Random Thoughts . . .

WHY STUDENTS FAIL TESTS
2. INEFFECTIVE TEACHING

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In our last column,[1] we reviewed the most common—and ineffective—ways students study for problem-solving tests (rereading their textbooks and glancing over old problem solutions), outlined better study strategies based on cognitive science, and proposed teaching strategies that facilitate students' use of those study strategies. In this column, we outline several more insights into the learning process from cognitive science[2–4] and suggest additional teaching strategies based on the insights. The study and teaching strategies recommended in both columns are summarized at the end.

The rate at which people can absorb new information is severely limited

Most of the signals that reach our eyes, ears, tongues, noses, and skin are filtered out by our brains without our ever being consciously aware of them. Any signals that manage to get past that initial screening go to working memory, where conscious information processing occurs. Working memory can only hold about four chunks of information at any time. An executive control center in the brain scans long-term memory for material relevant to each new chunk that enters working memory, rapidly judges the relative importance of that chunk and the chunks that entered previously, and deletes the least important chunk or chunks to keep the contents of working memory at or below capacity. If the information in a chunk is consciously rehearsed (repeated), the chunk stays in working memory longer and has a better chance of being stored in long-term memory. When storage takes place, the chunk is integrated into long-term memory as a memory trace—a distributed network of neurons with links to other stored traces that the executive considers relevant. When the chunk is first stored, the links are weak and retrieval of the trace back into working memory can be difficult. Each subsequent retrieval strengthens the links, adding to the cues that can trigger retrieval and making future retrievals easier.[2]

Keeping all that in mind, think about what goes on in a traditional lecture. When you give one, you are fire-hosing your students with a torrent of words and projected images—and that's just the information *you* are presenting. The students are simultaneously bombarded with other sensory signals coming from their surroundings and from inside their bodies, plus random thoughts and images that pop up from their subconscious minds. They can focus their conscious attention on only a tiny fraction of that tsunami of information and can store an even tinier fraction in their long-term memories. Even if you are an award-winning lecturer, the chances are that most of what you are trying to convey will not be on the storage list—and if you're a mediocre lecturer or even an

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average one, you can guess the outcome. Little wonder that traditional lecturing has been shown by extensive research to be a supremely ineffective way to teach.[5]

The alternative is *active learning*.[6] Periodically stop your lecture and give the students things to do, working individually or in small groups, related to the most important points in the material you just presented. You might ask them to explain a term or concept in their own words, carry out a brief calculation, start a problem solution or explain a step in a worked-out solution, predict the outcome of an experiment, and so on—the possibilities are endless. The rehearsal and retrieval practice provided by an activity dramatically increase the likelihood that students will leave that class session with the content of the activity stored in their long-term memories.

Not all information chunks are created equal

When the executive center in the brain determines the importance of a chunk of information in working memory, it applies three criteria: *relevance* (of the new material to previously stored and retrievable information), *meaning* (comprehensibility of the information to the student), and *emotional associations* (that the information may have for the student). The greater the extent to which these criteria are satisfied, the more likely the chunk is to be stored in long-term memory.[2]

The implication for teaching is that when you introduce a complex theoretical or experimental method new to the students, try to make connections between it and things the students are likely to know and care about, and give examples of important problems the method may be used to solve. Also, consider presenting a problem for which previously taught methods don't work and let the students spend a short time trying to solve it to establish the need for the new method. People learn material best when they clearly perceive a need to know it.

Confronting students with a problem before teaching them how to solve it may sound counterintuitive, but it is in fact a powerful instructional approach known as *generative learning*[1,3] or *inductive teaching*.[7] Instead of beginning a course topic with a theory or set of equations and deriving your way to applications and problem solutions, begin by posing an interesting challenge—a question to be answered, a problem to be solved, or a physical observation or a set of experimental data to be interpreted. Then direct the students—generally working in active learning groups—to figure out what they know, what they need to find out, and how to begin, and thereafter teach the course content in the need-to-know context of addressing the challenge. Inductive teaching methods include guided inquiry, problem-based learning, project-based learning, and just-in-time teaching.

When you use an inductive method, the students may initially be frustrated in their efforts to find something in their long-term memories that helps them meet the challenge, but their struggle is a desirable difficulty.[3] Even if they are unsuccessful, when they subsequently see the solution they tend to process it more intensively and gain a deeper understanding of it than they normally ever would without the struggle. The effectiveness of inductive methods at promoting a wide variety of learning outcomes has been repeatedly demonstrated.[7]

Summing up

Ineffective teaching and ineffective studying can both lead to low grades on tests. Teaching strategies likely to promote deep learning and good academic performance include introducing new material in the context of students' prior knowledge, experiences, and interests; periodically cycling back to previously taught course content in class sessions, assignments, and exams (interleaving); providing spaced retrieval practice through self-tests and low-stakes quizzes in class sessions and online lessons; using active learning and inductive teaching; and encouraging students to incorporate into their studying self-testing, paraphrasing important concepts from readings, and solving old homework problems without looking back at the solutions. Cognitive science does not guarantee that those measures will equip all your students with the knowledge and skills you are trying to teach: how much they learn also depends on their intelligence, motivation, work ethic, and an uncountable number of other factors you have no control over. However, the measures will greatly increase the likelihood that the students capable of meeting your learning objectives will meet them, and that's all you can ask for.

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