learning contexts, 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 that? Does that schedule—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.[2,3] 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.

Defining robust learning in this multidimensional 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. Robust learning is defined to include such sophisticated skills as the ability to build further knowledge on one's own and the transfer of 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. Thanks to 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 directed toward a variety of learners are required if all students are to learn. Variety is actually a good idea because it reinforces learning for everyone, but this is not because of differences in learning style. Research has shown that such differences in preference or aptitude exist, but are very small—more than zero, but not enough to take into account—by comparison with the techniques that we know increase robust learning by much larger amounts for everyone.[4]

This notion of learning styles is easily confused with another popular idea, proposed by Gardner and Hatch[5] that people have "multiple intelligences," that is, 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). These could be correlated with learning styles but are conceptually different. In one case, it is about how one learns best, and in the other, it is about where one's talents lie. If the theory of multiple intelligences is correct, one might have to consider teaching to each intelligence in a different way for each learner. Fortunately, this degree of individualization is not at all necessary.

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 people, according to some of those who label themselves so). But except for those with grievous brain trauma, in fact, everyone uses both sides of the brain, and the two sides are richly interconnected. True, there are differences between individuals, and these seem to be somewhat influenced by experience and training. For example, while playing or listening to music, the left brains of professional musicians seem to be more active than are those of beginners, but that does not make them "left-brained." For most people, the part of the brain that shows activity depends on the circumstance; people's brains are more similar than different in this respect.

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 colleges and universities: passive reading and passive listening to lectures.[6] The emphasis here is on passivity; inserting even a short discussion or a 3-minute writing break during a lecture on the same material causes learning to spike upward. The attention span of someone listening passively is likely to be short—reportedly about 15 minutes for a typical adult student. However, the usual length of a lecture class at this level is 50 to 90 minutes, a very inefficient use of student time and teacher energy. Three factors perpetuate this state of affairs: (1) most teachers teach as they were taught; (2) more likely than not, students who went on to become professors were relatively better than others at learning through passive methods; and (3) instructors value coverage of the material over retention of the material, that is, teaching over learning. Despite study after study demonstrating the ineffectiveness of lectures, modern technology is being used to deliver lectures to more students in ever more remote locations. Despite what is known about passive reading, more and more students spend their learning time looking at not just books and articles, but computer screens and PowerPoint slides.

Also proving to be inefficient is the much-touted teaching method known as "discovery learning," where free exploration is supposed to result in higher quality, longer-lasting results. Research has shown that, although this technique can be motivating, it is not effective in promoting robust learning. It seems that a more deliberate intervention is required of the instructor and the environment or that the lesson needs to be more structured if learning is to be optimized.[7]

What then does the research tell us about 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:

1. *Enlist the brain's motivational and reward systems, ensuring effective competition with other rewards.* Extrinsic rewards such as prizes and bribes may actually work, but most effective is to make the learning environment and the lessons themselves intrinsically rewarding—interesting, exciting, socially rewarding, even entertaining, as well as productive of confidence, self-worth, and self-education.

2. *Provide plenty of social interaction.* In classical 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.[8,9] Research at the Learning in Informal and Formal Environments 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 may not learn much from video presentations, learning in older children is enhanced by social video games and interactions with computer avatars (especially "teachable agents," i.e., avatars being taught by the human learner) in virtual environments such as *Second Life*.[10,11] At this point in time, it is not clear to scientists whether the contribution to learning from social interaction is, at its heart, a matter of motivation and reward or whether something else is operating. Experiments with "social robots" in which elements of social interaction are systematically manipulated (e.g., human appearance, gaze following, emotional mirroring, and timing of responses) may reveal exactly which elements of a social situation best promote learning.[12]

3. *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 they had learned. This is an example of multimodal learning: the cognitive content is linked to a melody, enlisting more than one part of the brain, ideally including the hippocampus, which is central to motivation. The neural systems reinforce one another, contributing to learning. It is not just that melody serves memory as a mnemonic device. Laboratory experiments have shown that, if music is played during learning, the same music can improve performance during recall, and odors seem to work in the same way in triggering recall.

4. *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 strongly positive effect on memory. Although the precise roles of sleep and dreaming in learning are not well understood, empirical studies are uniform in showing that regular and adequate sleep seems to consolidate memories of all kinds, a powerful effect. Different kinds of learning are reinforced by different phases of sleep—factual knowledge by some phases, kinesthetic learning by others.

5. *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".[13] Learning performance plotted against the timing of assistance turns out to produce a 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.

6. *Ensure engagement through active learning.* The term "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: engaging a learner actively promotes all kinds of learning. The well-known and documented benefits of small classes are probably 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. Clearly irritated, he replied, "But I will require a lectern.") Of course, small classes are expensive, as is equipment that fosters interaction ("clickers," linked laptops, swivel chairs) or special architecture (break-out rooms), but research demonstrates that simple and less expensive techniques are also effective—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 even more effective:

   - Short writing breaks during lectures, labs, or other activities.
   - "Self-explanation" requiring all learners to repeat what they have learned in their own words.
   - Discussion with classmates or actually teaching others in small groups or pairs ("buddy system").
   - Problem solving, especially using worked examples or specimen solutions.
   - "Guided inquiry" or very 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 interactively by small groups of students (for well-validated models in undergraduate chemistry see Process Oriented Guided Inquiry Learning at http://pogil.org).

Following is a useful synthesis of much of this research, confirmed primarily in the context of STEM (science, technology, engineering, and mathematics) learning in the formal environments of high schools and colleges but likely to be applicable to most learners in many settings:

> *Expert explanation* … is not as effective as
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> *Peer explanation* … which is not as effective as
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> *Self-explanation* … which is not as effective as
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> *Teaching another*, whether that other is a fellow student or a computer-generated avatar.

When I present these findings as a workshop, the learning techniques are *demonstrated* as well as *described*. For example, to engage audiences in the ways that best promote memory—according to the research described here—participants are paired up and asked to record everything they find new, surprising, or likely to be especially useful in their own practice. During specific points of the presentation, audience members exchange and review 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 likely to remember.

To take advantage of these research findings, health practitioners might ask patients to repeat instructions back to them or, better still, to explain them to another patient or, best of all, a long-term peer partner with whom to review new understandings and health habits periodically. An exciting use of technology to reinforce learning would be to enroll patients in *Second Life* or another virtual world where an avatar under the control of a patient would need, for example, to lose weight or manage diabetes.

Translation of Research to Educational Practice

This essay began with the premise that enough is already known about effective learning to drive reform efforts; indeed, this has been true since, at least, 1980. Too few of the advances in knowledge brought about by the exciting new research being done at the six Science of Learning Centers 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. Expensive as it is to support research in the Science of Learning, 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 to improve themselves, their communities, and the country, then isn't that investment justifiable? Ignaz Semmelweis, a 19th century obstetrician, discovered empirically that, by washing his hands between patients, he could cut down sharply the number of deaths from childbed fever (see, for example, Wikipedia, http://en.wikipedia.org/wiki/Ignaz_Semmelweis), but he could not persuade his colleagues to wash their hands, condemning many women to die of preventable illness. We are like Semmelweis; we seem unable to convince our colleagues in the classroom 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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