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Thad A. Polk is an Arthur F. Thurnau Professor in the Department of Psychology at the University of Michigan. He received an interdisciplinary Ph.D. in Computer Science and Psychology from Carnegie Mellon University. Professor Polk’s teaching—on topics ranging from the human mind and brain to cognitive psychology—has been recognized with numerous awards, including being named one of The Princeton Review’s Best 300 Professors in the United States. He is also a frequent visiting scientist at the Max Planck Institute for Human Development in Berlin.
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Professor Polk’s research combines functional imaging of the human brain with computational modeling and behavioral methods to investigate the neural architecture underlying cognition. Some of his major projects have investigated changes in the brain as we age, contributions of nature versus nurture to neural organization, and differences in the brains of smokers who quit compared with those who do not. Professor Polk regularly collaborates with scientists at the University of Texas at Dallas and at the Max Planck Institute for Human Development in Berlin, where he is a frequent visiting scientist. At the University of Michigan, he is an associate chair of the Department of Psychology and the chair of the Health Sciences and Behavioral Sciences Institutional Review Boards.
Professor Polk regularly teaches large lecture courses as well as small seminars on topics ranging from the human mind and brain, to cognitive psychology, to computational modeling of cognition. His teaching at the University of Michigan has been recognized with numerous awards, including the Excellence in Education Award from the College of Literature, Science, and the Arts and the Arthur F. Thurnau Professorship, the university’s highest undergraduate teaching award. He was also featured in the University of Michigan’s Professors Reaching Out for Students (PROFS) lecture series and was named to The Princeton Review’s list of the Best 300 Professors in the United States.

Professor Polk’s other Great Courses are *The Aging Brain* and *The Addictive Brain.*
I’d like to express my heartfelt gratitude to Alyssa Skelton, who worked tirelessly on almost every aspect of this course with me. She identified potential topics to include, performed extensive literature reviews, provided detailed feedback and suggestions on drafts of the lectures, and proposed potential graphics to use throughout the course. The course is significantly better than it would have been without her many significant contributions. Thank you so much, Alyssa!

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# Table of Contents

## Introduction

Professor Biography .................................................. i
Acknowledgements ..................................................... iii
Course Scope ........................................................... 1

## Guides

1  Learning 101 ......................................................... 4  
2  What Amnesia Teaches Us about Learning .................. 11  
3  Conscious, Explicit Learning .................................... 20  
4  Episodic Memory and Eyewitness Testimony ............... 30  
5  Semantic Memory .................................................. 41  
6  The Neural Basis of Explicit Learning ......................... 50  
7  Strategies for Effective Explicit Learning ................. 60  
8  Controversies in Explicit Learning Research ............. 70  
9  Unconscious, Implicit Learning ................................. 80  
10 The Psychology of Skill Learning ............................... 91  
11 Language Acquisition ............................................ 100  
12 The Neural Basis of Implicit Learning ....................... 109
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>Strategies for Effective Skill Learning</td>
<td>120</td>
</tr>
<tr>
<td>14</td>
<td>Learning Bad Habits: Addiction</td>
<td>130</td>
</tr>
<tr>
<td>15</td>
<td>Introduction to Working Memory</td>
<td>140</td>
</tr>
<tr>
<td>16</td>
<td>Components of Working Memory</td>
<td>149</td>
</tr>
<tr>
<td>17</td>
<td>The Neural Basis of Working Memory</td>
<td>159</td>
</tr>
<tr>
<td>18</td>
<td>Training Your Working Memory</td>
<td>169</td>
</tr>
<tr>
<td>19</td>
<td>How Motivation Affects Learning</td>
<td>178</td>
</tr>
<tr>
<td>20</td>
<td>How Stress and Emotion Affect Learning</td>
<td>188</td>
</tr>
<tr>
<td>21</td>
<td>How Sleep Affects Learning</td>
<td>199</td>
</tr>
<tr>
<td>22</td>
<td>How Aging Affects Learning</td>
<td>210</td>
</tr>
<tr>
<td>23</td>
<td>Dyslexia and Other Learning Disabilities</td>
<td>220</td>
</tr>
<tr>
<td>24</td>
<td>Optimizing Your Learning</td>
<td>231</td>
</tr>
</tbody>
</table>

**Supplementary Material**

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bibliography</td>
<td>241</td>
</tr>
<tr>
<td></td>
<td>Image Credits</td>
<td>249</td>
</tr>
</tbody>
</table>
The Learning Brain

One of our most important assets as human beings is our ability to learn and adapt. As babies, we learn to crawl, stand, and eventually walk. As toddlers, we learn to speak and understand our native language. As we get older, we learn how to read and write; we learn about history and literature, and about science and engineering. We’re also constantly acquiring new skills, such as playing a sport or mastering a musical instrument.

But how? This course will explore what’s going on in our minds that allows us to learn so effortlessly and in so many ways. The course will examine not only the psychological mechanisms, but also the neural mechanisms, that are involved. You will discover that your brain is equipped with multiple, powerful, but very different learning mechanisms that depend on specific neural circuits and that understanding how learning works can make you a more effective learner.

The course begins by explaining what psychologists mean by learning and how it relates to memory. It also outlines some of the major themes in the science of learning that you will encounter in the course.

Then comes a detailed examination of explicit learning, which refers to learning verbalizable, conscious information, such as the knowledge you acquire in school and information about the personal episodes that you experience every day. You will examine amnesia, which dramatically impairs explicit learning and has taught us a great deal about how normal learning and memory work. You will discover that your memory for personal episodes tends to focus on the gist, or the big picture, and often overlooks, or even misrepresents, many of the details. Rather than thinking of your memory as an accurate video of what happened, it’s probably better to think of it as a plausible, but
somewhat unreliable, reconstruction of what *might* have happened. Unfortunately, we usually can’t tell the difference between reality and our reconstructions.

Next, the course will take you inside the skull to examine what’s going on in your brain when you’re learning explicit information. You will discover that one brain area, called the hippocampus, plays a particularly important role, but that the information you learn tends to get consolidated into other brain regions and therefore depends less and less on the hippocampus as time goes by.

The course then changes gears to explore the fascinating world of unconscious, implicit learning. You will discover that your brain does at least as much learning behind the scenes as it does in your conscious awareness. You will examine the fundamental mechanisms of classical and operant conditioning that underlie your ability to learn associations between stimuli in your environment and between rewards and the behaviors that lead to those rewards. You will also discover how people learn the amazing skills that they perform so effortlessly, such as how athletes learn to play their sport and how musicians learn to play their instrument. An entire lecture is devoted to exploring how children learn their native language, which may be the most amazing learning accomplishment of all. You will also explore cutting-edge neuroscience research that is beginning to shed light on how this kind of learning works at a cellular level.

Next, the course turns to working memory and explores the critical role it plays in all complex thought. You will learn about leading theories of how working memory works, at both a psychological and a neural level. You will also explore recent research examining whether it’s possible to expand working memory and perhaps even increase intelligence.
The final section of the course will dive into some of the key factors that influence learning and memory. You will discover that motivation is at least as important as ability and that how you feel can have a dramatic impact on what you learn. You will examine the fascinating and crucial role that sleep plays in learning and explore how learning changes as you age—as well as how it doesn’t. You will also discover what’s going on when learning disabilities such as dyslexia rear their head.

Throughout, the course will repeatedly identify specific ways that you can apply what you’re learning to become a more effective learner in your daily life. For example, you will discover study strategies that are scientifically proven to improve learning and memory as well as practice strategies that have been proven to help people learn skills more effectively.

By the end, you will have a new understanding about how learning works, how it is implemented in the brain, and how you can be a more effective learner. ☑️
LEARNING IS CRUCIAL TO OUR LIVES AS HUMAN BEINGS. OUR ABILITY TO LEARN AND adapt is one of our most important and powerful assets. The goal of this course is to help you understand how the truly amazing learning mechanisms in your brain work so that you can get the most out of them in whatever kind of learning you’re doing in your life. In this lecture, you will explore what learning is and why it is so crucial to us as human beings. You will also learn about how the scientific study of learning got started as well as some of the key themes that will be addressed in the course.
Defining Learning and Memory

• One fairly intuitive definition of learning is that it is changing your behavior in response to previous experience. That’s not a bad definition, but there are a few important points to keep in mind that might lead us to refine it a little.

• First, there are situations in which you learn something but there is no opportunity to show it in your behavior. For example, suppose that you learn some interesting but obscure fact about Berlin, such as that a former airport there has been turned into a park. You may have learned that fact and stored it in your memory, but it’s quite possible that it will never influence your subsequent behavior, unless you happen to visit Berlin or have a conversation about its former airport.

The reason human beings can live and thrive in an incredible range of different environments is because we can learn. More than any other species on the planet, we can adapt and change our behavior to better fit the needs of our environment.
• In other words, not everything you know is reflected in a change in behavior, but that doesn’t mean you didn’t learn it.

• Let’s revise our definition and say that learning is acquiring knowledge from experience. Now, that new knowledge could affect your behavior. For example, if someone asked you if you knew that a former airport in Berlin had been turned into a park, then your answer would be different after learning that fact. But learning doesn’t always have to be reflected in your behavior.

• But here is still at least one problem with our new definition. When people think of knowledge, they typically think of information that is consciously available and verbalizable, such as the fact that birds have wings. We obviously do learn that kind of information, but we also learn a lot of behavioral responses that are not consciously available.

• For example, if we sit in a room where a fan is blowing, we typically get habituated to the sound of the fan and learn to ignore it. That kind of learning has been studied extensively in lower organisms, and although you could call it a kind of knowledge, doing so seems a little strange.

• So, let’s define learning as acquiring knowledge or behavioral responses from experience. The “from experience” part is also crucial. Learning might come from studying, or from being taught, or just from living life, but it has to come from experience. Behavioral responses that are genetically programmed, such as instincts and reflexes, don’t count as being learned.

• Psychologists typically consider memory to be the result or product of learning. It is the record of learning that is stored in your mind. Learning involves making physical changes in the brain that allow information to be retrieved later on. And those changes constitute the physical basis of memory.
The Scientific Study of Learning

• For most of human history, the study of learning was restricted to philosophy. And even after the power of the scientific method became clear in fields like chemistry and physics, it still wasn’t applied to study the human mind for quite some time.

• In fact, up until the late 19\(^{th}\) century, most scientists and philosophers probably didn’t think that learning could be studied scientifically. Mental processes like learning and memory were seen as fundamentally different than the natural phenomena of chemistry and physics.

• But that all changed in 1885, when Hermann Ebbinghaus published his famous book Über das Gedächtnis, which means “about memory” in English. Like all psychologists at the time, Ebbinghaus was trained as a philosopher. But inspired by scientific studies of human perception that had recently been published, he decided to try applying scientific methods to study human learning and memory. His work ultimately revolutionized the field and helped establish psychology as a legitimate scientific field in its own right.

• Ebbinghaus used only a single human participant in his experiments—himself. He wanted to study learning in a way that wasn’t contaminated too much by what he already knew, so he decided to try to learn lists of meaningless syllables. He studied a list until he could repeat it back twice in a row without any errors.

• Ebbinghaus plotted his performance as a function of the delay and produced what are now called forgetting curves. His performance got worse with longer delays. But the drop-off wasn’t continuous.

Scientific advances have radically changed our environment and require us to constantly learn about new technologies.
In fact, he found that most of the forgetting happened during the first hour or 2. Performance after a day wasn’t much worse than performance after an hour, and performance after 2 days wasn’t much worse than performance after 1 day.

* Ebbinghaus also studied how much he learned as a function of each repetition. And like the forgetting curve, he found that the first repetition led to the most learning, the second repetition to a little less, and so on.

* Ebbinghaus’s findings have been confirmed in countless experiments since then. But by far his biggest contribution was to demonstrate that human learning and memory could be studied scientifically in a way that other scientists could replicate and extend. And the repercussions of that contribution are still being felt to this day.
• This course will explore those repercussions in depth. In particular, you will repeatedly discover how the scientific study of learning has made major advances in at least 3 major directions: It has dramatically improved our ability to help people learn more effectively, whether in the classroom or in real life; has led to much better theories of the cognitive mechanisms involved in learning; and is beginning to shed light on the neural mechanisms that underlie learning.

1 Learning scientists have recently discovered that there is a lot we can do to make our learning more effective—not only in the classroom, but also in our daily lives. There are also ways to optimize our learning so that we increase how much we learn.

2 Many people think of learning as a single, unitary process, but nothing could be further from the truth. In the past few decades, cognitive psychologists have discovered that human beings are equipped with a variety of very different mechanisms that are tailored for learning different kinds of information. Specifically, short-term working memory is very different from long-term memory. In fact, psychologists have discovered that we even use different mechanisms for storing different kinds of information within working memory and long-term memory.

Our capacity to learn has never been more important than it is today. A few hundred years ago, most people could do just fine without much formal education. But today’s workforce requires people to learn new skills all the time.

For example, the US Bureau of Labor Statistics reported that people born between 1957 and 1964 held an average of 12 different jobs before the age of 50, and more than half of those jobs were held after the age of 25.
There are physical changes in our brain when we learn a new piece of information. Our extraordinary ability to learn depends largely on making millions of very small changes in the strength of brain connections. Different types of learning that have been hypothesized to depend on different psychological mechanisms have been found to depend on different parts of the brain.

### Suggested Reading

Anderson, *Learning and Memory.*


Schacter, *Searching for Memory.*

### Questions to Consider

1. Many simple organisms (e.g., cockroaches and earthworms) thrive without doing nearly as much learning as humans do. What do you think allows them to do so?

2. Why do you think it was difficult for early scientists to recognize that human learning could be studied scientifically?
This lecture tells the story of a man who may have taught us more about learning and its neural substrates than anyone in history: Henry Molaison. He wasn’t a famous psychologist or neuroscientist, but a neurological patient who suffered from profound amnesia. Studies of Henry—or patient HM, as he’s known in the scientific literature—have radically changed our understanding of how learning works and how it’s implemented in the brain. In this lecture, you will discover what those studies have taught us about the learning brain.
Explicit learning is very different from implicit learning. Likewise, storing information in long-term memory depends on different cognitive and neural mechanisms than does storing information in working memory.

These facts have important implications for us if we want to optimize our learning. In particular, we shouldn’t expect strategies that optimize explicit learning to be effective when learning implicit information.

For example, strategies that are very effective when learning US history might not be the best strategies to use when learning to play golf.

If we want to optimize our learning, then we need to tailor our learning strategies depending on the kind of information that we’re trying to learn.

A Case of Amnesia

* Henry Molaison was born in 1926 and grew up near Hartford, Connecticut. When he was around 7 years old, he was run over by a bicycle, hit his head, and was unconscious for a few minutes. Later, he started experiencing epileptic seizures. At first, the seizures were manageable, but they grew worse over time.

* By the time Henry was 27, he was having about 10 seizures a day, and large doses of anticonvulsant medication weren’t helping. He was therefore desperate to find an alternative treatment. That’s when a renowned neurosurgeon named William Scoville suggested surgery, which can often be an effective way to treat epilepsy when medications don’t work.
• Doctors put electrodes on Henry’s scalp, recorded his brain waves, and waited for a seizure in the hopes that they would be able to isolate the source. They found some brain wave abnormalities in the temporal lobes during one of his seizures and decided to perform an experimental surgery and remove some parts of his temporal lobes.

• The hope was that the surgery would help control Henry’s seizures, and it did. After the surgery, he only had about 5 minor seizures a month. Unfortunately, he also suffered a very serious side effect: He became profoundly amnesiac. As a result, that surgery has never been performed again.

• Henry still remembered who he was and where he grew up. He remembered his family and his childhood friends. He also remembered many specific events from his childhood, including the bicycle accident that may have led to his seizures.

When many people think of amnesia, they imagine a person who no longer remembers their family and friends, or even who they are and where they grew up. But that’s not the way it is for the vast majority of people who have developed amnesia as a result of brain damage.
• But Henry did have trouble remembering events that occurred right before the surgery. In fact, he remembered almost no events from the 2 years preceding the surgery, and his memory for the 9 years before that was also impaired. This kind of memory impairment is typically called retrograde amnesia. The term “retrograde” refers to when the forgotten events occurred. In retrograde amnesia, the forgotten events occurred before the brain damage.

• Henry’s retrograde amnesia exhibited a temporal gradient; that is, his older childhood memories were intact, but later memories from the years immediately preceding his surgery were impaired. This pattern, sometimes called Ribot’s law (after the French psychologist Théodule-Armand Ribot), is very common in amnesia.

• But Henry’s most significant deficit wasn’t in remembering; it was actually in learning. After his surgery, Henry’s ability to learn new information was catastrophically impaired, even if that information was encountered over and over again on an almost daily basis.

• This kind of impairment in learning new information and laying down new memories is often called anterograde amnesia, in which the forgotten events occurred after the brain injury. Henry’s anterograde amnesia included difficulty learning traumatic information. Even though people typically have stronger, more vivid memories for traumatic, stressful events than for more mundane events, Henry’s memories for traumatic events were dramatically impaired.

Most patients with amnesia have both a temporally graded retrograde amnesia and an anterograde amnesia.
Types of Learning and Memory
Preserved in Amnesia

- Many other aspects of learning and memory were preserved in Henry. And it was the specific pattern of spared versus impaired functions that taught scientists the most about human learning.

- One of the first discoveries was made by Brenda Milner, who did most of the early research on Henry. She asked him to trace drawings while looking at a mirror rather than directly at the paper itself. Left and right were reversed, and so were up and down.

- This task is difficult, and at first, Henry was bad at it. But after practicing the task repeatedly for 3 days, he could trace the figure quickly and accurately. Henry’s performance was changing as a result of his experience—in other words, he was learning.

- When Milner returned for the second and third day of training, Henry didn’t remember having ever done the task before. He was much better at it than he was the previous day, but his learning was all unconscious. Apparently, learning a motor skill is fundamentally different than learning a person’s name or other conscious facts.

- And it’s not just motor skill learning that is preserved in amnesia. For example, in 1980, Neal Cohen and Larry Squire investigated the ability of amnesiacs to learn a perceptual skill in which they had to learn to recognize unfamiliar visual stimuli. Specifically, they asked them to read mirror-reversed text as fast as they could. As in Milner’s study, the participants practiced the skill for 3 straight days. A group of nonamnesiac control subjects practiced the same task.
• The amnesiacs improved at reading mirror-reversed text the more they practiced. In fact, they learned just as quickly as the normal control subjects did. Furthermore, they were still good at it 3 months later. So, not only did the amnesiacs learn to perform this skill, but they also had retained this newly acquired ability. And like HM, the amnesiacs in this study learned this perceptual skill even though they didn’t consciously remember having done the task before.

• Inspired by these early findings, several scientists looked for and found other types of learning and memory that were preserved in amnesia, including priming, which occurs when previous exposure to a stimulus facilitates your processing of similar stimuli in the future.

• For example, suppose that you’re reading a magazine and see a picture of a celebrity that you know, but it takes you a minute to recognize the person. If you see a picture of the same celebrity a few minutes later, you’ll probably recognize them faster than you did the first time. Previous exposure to the celebrity’s picture primes you and makes you a little faster to recognize that person the next time.

**Amnesiacs can learn perceptual and motor skills just like everyone else. Although they may not consciously remember ever having performed the tasks before, their performance continues to improve with additional practice. Another way of putting this is in terms of knowing how versus knowing that. Amnesiacs can learn how to perform a skill, even when they don’t know that they’ve ever practiced it before.**
• Priming is another type of unconscious learning. A study by Carolyn Cave and Larry Squire found that amnesiacs exhibit normal priming effects that last at least a week, even though their conscious memory is dramatically impaired.

• In 1995, John Gabrieli, along with a number of his colleagues, investigated whether amnesiacs exhibit intact classical conditioning, or Pavlovian conditioning, after Ivan Pavlov. In experiments with his dogs, Pavlov measured how much they salivated. They salivated a lot when Pavlov got their food out. But by accident, he noticed that they also started salivating as soon as he entered the room, even if he didn’t have any food with him.

• Pavlov hypothesized that the dogs had learned that they were likely to be fed soon after he came in, so they were anticipating the food even before it arrived. He began to investigate the phenomenon systematically and discovered that if he consistently paired the sound of a bell with the presentation of food, then pretty soon the dogs would learn an unconscious association between the bell and the food. In particular, they would salivate whenever they heard the bell, even if there wasn’t any food.

• Classical conditioning is another type of learning. It’s another example of behavior being changed as a result of previous experience. And just like skill learning and priming, classical conditioning is preserved in amnesia.

• Together, these results radically changed our understanding of learning and how it’s implemented in the brain. At the most general level, they conclusively demonstrate that human beings use multiple different learning systems, depending on what they’re learning.
• In particular, learning unconscious information is fundamentally different than learning conscious information and even depends on different parts of the brain. After all, amnesia clearly shows that brain damage that dramatically impairs conscious memories can leave unconscious memories intact.

• Psychologists often refer to conscious memories as explicit and unconscious memories as implicit.

  ◦ Explicit memories, sometimes called declarative memories, are memories that you can consciously bring to mind and describe verbally. When most people think of learning and memory, they’re thinking of explicit learning and memory, such as remembering what you ate for lunch. These are the kinds of memories that amnesiacs have difficulty learning.

  ◦ Implicit memories are memories that you can’t consciously recall but that nevertheless influence your subsequent behavior. For example, your memory for how to ride a bike is an automatic, implicit memory. The same is true for priming and conditioning; amnesiacs typically don’t have trouble learning these kinds of implicit memories.

• Another aspect of learning and memory that was spared in Henry was working memory, which refers to the ability to store, rehearse, and manipulate information temporarily. For the purposes of this course, working memory will be considered synonymous with short-term memory. Working memory is a temporary memory system that we actively use to help us solve problems and achieve our goals.

• Henry’s working memory was very much intact, despite his profound deficit in storing explicit information into long-term memory. He could temporarily store information, rehearse it, and manipulate it in all the same ways that other people do. In fact,
his intelligence as measured by traditional IQ tests was in the normal range. He also performed normally on more formal tests of working memory.

SUGGESTED READING

Corkin, Permanent Present Tense.
Dittrich, “The Brain That Couldn’t Remember.”
Squire, “The Legacy of Patient HM for Neuroscience.”
Wearing, Forever Today.

QUESTIONS TO CONSIDER

1. Do you think conscious, explicit learning or unconscious, implicit learning is more important in our daily lives?

2. Why do you think we use different mechanisms to learn conscious, explicit information and unconscious, implicit information? Why would that division of labor be adaptive?
Learning explicit, conscious information is fundamentally different than learning unconscious, implicit information. And this fact has some important implications for optimizing our learning. In particular, strategies that are effective for explicit learning might not be effective for implicit learning, and vice versa. Therefore, this course will separately address explicit learning and implicit learning. The next few lectures—including this one—will be devoted to the psychology and neuroscience of explicit learning.
Learning about Explicit Learning

• In an experiment testing explicit learning, John Bransford and Jeffery Franks started with the following 4 relatively complicated sentences:

1. The ants in the kitchen ate the sweet jelly which was on the table.
2. The warm breeze blowing from the sea stirred the heavy evening air.
3. The rock which rolled down the mountain crushed the tiny hut at the edge of the woods.
4. The old man resting on the couch read the story in the newspaper.

• They then used these complicated sentences to make up simpler sentences that conveyed one or more of the key ideas from the original sentence. For example, from the first sentence, they created “The ants were in the kitchen” and “The jelly was on the table,” which conveyed some of the ideas from the original sentence but not all of them.

• They also varied how many ideas from the original sentence these simpler sentences conveyed. For example, the sentence “The jelly was on the table” basically conveys a single idea, while the sentence “The ants in the kitchen ate the jelly” conveys 2: that the ants were in the kitchen and that they ate the jelly.

• They presented 24 of these sentences to subjects and asked them to answer some questions about them. Then, they tested their memory about 5 minutes later. Once again, they presented sentences that conveyed ideas from the original sentences and varied how many ideas were included in each test sentence. Some
of these sentences really had been in the original list, but others had not. And the subjects were asked to give a rating indicating whether each sentence was from the original list or not.

• Subjects gave almost exactly the same ratings for new sentences as they did for old sentences. Essentially, they had no idea which sentences were new and which were old. This doesn’t mean that they didn’t learn anything, but what they learned was the ideas from the original sentences, not the exact wording.

• For example, when Bransford and Franks plotted the confidence ratings against the number of ideas that each test sentence conveyed, they found that the ratings increased systematically the more ideas were included. Subjects gave ratings close to 4 for test sentences that conveyed 4 ideas from the original sentences and tended to give negative ratings for test sentences that only conveyed a single idea. And that was true whether the test sentence was new or old.

• This experiment showed that we learn and store ideas, not verbatim information.

Visual versus Verbal Information

• Another characteristic of long-term explicit learning is that we remember visual information significantly better than verbal information. And we can exploit this fact to help us remember more information.

• One of the first studies in this area was conducted by Roger Shepard, who gave college students a deck of more than 500 index cards that each had a single word written on it and asked them to look through them all at their own pace in preparation for a
subsequent memory test. Another group of students got a deck of index cards containing sentences. A third group of subjects saw a series of a few hundred pictures.

- Next, all 3 groups were given a forced-choice recognition test, in which they were shown a bunch of stimulus pairs and one stimulus in each pair had been studied while the other had not. Then, the participants had to guess which stimulus they had studied.

- Shepard found that the participants remembered about 90% of the words and sentences that they had studied, which is pretty impressive in its own right. But he also found that their memory for the pictures was much better. Most of the participants remembered more than 98% of the pictures, and many of them didn’t make any errors.

Many people have the mistaken idea that we have some kind of automatic recorder in our heads that is constantly storing a detailed representation of whatever we pay attention to and that we can just rewind and play back the recording whenever we want to.

Instead, we’re constantly processing the information that we encounter and trying to pull out the key ideas—the gist of the information. And it’s that gist that gets stored into long-term memory, not the detailed, verbatim information.
He also tested their memory for the pictures after various delays. Even a week later, people remembered about 90% of the pictures. In other words, memory for pictures you saw a week ago is similar to memory for words and sentences that you saw just a few minutes ago. These findings suggest that our memory for pictures is better than our memory for words and sentences.

Leo Standing has probably done the most work investigating how much visual information we can remember, and his results suggest that although we may forget a little of the visual information we encode, there always seems to be more room to store new information, particularly for pictures.

In one very ambitious study, he asked participants to try to remember up to 10,000 pictures that were presented once each for 5 seconds. Afterward, he gave them a forced-choice recognition test. Participants correctly identified the picture they had seen before more than 70% of the time. Even if you factor in cases where they didn’t remember but just happened to guess correctly, they still were able to remember more than 6500 pictures, each of which had been presented a single time for about 5 seconds many days earlier.

There are at least 3 lessons that can be drawn from studies of visual memory.

1. Scientists have been unable to find any kind of capacity limit on how much we can store.

2. We remember visual information significantly better than verbal information.

3. We remember vivid, striking pictures better than we do ordinary pictures.
• Standing also compared memory for what he called vivid pictures with memory for ordinary pictures. The vivid pictures contained striking, interesting, or unusual features that were absent in the ordinary pictures. For example, the vivid picture might be of a crashed plane, while the ordinary picture would be a plane on a runway. And vividness also improved memory. In fact, participants made at least twice as many errors when trying to remember the ordinary pictures compared with the vivid pictures.

Previous Knowledge

• How does what you already know affect your ability to learn new information? It turns out that your previous knowledge can have a dramatic effect.

• In a famous experiment conducted by John Bransford and Marcia Johnson, participants listened to a paragraph and then their memory for the ideas conveyed in the experiment was tested. Here's the paragraph:

The procedure is actually quite simple. First, you arrange items into different groups. Of course, one pile may be sufficient depending on how much there is to do. If you have to go somewhere else due to lack of facilities, that’s the next step. Otherwise, you’re pretty well set. It’s important not to overdo things. That is, it’s better to do too few things at once than too many. In the short run, this may not seem important, but complications can easily arise. A mistake can be expensive as well. At first, the whole procedure will seem complicated. Soon, however, it will become just another facet of life. It’s difficult to foresee any end to the necessity for this task in
the immediate future, but then one can never tell. After the procedure is completed, one arranges the materials into different groups again. Then, they can be put into their appropriate places. Eventually, they’ll be used once more, and the whole cycle will then have to be repeated. However, that’s a part of life.

• If you don’t know what that paragraph was about, then it probably sounded pretty weird and may have been difficult to make sense of. But what if you know that the paragraph was about washing clothes? Once you have that prior knowledge, everything in the paragraph makes sense.

• Bransford and Johnson were interested in how people’s understanding and memory were affected by this kind of knowledge. They tested people’s memory under 3 different conditions:

1. Subjects listened to the paragraph without any prior context. Most of them probably had no idea what it was about but did their best to remember as much of it as they could.

2. Subjects were told that the paragraph was about washing clothes before they heard it. They understood the appropriate context when they were hearing the paragraph.

3. Subjects were also told that the paragraph was about washing clothes, but they were only told after they had already heard the paragraph. They did, however, know what the paragraph was about before they had to try to remember it.

• The researchers imposed a 2-minute delay to ensure that the information wasn’t still in working memory. Then, all 3 groups wrote down as much as they could remember. Finally, the researchers counted how many of the key ideas each group had written down.
• They found that the subjects who were never told that the paragraph was about washing clothes typically remembered about 3 of the main ideas. In contrast, the group that knew the paragraph was about washing clothes before they heard it remembered about 6 of the main ideas on average. So, they remembered about twice as much information.

• One of the most interesting and surprising findings from this study came from subjects in the third group, whose responses looked a lot like the people who were never told that the paragraph was about washing clothes. They also only remembered about 3 of the main ideas on average, or about half as much information as the people who knew the appropriate context from the beginning.

• The standard interpretation of these results is that relevant knowledge mainly helps you learn when you’re encoding new information into memory, rather than when you’re trying to retrieve it from memory. If you know that the paragraph is going to be about laundry beforehand, then you can activate all your existing knowledge about that topic and then connect the new information to what you already know. You can build associations or connections with your existing knowledge base and get the new information integrated. Then, you can use those associations to pull the new information back out of memory when you need it.

• After encoding, it’s too late. If you didn’t know what the paragraph was about when you were encoding it, then you wouldn’t be able to connect the new information to everything you already know about laundry. You couldn’t build those associations with your existing knowledge. And if those associations didn’t get built during encoding, then they won’t be available when you try to retrieve the information from memory.
Effectively Learning Explicit Information

• Memory strategies that exploit principles that help people learn explicit information more effectively have been around for a long time. Probably the most famous, and certainly one of the most effective, is called the method of loci.

• Imagine a building with many rooms that you have a strong memory for, such as a house that you’ve lived in. The idea is to create visual images for new information that you’re trying to learn and then to store those visual images in the different rooms of the building. The more vivid and striking you can make those images, the better. For example, if you’re trying to remember a grocery list, you might begin by trying to store the image of a cow being milked in your living room and then storing one more striking image in each subsequent room in the building.

• When you get to the grocery store, you can walk through the building in your mind’s eye and conjure up the strange image that you stored there. You remember the cow being milked in your living room, so you buy milk. You continue mentally walking through each room in the building, retrieving the associated image and recalling the next item on the list.

• This age-old method has been proven to work time and time again—because it exploits the principles in this lecture: You are storing visual information rather than verbal information; storing vivid, striking visual images rather than standard, ordinary images; and connecting the information that you’re trying to learn with information you already know.
SUGGESTED READING

Schacter, *The Seven Sins of Memory.*
Tulving, *Elements of Episodic Memory.*
———, “Episodic Memory.”

QUESTIONS TO CONSIDER

1. Why do you think we remember visual information better than verbal information?

2. What are some strategies you can employ in your daily life to optimize your explicit learning?
This lecture is about how some of the information that we learn is actually information that we infer. We are constantly drawing conclusions about the information that we encounter, and some of the information that we store during learning may be our inferences rather than accurate memories. And this has important real-world implications for eyewitness testimony and for how to interview witnesses.
Evidence suggests that our memory is constructive, meaning that we take fragments of memory and then put together, or construct, our memory. The problem is that we can’t always tell the difference between the true fragments and what our mind has added.

Making Inferences

- We are constantly making inferences to construct a plausible mental model of the situations we encounter. And we tend to remember our mental simulation of events, including all the inferences we made, rather than the original information itself.

- And it turns out that we make these kinds of inferences all the time. We do it when we’re encoding new information and when we’re retrieving information from our memory. In an experiment that demonstrates this fact very clearly, a group of subjects were asked to try to remember the following story:

  Carol Harris was a problem child from birth. She was wild, stubborn, and violent. By the time Carol turned eight, she was still unmanageable. Her parents were very concerned about her mental health. There was no good institution for her problem in her state. Her parents finally decided to take some action. They hired a private teacher for Carol.

- A week after reading the paragraph, subjects were asked some questions about it. But before the questions, half the subjects were told that the story they had read last week was actually about Helen Keller, and the other half of the subjects weren’t told that.
Then, all subjects were asked the same question: Do you remember reading the sentence “She’s deaf, blind, and cannot speak?” That sentence wasn’t actually in there, but the scientists found that about half the group who were told that the story had been about Helen Keller said that they remembered that sentence. In contrast, only 5% of the control group said that.

The Helen Keller group was making an inference: That sentence wasn’t in there, yet half of them said that it was. But when were they making that inference? It had to be at the time of retrieval. After all, there was no difference between the 2 groups of subjects until then. Nothing was different during encoding or the week before the test. The difference between the 2 groups only happens right before the retrieval.

We make inferences all the time and tend to remember the inferred information as if it actually happened.
Studies of Eyewitness Testimony

• Our legal system often relies on the testimony of eyewitnesses. But how reliable is eyewitness testimony? Some experiments have explored this question.

• One of the scientists who pioneered the study of eyewitness testimony is Elizabeth Loftus, who designed a simple experimental paradigm in which participants first encode some event—such as by watching a video of a car accident, so they are now an eyewitness—and their memory for that event is subsequently tested.

• But before that happens, they may or may not receive some misinformation—some subtle information that could potentially distort their memory for the original event. Then, everybody’s memory gets tested and the researcher determines whether the people who were misinformed exhibit memory distortions relative to the people who weren’t misinformed.

• Loftus, along with John Palmer, performed one of the first experiments like this, in which participants watched a video of a car accident in which 2 cars collide. The 2 groups were then asked a question about the video. The control group was asked this question: How fast do you think those cars were going when they hit each other? The misled group was asked a very similar question with a minor tweak: How fast do you think those cars were going when they smashed into each other?

• Using the phrase “smashed into each other” suggests that it may have been a more violent collision, while the phrase “hit each other” doesn’t have the same strong connotation of a violent collision. But that’s the only difference between the 2 groups.
• Then, everyone from both groups is asked the same test question: Did you see broken glass in the video? In reality, there was no broken glass. But about 14% of the control subjects misremembered seeing broken glass. In contrast, 32% of the subjects in the misled group made the error. In other words, that one small change in phrasing more than doubled the probability of a false memory for broken glass.

• This study demonstrates that some relatively subtle suggestive information can have a dramatic influence on somebody’s eyewitness testimony for an accident.

• In another study, all participants watched a video of a Datsun, an old brand of car, stopped at a yield sign in front of an intersection when another car comes from behind the Datsun, passes it to enter the intersection, and causes an accident.

• The control group is asked this question: Did the car pass the Datsun when it was stopped at the yield sign? The misled group is asked a slightly different question: Did the car pass the Datsun when it was stopped at the stop sign? After a delay, both groups are shown a picture of the Datsun parked at a yield and another picture of the Datsun parked at a stop sign. Then, they’re asked a final question: Which one did you see?

• About 75% of the control group got it right and picked the picture with the yield sign. But only 41% of the misled group got the same question right. Most of them thought they remembered seeing a stop sign. And most of them were completely unaware of having been misled in any way. Nevertheless, the subtle misinformation did affect their memory.
• This is another example in which some relatively subtle misinformation between the time of encoding and the time of retrieval is leading to false memories and distorting eyewitness testimony.

• These findings raise an important question: What happened to the original information? For example, what happened to the information about the yield sign in the people who were getting it wrong?

• One possibility is that the original information is sort of deleted or overwritten by the misleading information. So, when you first watch the video, you see the car at the yield sign. Then, there’s some misinformation: Did the car pass the other car while it was parked at the stop sign? Maybe at that point “stop” simply replaces “yield” in memory. In that case, “yield” is no longer in there; it’s been overwritten.

• Another possibility is that “yield” is still in there, even though “stop” has now been added. So, rather than overwriting the original memory of the yield sign, you simply augment your memory with the stop sign. In that case, both pieces of information are in your memory simultaneously.

• To distinguish these 2 alternatives, Michael McCloskey and Maria Zaragoza conducted a famous experiment, in which all participants see a sequence of pictures of a repairman who enters an office, fixes a chair, and then finds and steals $20 and a calculator. Critically, in one of the pictures, you can see that the repairman has a hammer. The subjects are eyewitnesses to this crime.
• Next, the participants read a description of what happened. One of the narratives was misleading while another one was not. Specifically, in the misleading narrative, the repairman was described as having a screwdriver rather than a hammer. In the other narrative, the repairman was described as having a tool—a neutral description that is consistent with the original story and isn’t misleading.

• Finally, everyone’s memory is tested, but this time in 2 different ways. Some of the people are asked if the repairman was carrying a hammer or a screwdriver—directly contrasting the original information (the hammer) with the misinformation (the screwdriver). This is the way all the previous misinformation experiments had been done.

• Sure enough, McCloskey and Zaragoza found the traditional misinformation effect: The people who were misled—who read the narrative that mentioned a screwdriver—picked the screwdriver more than the hammer. In fact, across 6 different experiments, they only picked the hammer 37% of the time.

• In contrast, the people who read the neutral description that was not misleading correctly picked the hammer 72% of the time. So, there was a whopping 35% difference in accuracy between the 2 groups. This is the standard misinformation effect seen in previous studies.

• The critical question is why. Did the people who fell prey to the misinformation effect and picked the screwdriver overwrite the hammer in their memory, or was their memory of the hammer still in there?

When we learn new information, we tend to add it to the information that we already have stored.
To answer that question, McCloskey and Zaragoza tested another set of subjects in a different way. Everything was kept the same as the previous setup, but this time they changed the memory test: Rather than asking people to choose between the hammer and the screwdriver, they asked them whether the repairman was carrying a hammer or a wrench. In other words, they’re not even given the option to choose the screwdriver.

Subjects chose the hammer 72% of the time, which was very similar to the people who read the neutral description. These results suggest that “hammer” is still in their memory somewhere. They didn’t overwrite it; instead, they augmented their memory.

Imagine that you’re walking down the sidewalk and see some bank robbers run out of a bank, jump into a getaway car, and speed away. The police interview you to ask you about what you saw. How could they do that in such a way that they’re more likely to get accurate information and less likely to get misinformation?

That question led psychologists to develop the cognitive interview. Specifically, scientists who study memory came up with an approach that police departments can use to try to elicit the most accurate eyewitness testimony possible.
Imagine that you try to learn a list of words while you are scuba diving or while you are standing on dry land. When you try to retrieve the words, you will tend to remember the words you studied underwater better if you go scuba diving again.

The surrounding context provides a whole bunch of cues that got associated with the original memory. And if you reinstate the same context, then all those cues can help you retrieve the original information.
The cognitive interview is based on 3 key ideas: Reinstate the original conditions as closely as possible, let the witness tell the story without interruption before asking any questions, and when you do ask questions, ask them in reverse chronological order.

1 To the extent that you can recreate, or reinstate, the same conditions that were present when you encoded the original memory, that should help you remember. Reinstating the original conditions exploits a principle from cognitive psychology called encoding specificity, which means that our memories are tied quite specifically to the conditions that were present when that information was learned.

2 The goal of letting the eyewitness tell his or her story without interruption is to try to eliminate the possibility of introducing a misinformation effect. A police officer asking an eyewitness about a traffic accident he or she just saw might unconsciously say something that could bias the witness testimony. By avoiding asking any questions at first, there is no way the officer’s questions can bias the eyewitness’s memory.

3 There will probably be a lot of details that the witness may not have mentioned when he or she was first trying to tell the story, so you need to ask questions. If you ask questions about what happened first before asking about later events, then the witness will construct a memory for the beginning of the event, and some of the stuff that’s in that memory may not actually be accurate. The problem is that anything that has been added will then influence every subsequent answer that the witness gives. While asking questions in reverse chronological order doesn’t completely eliminate this problem, it does alleviate it, because things that happened later can’t influence earlier events.
Learning about episodes and events is what psychologists often call episodic memory.

Learning facts—relevant information about the world—is what psychologists typically call semantic memory.

**SUGGESTED READING**


Loftus, *Eyewitness Testimony.*

**QUESTIONS TO CONSIDER**

1. Do you think we would be better off or worse off if our memory were more like an accurate video recording?

2. Is there anything you think we should change about the US legal system in light of what you learned from this lecture?
We don’t have a single, unitary system in our mind that is responsible for learning. Instead, we have multiple brain systems for learning different kinds of information. For example, learning explicit information depends on different mechanisms—and brain circuits—than learning implicit information. Psychologists typically even distinguish between different types of explicit, conscious memory: episodic memory and semantic memory. As you will learn in this lecture, episodic memories are tied to a specific time and place and are remembered from a first-person perspective, while semantic memory is our memory for facts—that is, our general knowledge about the world.
Episodic versus Semantic Memory

• Explicit memory refers to memory that is consciously accessible and verbalizable. You know that $2 + 2 = 4$; this is an example of verbalizable, conscious, explicit memory.

• Episodic memories are a type of explicit memory that refers to memories for personal episodes in your life. For example, your memory of eating breakfast today is an episodic memory.

• Episodic memories all share some specific characteristics. First, they are all tied to a specific time and place. Your memory of eating breakfast this morning is tied to your kitchen table at about 8 a.m. In addition, episodic memories have a first-person, personal perspective. These are memories that you can bring to mind, and when you do, it’s as if you’re seeing that memory through your own eyes again. Maybe you have a memory of walking your dog this morning.

• Episodic memories aren’t the only type of explicit memories. We also have explicit memories for facts about the world. For example, you remember that $2 + 2 = 4$, and this is a piece of knowledge that you’ve learned and stored in your memory.

• These types of memories are not tied to a specific time and place and are not remembered from a personal perspective. They are just disembodied facts that you happen to know; they are part of your general knowledge about the world.

• Psychologists call this semantic memory. Semantic memories are still explicit. You can still verbalize these facts and consciously bring them to mind. But they’re not personal episodic memories that are tied to a specific time and place.
Categorization

• How do we learn all this information and store it in such a way that we can access it quickly and easily? Our semantic memory is organized by category. For example, if you see a bunch of pictures of robins, sparrows, and finches, you can quickly recognize that they’re all birds. Even though they look different from each other, you immediately realize that they all belong to the same category: birds. And you have a lot of knowledge organized around that category. For example, you know that birds lay eggs and that they typically make nests and can fly.

• Organizing our semantic memory around categories is very useful because it helps us interact with the world efficiently. For example, knowing that 2 different creatures that look a little bit different are both birds allows us to make all kinds of useful inferences. We can infer that they probably both fly, that they probably make nests, that they probably lay eggs, and so on.

• The reason categorization is so useful is because there are a lot of similarities among the members of any given category. And those similarities mean that we can treat them in similar ways.

• If we can categorize something as food, that can tell us whether we should eat it or not, which is very important for our survival. Likewise, being able to categorize something as an enemy that might be a threat is also very useful.

• If categorization and category learning are so important and fundamental, then we might expect to see lots of other species doing it—even species that don’t seem all that smart. And sure enough, we do see this. For example, Ramesh Bhatt, Edward
Wasserman, and colleagues found evidence that pigeons learn to categorize the objects they see and organize their world in terms of those categories.

• How do we categorize things? One natural idea would be that we categorize based on how things look, or sound, or smell, or feel; that is, maybe we categorize based on the perceptual features of the objects that we encounter. Things that look alike get grouped together, foods that taste similar get grouped together, and so on.

• It turns out that our categories are more sophisticated than that. And this is even true in children. For example, in an experiment conducted by Susan Gelman and Ellen Markman, they found that children as young as 4 years old can categorize objects based on essential underlying features rather than just on superficial perceptual features.

Essentialism refers to the idea that we can categorize objects based on underlying features that we can’t see but that are more essential to the nature of an object than its perceptual features.

• The intuitive idea that many people initially have is that there are some specific features that define a mental category. And if an object has those features, then it’s guaranteed to be a member of the category. If it doesn’t, then you know it’s not. So, these features are both necessary and sufficient to determine category membership.

• Defining features play a significant role in scientific classification systems. For example, scientists often identify defining features when classifying a biological organism into its family, genus, and species.
• But this is probably not the way our mind works. Our brains probably don’t categorize things based on these kinds of defining features that are necessary and sufficient to define a mental category.

• To illustrate, consider the concept of a game. Basketball is a game, and chess is a game. But can you come up with a set of defining features that is guaranteed to tell you whether something is a game or not? Those features need to guarantee that both tennis and playing solitaire are in, while similar things, such as running a marathon or swimming, are out. This is pretty difficult.

• These kinds of issues have led psychologists to a view of categorization that assumes that mental categories are not black and white, with clearly defined boundaries; rather, mental categories have gray areas, and some members of a category are better examples of that category than others. And instead of assuming the existence of defining features that are both necessary and sufficient for category membership, psychologists instead view features as being characteristic of a category—but not defining.

• According to this view, you don’t just check off the defining features and decide whether an object is guaranteed to be in or out of the category. Rather, you ask how similar is it to other members of the category.

Category boundaries aren’t black and white. They’re fuzzy. And as you get close to the edges of a category, people will be unsure whether something is in a category or not. For example, although scientifically a tomato is classified as a fruit, most people think of it as a borderline case.
And some category members should therefore be better examples of a category than others. For example, robins seem like a really good example of the bird category. A chicken is also a bird, but it doesn’t seem like a very good example of a bird. This is because chickens have fewer characteristic features of birds than robins do. Robins fly, make nests, sing, and lay eggs. They have pretty much all the characteristic features of birds. Chickens, on the other hand, don’t fly, don’t make nests, and don’t sing.

Category Learning Systems

How do we learn these incredibly useful, often fuzzy categories that underlie our semantic knowledge base? There is now a fair bit of evidence that we can learn categories in more than one way—that is, we have multiple category learning systems in our brains.

The distinction between the different category learning systems is similar to the differences between explicit, conscious learning and implicit, unconscious learning. Specifically, we can learn categories consciously and explicitly using a kind of rule-based approach, but we can also learn categories unconsciously and implicitly over time by detecting subtle consistencies or regularities in our environment. Which system we use depends a lot on the nature of the categories we’re trying to learn.

For example, suppose that a child is trying to learn what a triangle is. It’s pretty easy to try out various conscious hypotheses that can be explicitly verbalized. And once the child hits on the idea that a triangle is a closed figure with 3 straight sides, then he or she can easily decide whether other geometric figures are triangles or not.
• That kind of category learning is a lot like hypothesis testing. You come up with a specific, verbalizable hypothesis and then test it to see if it correctly categorizes new examples. If it doesn’t, then you immediately reject your previous hypothesis, come up with a new one that fits with the examples you’ve already seen, and try to test it. That’s rule-based category learning, and it can be very fast and effective if the category being learned can be captured by a straightforward verbal rule.

• On the other hand, most of the natural categories that we encounter in the world are fuzzy and can’t be captured by a simple verbal rule. For example, children are constantly learning the meanings of new words without ever being given an explicit definition. In this case, there is no verbalizable rule that captures the category that’s being learned, so we rely on our implicit learning systems to gradually pick up on the subtle regularities that distinguish members of those categories from members of other categories.

• There is evidence that these 2 types of category learning depend on different brain circuits. Edward Smith, Andrea Patalano, and John Jonides performed one of the first experiments in support of this hypothesis. They found that rule-based categorization activated regions near the front of the brain while similarity-based categorization activated regions farther back.

• So, we use a rule-based explicit approach to learn categories and also a more implicit approach that gradually picks up on subtle regularities in the features that characterize members of those categories.

• While the explicit approach relies on generating verbalizable rules and then testing them and replacing them with new rules if they don’t work, 2 major classes of theories have been proposed to explain how the implicit category learning system works: one based on prototypes and the other based on exemplars.
• Prototype theories assume that we compute a kind of running average for each of our categories. That running average is the prototype for that category.

• For example, the first time a child encounters a dog, he or she stores a prototype representation of the dog category that is based exclusively on that one dog. But when the child encounters a second dog, he or she updates the prototype to try to capture the similarities between the first 2 dogs. And every time the child encounters a new dog, his or her prototype dog is getting modified a little bit until it finally becomes a kind of an ideal dog.

• Notice that the prototype dog doesn’t correspond to any particular real dog that the child has seen before. It’s more like a running average of all of them. And that prototype then forms the basis for categorization. When the child encounters a new creature, he or she compares it against the prototypes that he or she has stored in memory and tries to find the best fit. Whatever matches best is then used to determine the category of the new creature.

• The other major class of category learning theories is based on storing exemplars rather than prototypes. The specific items that are stored in memory are referred to as exemplars, which just means examples.

• According to exemplar theories, we use our memory of specific dogs as the basis for categorization. After encountering his or her first few dogs, a child has a memory for each of those animals. When the child encounters a new creature, he or she identifies the memory that is the best match to the new creature. And if that matching item from memory was a dog, then the child categorizes the new creature as a dog.
• It’s still an open question as to which of these 2 classes of theories is closer to the truth because it has been very difficult to distinguish them experimentally.

SUGGESTED READING

Markman, *Categorization and Naming in Children: Problems of Induction.*
Markman and Ross, “Category Use and Category Learning.”
Rosch and Lloyd, *Cognition and Categorization.*

QUESTIONS TO CONSIDER

1 Based on the information that animals also form categories, do you think the categories in a dog’s semantic memory would be similar to those in a human’s?

2 Do you think explicit, rule-based category learning or unconscious, implicit category learning is more important in real life?
So far, this course has focused on the psychology of explicit learning and memory. You have discovered that learning explicit information is fundamentally different than learning implicit information, and that even within explicit learning, learning and remembering episodic information is distinguished from learning and remembering semantic information. But how does our brain do this? What are the neural mechanisms that allow us to learn new explicit information and store it for later retrieval? Are there specific parts of the brain that are dedicated to learning explicit information, and if so, what are they? This lecture will address these questions.
Brain Anatomy

• Your brain is divided into 2 cerebral hemispheres: one on the left and the other on the right. Each cerebral hemisphere is often divided into 4 lobes: the left and right frontal lobes at the front, the occipital lobes at the back, the parietal lobes at the top, and the temporal lobes on the left and right behind your ears.

• Directional terms are also critical when discussing brain anatomy: Superior means toward the top and inferior means toward the bottom, anterior means toward the front and posterior means toward the back, and lateral means toward the side while medial means toward the middle.

• The 2 temporal lobes are on the bottom of the left and right side of your brain. They are below, or inferior to, the parietal lobes and are in front of, or anterior to, the occipital lobes. The medial temporal lobes—the part of each temporal lobe toward the middle of the brain, away from the ears—are the parts of the brain that were surgically removed in Henry Molaison (the amnesiac patient you learned about in lecture 2), and doing so led to a profound, but also quite isolated, deficit in learning explicit, conscious information.

• There are quite a few brain structures in the medial temporal lobes. There are some cortical regions (the cortex is the layer of tissue on the outside of the brain) in the medial temporal lobes, and underneath those cortical regions are 2 major subcortical structures: the hippocampus and the amygdala.
• Henry’s surgery removed most of this entire region in both hemispheres. This raises a few questions: Do all of these structures have equal importance in learning and memory, or is one of them particularly crucial? In particular, could a smaller and more restricted lesion also lead to impairments in learning and memory?

• To answer such questions in humans is difficult, because we can’t always see subtle brain damage on MRI or CT scans. We really need to examine the brain at autopsy to get the full picture. But that means we need to find amnesiac patients who are willing to participate in experiments investigating their memory and who offer to donate their brains for study after they die. Fortunately for scientists, a number of very generous amnesiac patients have done just that.

• Stuart Zola-Morgan, Larry Squire, and David Amaral studied the brains of several of these patients after their death and found that damage that was restricted exclusively to the hippocampus was sufficient to produce amnesia. These results imply that the hippocampus is the key player in explicit learning and memory.

• Subsequent work in animals has confirmed this hypothesis. Specifically, animals with damage that is restricted to the hippocampus also exhibit impairments in explicit memory. These studies also helped refine our understanding of what explicit memory is.

• These studies involved carefully examining the characteristics of learning and memory tasks that were impaired in animals after medial temporal lobe damage. And these studies led to an important insight: Learning tasks that depend on the medial temporal lobes involve learning relationships among multiple concepts and in a way that can be expressed in novel situations.
Learning New Information and Memory Storage

• Learning new explicit information depends critically on the hippocampus, and damage to this region leads to a severe anterograde amnesia—that is, a difficulty in learning new information. But amnesiacs don’t just suffer from anterograde amnesia; they also typically suffer from a temporally graded retrograde amnesia. They have difficulty remembering explicit information that they learned a few days, weeks, or even years before their brain damage. But their more remote childhood memories are typically intact. That’s what is meant by a temporal gradient: The older memories are preserved, but the more recent memories are impaired.

• Results about the neural basis of explicit learning and memory tell us that the medial temporal lobe structures, such as the hippocampus, are not the ultimate site of memory storage. If amnesiacs who have damage to these structures can still remember their childhood, then those childhood memories obviously can’t reside in the medial temporal lobes.

• Instead, evidence suggests that they reside in the cerebral cortex. Specifically, explicit memories seem to be stored in the same cortical regions that were involved in processing the information when it was first encountered.

• The cerebral cortex performs many functions, and different parts of the cerebral cortex perform different functions. For example, your occipital lobe at the back of your brain processes visual information. The parietal lobe at the top of your brain processes spatial information and your sense of touch. Hearing is handled in superior parts of your temporal lobe, and motor function is controlled in posterior parts of the frontal lobe. And the list goes on and on.
• When you process new information, many different parts of your cerebral cortex are involved. For example, suppose that you see an apple on a table, pick it up, and take a bite. Your occipital cortex will process the visual information, and your frontal cortex will control your movements to allow you to pick it up. The sound of taking the bite will be processed in the auditory cortex in your temporal lobe, and the taste of the apple will be processed in the insula, which is under the frontal lobes.

• It turns out that your memory of picking up and biting into that apple depends on those same brain areas. When you remember what the apple looked like, you’re activating the occipital cortex. When you remember what biting it sounded like, you’re activating the auditory cortex. When you remember what it tasted like, you’re activating the insula—and so on.

Information Processing and Memory Consolidation

• Memories ultimately get stored outside the hippocampus and medial temporal lobe structures. But if explicit memories get stored outside the hippocampus, then why do amnesiacs experience retrograde amnesia? In other words, why do they have trouble retrieving memories of what happened before their brain damage? After all, if those memories are stored outside the hippocampus, then shouldn’t they be immune to hippocampal damage?

• The explanation is based on memory consolidation. When we first learn new explicit information, the memory depends critically on the hippocampus. Even though the memory is stored in a variety of different cortical regions, you need the hippocampus to reactivate the appropriate patterns in each of those regions. But gradually
over the course of days, months, and even years, the hippocampus becomes less and less critical to the representation and retrieval of the memory. The memory becomes consolidated in the cortex and no longer depends on the hippocampus.

• That’s why childhood memories are spared in amnesia while memories from the days and weeks immediately before the brain damage are not. The childhood memories have been consolidated in the cortex and don’t need the hippocampus anymore. In contrast, the more recent memories haven’t been consolidated yet. So, if the hippocampus gets damaged, those memories get lost.

• Why is our memory system organized this way? Why not just consolidate the memory into the cortex right away? Why does consolidation take so long? Isn’t that inefficient?

Many scientists think of the hippocampus as a kind of organizer that gets all the relevant cortical regions together to regenerate the visual, auditory, and tactile experiences associated with a particular memory.

But over time, those cortical regions begin to communicate directly with each other and no longer need the hippocampus to get them together. Once that happens, the memory has become consolidated, and hippocampal damage will no longer affect it.
• A very interesting answer to these questions was proposed by Jay McClelland, Bruce McNaughton, and Randy O’Reilly, who argued that gradual consolidation of memories is actually helpful, rather than harmful. In particular, gradual consolidation allows us to incorporate new information into our memories without overwriting existing information. To understand why, we need to address how information gets processed in the brain.

• Your brain is an extremely complex network of brain cells—called neurons—and connections—called synapses. When a brain cell fires, or gets activated, it sends signals through synapses to other brain cells. Some of those signals are excitatory and tend to make the next cell fire, while other signals are inhibitory and tend to prevent the next cell from firing.

• When you see an apple, a large population of neurons is firing to represent the apple. And the pattern of activation across those neurons can then trigger another pattern of activation corresponding to another thought, and so on. Seeing the apple can make you think about lunch, for example.

• Storing a memory really means changing a bunch of synapses in such a way that the neural activation pattern corresponding to the new information will get activated at an appropriate time in the future. By changing those synapses, you can also store memories. And at a cellular level, that’s what learning does in the brain: It changes synapses.

• One synapse might get a little bit stronger and excite the next cell a little more than it did before. Another synapse might get weaker and excite the next cell a little less. By changing those synaptic strengths in just the right way, the brain learns a long-term memory. And when appropriate cues are encountered in the future, they will trigger the neural activation pattern associated with that memory. That’s memory retrieval.
• But the problem is that we have to store lots of different memories using the same synapses. And that can lead to significant interference and memory problems, such as proactive interference, which means that previous learning interferes with new learning, and retroactive interference, which means that later learning interferes with the retrieval of earlier memories.

• So, we are left with a dilemma: We want to learn new things, but we also want to be able to remember things we have learned in the past. And new learning can interfere with that. This is sometimes called the stability-plasticity dilemma. We want our existing memories to remain stable, but we also want memory to be plastic, or malleable, so that we can add new information to what we already know.

• According to McClelland, McNaughton, and O’Reilly, that’s why slow, gradual consolidation of memories into the cortex is helpful rather than harmful. The hippocampal learning system can quickly learn new relationships and associations. And that makes us plastic and flexible. But consolidation of those memories into the cortex needs to be gradual and slow so that we don’t overwrite the information that’s already stored there.

• In particular, they argued that if we interleave the rehearsal of previously stored information with the rehearsal of new information, then we can make synaptic changes that incorporate both memories simultaneously. But that requires regularly rehearsing previously stored information.

• There is actually evidence that we do this when we sleep. In a study conducted by Daoyun Ji and Matthew Wilson, they trained rats to run around a circular maze in alternating directions and recorded from neurons in the hippocampus and the visual cortex. Different cells fired at different times as the rats ran around the maze.
• But they kept recording from those cells after the rats went to sleep and found that sequences of cell firings that occurred when the rats were awake and running around the maze reappeared when the rats were asleep. And that was true in both the hippocampus and the visual cortex.

• Furthermore, the firing sequences in the hippocampus and visual cortex were coordinated: If the hippocampus sequence during sleep corresponded to the sequence when the awake rat was running in a clockwise direction, then the visual cortex sequence during the same period of sleep also matched the awake clockwise sequence.

• These results suggest that the memory of running around the maze was being reactivated in the hippocampus and cortex during sleep—which is exactly the kind of mechanism that could consolidate memories in the cortex.

SUGGESTED READING

Burgess, Maguire, and O'Keefe, “The Human Hippocampus and Spatial and Episodic Memory.”
Eichenbaum, Yonelinas, and Ranganath, “The Medial Temporal Lobe and Recognition Memory.”
Hart and Kraut, Neural Basis of Semantic Memory.
McClelland, McNaughton, and Oreilly, “Why There Are Complementary Learning Systems in the Hippocampus and Neocortex.”
Redish, Beyond the Cognitive Map.
Squire, “Memory Systems of the Brain.”
QUESTIONS TO CONSIDER

1. Most of the research on memory consolidation has focused on episodic memory. Do you think semantic memories are likely to be consolidated the same way? How would you test your idea experimentally?

2. Damage to the hippocampus affects explicit learning and memory. How do you think damage to cortical consolidation sites would affect explicit learning and memory if the hippocampus were intact?
The vast majority of students have adopted study strategies based more on trial and error than on solid scientific evidence. The good news is that educational and cognitive psychologists have studied this topic and learned a lot about which study techniques work and which don’t. In this lecture, you will learn about methods that have been tested in real experiments and that have been demonstrated to improve learning and retention of explicit information.
Ineffective Study Techniques

- There are a few study techniques that many people swear by but that research demonstrates aren’t the most effective.

- Highlighting or underlining books and notes is one of the most popular study techniques. Unfortunately, the evidence for the usefulness of highlighting is mixed at best, at least the way it’s normally done.

- In one representative experiment, Robert Fowler and Ann Barker asked 3 groups of undergraduate students to study scientific articles about boredom and about city life in preparation for a test that was given a week later. One group read the articles without doing any highlighting and served as the control group. A second group actively highlighted as much of the text as they wanted to. And a third group didn’t highlight themselves but read the articles that had already been highlighted by the second group.

- All 3 groups came back a week later and got to study the same materials from the week before for 10 minutes. The 2 highlight groups studied the highlighted articles while the control group studied the unmarked article. Then, they all took a test on the content of the articles. All 3 groups performed about the same. Highlighting didn’t help. And a number of subsequent studies have found similar results.
• In fact, one study found evidence that underlining can hurt later test performance. Sarah Peterson asked students to study a history chapter that they would later be tested on. One group of students was asked to underline important text in the chapter and was able to review their marked-up chapter before taking a test. Another group also underlined important text in the chapter but reviewed a clean copy of the chapter before the test. And a third group studied the chapter without doing any underlining and also reviewed a clean copy before the test.

• About half the questions on the test were basic factual questions about the material. On these questions, all 3 groups performed about the same. Once again, marking some of the text as particularly important—in this case by underlining—didn’t help. The other half of the questions required students to draw inferences based on what they had read. On these questions, the students who had used underlining during both the initial study period and the review period actually performed worse than the other 2 groups.

• One theory about why highlighting or underlining isn’t more helpful is that it restricts your attention to isolated facts and leads you to overlook the bigger connections among ideas. That might explain why students who underlined performed worse on inference-based questions compared with students who studied a clean copy of the chapter. By focusing on isolated facts, they missed some of the bigger connections that were tested by the inference-based questions.

• Another problem with highlighting and underlining is that students often don’t do a good job of distinguishing the truly central ideas from more peripheral information. Some students hardly highlight anything, but the more common problem is highlighting too much
information. In fact, in the original highlighting study by Fowler and Barker, students who highlighted more did worse on the test than students who highlighted less.

- It’s possible that highlighting is a good study technique for some students if they can highlight a little more thoughtfully, but we need more research to know for sure.

- Another study technique that is associated with mixed results is rereading. Rereading is extremely common among students. In fact, it may be the most common study technique. And it does have some benefits. For example, it seems to help with fill-in-the-blank and short-answer testing. But there isn’t good evidence that it actually improves comprehension or performance on inference-based questions.

- In addition, the benefits of rereading tail off very quickly. Although rereading once has some benefits, rereading a second or third time doesn’t seem to add anything—yet this is what many students do.

If you have read a chapter and then reread it, you will recognize a lot of what you read. And that familiarity may fool you into thinking that you really know what’s in the chapter. Unfortunately, you may be in for a rude awakening if you’re then tested on the chapter and have to actually recall the information. This happens all the time in classrooms around the world. Students who do poorly on an exam are often very surprised, because they really thought they had mastered the material. And part of the reason is probably because rereading gave them the illusion of mastery.
• An even more serious problem is that rereading can give students the mistaken impression that they’ve mastered the material because it seems familiar, so many students stop studying after rereading. The problem is that recognizing information you’ve encountered before is quite different from being able to recall that information.

• A final reason that rereading probably isn’t the best study strategy is very simple. Other techniques have been demonstrated to be significantly better. And any time you spend rereading is time that you’re not spending studying in these other, more effective ways.

Effective Study Techniques

• A 2013 review paper by John Dunlosky, Daniel Willingham, and colleagues evaluated study techniques from the scientific literature in terms of 4 criteria: whether they work for different students, for different types of material, regardless of how learning is tested, and in different learning environments. Two techniques that they categorized as moderately effective are generating explanations and interleaving practice.

• Generating explanations refers to deliberately trying to come up with explanations for why concepts are true or for how those concepts are related to what you already know. Instead of passively reading an article or chapter, the idea is to constantly ask yourself questions about the information.

• For example, if a chemistry chapter claims that some compound is more reactive than another, then ask yourself why that might be. Rather than just passively encoding information, you’re actively engaging with it and asking deeper questions about why things are the way they are.
• One of the first studies to investigate the effect of generating explanations was conducted by Michael Pressley and colleagues. A common interpretation of their results is that generating explanations forces students to process the new information deeply and to relate the new information to information they already have stored in their long-term memory. And both types of processing are associated with stronger and more durable memory.

• The other study technique that Dunlosky’s review characterized as moderately effective was interleaved practice.

• Imagine that you’re taking an algebra course. You’re going to be learning about a lot of different topics, such as isolating a variable on one side of an equation and slopes and intercepts when graphing lines. When a test rolls around, it will cover a bunch of different topics, including isolating variables and slopes and intercepts. How should you study? Should you spend a block of time studying about isolating variables, then a block of time studying slopes and intercepts, and so on? This is blocked practice. And this is the way most algebra textbooks are organized.

• An alternative approach is to mix up the topics as you study. For example, if you have a whole bunch of algebra problems covering a variety of different topics, then you could work on them in a random order. First, you solve a problem involving slopes and intercepts. Then, you solve a problem involving isolating a variable. Then, you solve one involving factoring, then another one involving isolating a variable, and then another one involving slopes and intercepts. This is interleaved practice.

• There is evidence that interleaved practice may improve learning. For example, Doug Rohrer and Kelli Taylor compared blocked versus interleaved practice with students who were learning how to
figure out the volume of different geometric forms, such as spheres and cones. One group of students learned using a blocked approach, while the other group learned using an interleaved approach.

• During the practice of the formulas in the experiment, the blocked group actually performed better than the interleaved group. This makes sense: If you need to figure out the volume of a sphere and just solved another problem involving the volume of a sphere, then you’re likely to remember the formula. But to investigate which approach is better for long-term learning, both groups were given a test a week later on all the geometric forms that they had studied, and the interleaved group did more than 3 times better.

• One theory about why interleaved practice is better than blocked practice is that seeing different types of problems in immediate succession makes it easier to notice the differences between them, and being able to distinguish different types of problems makes you better at choosing the appropriate solution strategy. Another theory is that interleaving forces you to retrieve the information from long-term memory, and practicing that kind of retrieval makes you better at doing so when the test rolls around.

• There are 2 other study techniques that were rated as even more effective by Dunlosky’s review than generating explanations and interleaving different topics when studying. The first is distributed practice, which refers to spreading out your study over time with breaks or lags between study sessions.

• This is not what most students do. In fact, scientific investigations of study schedules have found that most students exhibit procrastination scallop—or cramming—which means that students tend to procrastinate and do most of their studying right before the exam and then take a break until ramping up and studying right before the next exam. And it turns out that cramming isn’t nearly as effective as distributed practice.
• In one study, Harry Bahrick asked students to try to learn the English translations of a bunch of Spanish words. All the students studied the words during 6 sessions, but Bahrick varied the lag, or spacing, between the study sessions. One group had all 6 sessions back-to-back on the same day, kind of like cramming for an exam. For another group, the 6 study sessions were all a day apart. And for a third group, the study sessions were each a month apart.

• The students who took a month-long break between each study session forgot the meaning of a lot of the Spanish words they had studied, so they had to relearn them. In contrast, the students who had all 6 sessions back-to-back on the same day didn’t forget much from one session to the next.

• Then, Bahrick gave everyone a test 30 days after their last practice session to see how much they remembered. The group that crammed all their study into a single day remembered 68% of the Spanish word translations. The group that had study sessions separated by a day remembered 86% of the translations. And the group that studied once a month remembered 95% of the translations.

• The study technique that might be the most effective of all is the method of consistently testing yourself. The benefits of testing have been shown in hundreds of studies. In one such study, Andrew Butler asked students to study a few text passages. The students then restudied some of the passages and took a test on the other passages. A week later, they took a test that assessed how much they had learned from the passages.
• Across 3 different experiments, the students consistently learned more from the passages on which they had been previously tested, compared with the passages that they had restudied. And that wasn’t just true for fact-based questions; testing also led to improved performance on more conceptual, inference-based questions.

• Keep in mind that being tested on a passage meant that the students didn’t get to restudy it, so they had actually studied those passages for less time than the other passages, yet they learned more. This is a very valuable lesson for students: Rather than rereading a chapter they’ve already read, students would be much better off asking a friend to test them on the material.

• Another powerful strategy is creating flash cards that have questions on one side and answers on the other. Then, students can shuffle the cards and repeatedly test themselves on the material until they’ve really mastered it.
Students can even take notes in a way that encourages self-testing. One approach is to divide their notebooks into 2 columns: One column is a little wider and is for taking the actual notes, while the other column is for writing down key terms and questions related to the adjacent notes. Then, students can cover up the notes and test their knowledge of the key terms and questions that they wrote in the second column. This is sometimes called the Cornell note-taking system, proposed by a Cornell University education professor in the 1950s.

**SUGGESTED READING**

Carey, “Forget What You Know about Good Study Habits.”
——— , *How We Learn.*
Didau, *What If Everything You Knew about Education Was Wrong?*
Pauk, *How to Study in College.*

**QUESTIONS TO CONSIDER**

1. Do you have any personal study techniques that work well for you but that weren’t discussed in this lecture? If so, why do you think they’re effective, based on what you’ve learned in the course so far?

2. Are there any specific ways that you can apply what you learned in this lecture to make your learning more effective?
This lecture will address a few controversies in the field of human learning and memory. These are topics for which there seems to be a disconnect between what the general public believes to be proven fact and what science has actually demonstrated. By the end of the lecture, you should be in a much better position to evaluate the validity of claims you run across in the popular press.
Learning Styles

• Are some students visual learners while others are auditory learners? Are some students left-brained while others are right-brained? Do some students learn best by collaborating with others, while other students learn best on their own? In short, do different people have different styles of learning? And if so, should teachers tailor their instruction to the specific learning style of individual students?

• This certainly seems like a reasonable idea. After all, people are quite different in every way you can think of, so it makes sense to think that people probably also learn in different ways. And if so, then tailoring instruction to match someone’s learning style could have real benefits.

• And consistent with the intuition, the idea of learning styles has had an enormous impact in education and in society more generally. Testing to determine learning styles has been recommended by several education organizations, and a number of textbooks in educational psychology discuss the merits of the approach. The idea of learning styles has also led to commercial products and training programs that generate significant revenue.

• But there is not yet solid scientific evidence to support the claim that tailoring instruction to match learning styles works. It’s possible that future research will demonstrate the value of assessing learning styles and designing individualized instruction, but the evidence to date has a number of problems.

1 There is not a lot of theoretical agreement in the field about how learning styles should be categorized. In particular, many different learning style models have been proposed. For example, Frank Coffield, David Moseley, Elaine Hall, and Kathryn Ecclestone performed a systematic review of the scientific literature on learning styles and identified 71 different models;
an in-depth analysis of 13 models that they considered to be the most influential revealed very little convergence across the models. We really don’t know what the right way to categorize learners is, and the field doesn’t seem to be making progress toward an agreed-upon conceptual framework.

2 A lot of the work in the field is based on what students report that they like rather than what actually improves their learning. Most of the tests that have been designed to assess learning styles ask students to indicate their preferred way to perform different tasks, and based on those preferences, the student gets categorized into a particular learning style. But the critical issue isn’t how much students like a particular approach, but rather how much they learn using that approach. Learning methods that are actually the most effective might not be what students most prefer.

In 2008, the Association for Psychological Science charged 4 leading researchers on learning—Harold Pashler, Mark McDaniel, Doug Rohrer, and Bob Bjork—with the task of evaluating the evidence for considering learning styles in education.

They found plenty of studies showing that one type of instruction produced better results than another type, but it tended to be better for all the students.

They didn’t find any studies in which instruction type A was better for learning style A than learning style B but instruction type B was better for learning style B than learning style A.

In fact, they had a difficult time finding studies that had randomly assigned students with different learning styles to different types of instruction. But in the small number of such studies that they did find, matching the type of instruction to the student never helped.
There is very little solid evidence supporting the claim that tailoring instruction to match student learning styles has a significant positive impact. For example, John Hattie reviewed hundreds of studies in an attempt to identify the factors that most influenced learning. The effect of individualized instruction was so small that it’s probably not a good use of teacher’s time. Furthermore, very few of the studies that have claimed evidence for learning styles have actually provided a rigorous test of the idea.

The Mozart Effect

- A second controversial topic in the study of learning is the so-called Mozart effect. Does listening to Mozart make you smarter? Does exposing children to the music of Mozart and other classical composers help them do better in school? Should parents of preschoolers play classical music at home to help their children become better learners? Should pregnant mothers play Mozart to their unborn babies to stimulate their brains?

- Many people think that the answer to these questions is yes. Many popular books tout the benefits of listening to classical music—not only to improve cognitive function, but also to reduce stress and heal the body. Entire companies have sprung up marketing and selling products based on the assumed benefits of listening to classical music.

- Interest in the Mozart effect was triggered in large part by an influential study that was published as a 1-page article in *Nature* in 1993. In the study, conducted by Frances Rauscher, Gordon Shaw, and Katherine Ky, 36 college students listened to 10 minutes of a composition by Mozart (Sonata for Two Pianos in D major), or to 10 minutes of relaxation instructions, or to 10 minutes of silence.
• Immediately after the 10-minute listening period, the students completed one of 3 abstract reasoning tasks from a famous IQ test called the Stanford-Binet Intelligence Scale. The students did significantly better on the tasks after listening to Mozart than they did after listening to silence or to relaxation instructions. The authors also calculated an IQ equivalence score based on task performance that was about 8 to 9 points higher after listening to Mozart compared to the other conditions.

• This is the finding that has since been dubbed “the Mozart effect,” although the scientists who conducted the study never used that term in the original paper.

• The same authors published another study 2 years later in which they compared listening to Mozart with listening to the minimalist composer Philip Glass. Once again, they found that performance on a task from the Stanford-Binet IQ test was better after listening to Mozart.

In 1997, a musician and former music critic named Don Campbell published a popular book titled The Mozart Effect, which argued that music, particularly classical music—such as the music of Mozart—had the power not only to strengthen the mind, but also to heal the body and unlock a person’s creative spirit.

Based on the book’s success, Campbell started an online business selling CDs intended to enhance children’s creativity and success in school, and even to help treat dyslexia, autism, and attention deficit hyperactivity disorder. These CDs were among the best-selling classical CDs for more than 3 years.
• Bruce Rideout also published 3 replications in which listening to a Mozart composition led to improved performance on a task modeled after the task that Rauscher and colleagues had used.

• The popular press latched onto these findings because they seem to suggest that the simple act of listening to 10 minutes of Mozart can increase your IQ by almost 10 points. This is certainly an interesting finding, but there are 2 important limitations that often get glossed over:

  1. The tasks on which performance improved came from a single subtest of the Stanford-Binet test—specifically, the spatial subtest. The studies really showed that listening to Mozart makes you better at a specific kind of spatial processing. They definitely didn’t show that Mozart makes you smarter in general.

  2. More importantly, the effects were very short-lived. Specifically, the benefits of listening to the Mozart composition only lasted about 10 to 15 minutes. After that, the spike in spatial processing performance disappeared.

• An accurate summary of the results would therefore be that spending 10 minutes listening to Mozart’s Sonata for Two Pianos in D major made students better at a specific spatial processing task for the next 10 minutes or so. This is fairly different than the claim that listening to Mozart makes people smarter. But it’s still interesting in its own right. For example, if it were true, physicians conducting surgeries that require complex spatial processing might benefit from a presurgical music session. Because of its potential importance, many scientists followed up on the original study in an effort to understand it and extend it. Unfortunately, many of them failed to find the same kinds of effects.
• Scientists don’t yet know for sure why some studies have found the effect while others haven’t, but it’s fair to say that the effect isn’t particularly strong or robust. Furthermore, even if the effect were demonstrated to be real, scientists agree that it is short-lived and restricted to specific tests of spatial processing.

Repression and Recovery of Traumatic Memories

• A third controversy in the field of learning and memory is the issue of whether traumatic memories can be repressed and later recovered.

• The idea that it is possible to repress a memory of a traumatic event and then recover it decades later resonates with many people. The basic idea is that memory repression is a kind of psychological defense mechanism. Experiencing an extremely traumatic event, such as witnessing a murder, leads the mind to bury that memory as a coping mechanism. Then, later, perhaps when the victim is no longer in a threatening environment, the repressed memory might bubble to the surface when an appropriate cue serves as a reminder.

• A key controversy in the field is whether such recovered memories are authentic. Are they true, or are they actually false memories? Note that claiming that a recovered memory is false does not imply that the person is lying; he or she may adamantly believe that the memory is true, even if it isn’t.

• There are some reasons to believe that many recovered memories might be authentic. First, there are many people who claim to have recovered traumatic memories for events they had previously
forgotten, and the vast majority seem very genuine and might actually be events they prefer not to remember. Furthermore, many people who experienced traumatic events as children do claim that they don’t remember them.

- On the other hand, there are also reasons to doubt the authenticity of at least some recovered memories. First, a number of studies have shown that people tend to remember emotionally arousing information better than emotionally neutral information. For example, many combat veterans want to forget what they witnessed but are tormented by extremely vivid memories of the horrors they experienced. If forgetting is a psychological defense mechanism, then you might expect the opposite.

Linda Williams interviewed more than 100 women who had experienced some kind of sexual abuse as children, as documented by hospital records. More than 1/3 of them did not report any memories of the incident that necessitated the hospital visit. Maybe they did remember, but they just didn’t want to talk about it. After all, doing so could be extremely painful. But it turns out that many of these same women reported other very personal and potentially painful information about their lives, including details about their sexual activity, abortions, drug use, and illegal behavior.

In fact, some women who failed to report any memory of the incident that led to the hospital visit reported other incidents of sexual abuse from their childhood. And if they’re willing to report one experience of sexual abuse, then why would they be unwilling to report another?
• In addition, there have been a number of cases of recovered memories that have been demonstrated to be false. In one case, a woman remembered being abused by her father at home at the age of 2, but she was being raised in prison by her mother, who was serving a sentence at the time, so the girl actually had no contact with the father.

• There is evidence on both sides of this very controversial issue. Some experts believe that the vast majority of recovered memories are authentic and mostly accurate, while others believe that most, if not all, such memories are confabulations. The truth is probably somewhere in the middle.

• Memory is both fallible and malleable, so it seems not only plausible, but highly likely, that some recovered memories are not accurate, even if the person has no doubt about their authenticity. On the other hand, memory repression after a traumatic event is quite commonly reported, and the evidence to date probably does not warrant immediately dismissing all recovered memories as fiction.

SUGGESTED READING

Lilienfeld, 50 Great Myths of Popular Psychology.
Loftus, “Planting Misinformation in the Human Mind.”
Loftus and Ketcham, The Myth of Repressed Memory.
Pashler, McDaniel, Rohrer, and Bjork, “Learning Styles.”
Terr, Unchained Memories.
QUESTIONS TO CONSIDER

1. Although the evidence to date for incorporating learning styles in education is weak, it’s possible that future studies will demonstrate the value. Do you think they will? In other words, do you think that people do have significantly different learning styles and that tailoring instruction to those styles would make a big difference?

2. Why do you think listening to Mozart was associated with improved spatial reasoning (even if it was short-lived and only in a subset of studies)?

3. Do you think people can repress and subsequently recover an authentic traumatic memory?
In addition to learning conscious, explicit information, we do a lot of unconscious, implicit learning—the subject of the next 6 lectures of this course. There are 3 major types of implicit learning: procedural learning, nonassociative learning, and associative learning. Although these types of learning lead to changes in behavior, they don’t lead to new, explicit knowledge that can be verbalized. But they also differ from each other in important ways. This lecture will focus on nonassociative learning and associative learning.
Nonassociative Learning

- Nonassociative learning refers to changes in behavior related to a stimulus that do not involve associating that stimulus with another stimulus or event. When repeated exposure to a stimulus by itself changes your reaction to that stimulus, that’s nonassociative learning.

- A type of nonassociative implicit learning is habituation. We habituate to stimuli all the time, and we’re typically unaware of it. For example, you get habituated to the sound of a fan blowing. Over time, your response to the sound gets smaller and smaller until finally you don’t notice it at all.

- Admittedly, this is a very simple kind of learning, but it’s still learning. Your behavior is changing as a result of your previous experience—in this case, your experience of being repeatedly exposed to a stimulus. Essentially, you’re learning to ignore it.

- But this kind of learning is quite different from explicit learning. You’re not learning declarative, verbalizable information in this case; rather, you’re implicitly learning to pay less and less attention to a particular stimulus.

- Also, notice that this is not associative learning. You’re not associating the sound of the fan with something else in the world. You’re just learning to ignore one particular sensory input.

- The opposite can also happen; that is, rather than learning to ignore a stimulus, you can learn to become more sensitive to it. This is called sensitization, and it’s also a form of nonassociative learning.
• Imagine that you’re trying to watch a movie at the theater, but someone in the row behind you is constantly whispering to a friend throughout the movie. Rather than getting used to the sound and habituating to it, you might actually become more and more sensitive as the movie goes on. You might perceive the whispers as getting louder, even if they aren’t.

• This is an example of sensitization. Previous experience with the whispering makes you more and more sensitive to it.

• And just like habituation, sensitization is a type of nonassociative memory. You’re not necessarily learning to associate the whispers with something else; you’re just learning to become more sensitive to it.

• A related learning phenomenon is priming, which occurs when previous exposure to a stimulus makes you faster, or more efficient, at processing similar stimuli in the future. For example, suppose you are asked to repeatedly say a few relatively difficult-to-pronounce words out loud, such as “otorhinolaryngologist” and “antidisestablishmentarianism.” The more you say the words, you’ll probably get a little faster and more fluid. Saying them the first few times “primes the pump” and makes the words come out more fluidly and efficiently the next time.
Associative Learning: Classical Conditioning

- Associative learning includes both classical conditioning and operant, or instrumental, conditioning.

- The study of conditioning began by accident. The famous physiologist Ivan Pavlov was studying the digestive system of dogs and decided to measure how much saliva the animals produced when they were given meat powder.

- But he quickly discovered that the dogs started salivating as soon as the experimenters entered the room, which made it impossible for him to conduct the experiment he was planning. But being the brilliant scientist that he was, Pavlov realized that this behavior also demonstrated a clear type of learning.

- Pavlov devoted much of the rest of his career to studying this kind of learning, which has come to be known as classical conditioning. It’s also sometimes called Pavlovian conditioning in honor of its discoverer.

- Classical conditioning is associative because it involves learning new associations.

- An unconditioned stimulus is an environmental stimulus that automatically triggers some unconditioned response. For example, giving a dog meat powder automatically triggers salivation, so in Pavlov’s case, the meat powder is the unconditioned stimulus and the salivation in response to the meat powder is the unconditioned response.

- These are called unconditioned, or unconditional, because they’re not conditional on any learning. Salivating when given food doesn’t depend on learning; it’s just an automatic, reflexive response.
But then, a conditioned stimulus is presented with the unconditioned stimulus. Critically, the conditioned stimulus does not automatically trigger the response of interest; rather, the response is conditional on learning.

The conditioned stimulus in Pavlov’s case was the sound of the experimenters entering the room. That sound doesn’t automatically trigger salivation the way that having food in your mouth does, but the dogs eventually learned to associate that sound with getting food, so after a few days, they started salivating in response to that sound.

Such a response—that is conditional on learning—is called the conditioned response. Salivation in response to food is an unconditioned response, because that doesn’t depend on learning.

But when Pavlov’s dogs started salivating in response to the sound of the experimenters, that was a conditioned response, because that did depend on learning.

Why are these associations being learned? Many people assume that our brains automatically associate events that happen together in time and space.

According to that idea, the reason that the sound of the experimenters got associated with the meat powder is because the dogs were given the meat soon after they heard the experimenters. In other words, the association was formed because of temporal contiguity, because the sound and the meat powder occurred together in time. But that idea is wrong.

A number of studies have shown that what really matters is contingency, not contiguity. In particular, it’s not sufficient that the conditioned stimulus occurs at the same time as the unconditioned
stimulus. The conditioned stimulus actually needs to be a good predictor of the unconditioned stimulus, and a better predictor than other stimuli that may be present.

- For example, imagine that the unconditioned stimulus does tend to occur when the conditioned stimulus occurs, but it occurs just as frequently when the conditioned stimulus isn’t present. In Pavlov’s case, imagine that the dogs were just as likely to get meat powder from a machine as they were to get it from the experimenters when they entered the room.

- In that case, the sound of the experimenters isn’t a great predictor of the meat powder, even though it co-occurs with the meat powder in time. And a number of experiments have shown that conditioning doesn’t occur under those circumstances.

- The appearance of the conditioned stimulus needs to mean that the unconditioned stimulus is more likely to occur than before. Co-occurrence alone is not sufficient.

- Another important finding in the study of classical conditioning is associative bias. Put simply, not all associations were created equal. Some associations are quite natural while others are more artificial, and humans and animals both learn the natural associations more easily.
• Consider learned food aversions, for example. Many people have developed aversions to particular foods after eating a bad batch. Maybe you can no longer stand the sight of crab because you once ate some spoiled crab that made you sick.

• Learned food aversions are quite common, and they can be induced in laboratory animals very easily. For example, if rats are given a novel food to eat and are then injected with a drug that makes them sick, they will quickly learn an aversion to the novel food. And they learn this aversion much faster than Pavlov’s dogs learned their association. In fact, animals can learn food aversion after a single trial. And they can learn it even if they don’t get sick until hours after eating the novel food.

• Why is learning a food aversion so much easier than learning an arbitrary association? Presumably, it’s because eating spoiled food is a real-life risk that animals need to avoid in order to survive. Therefore, all animals, including humans, are particularly sensitive to learning those kinds of associations.

**Associative Learning: Operant Conditioning**

• Operant, or instrumental, conditioning involves learning how to behave in order to receive rewards and avoid punishments. Actions that are reinforced in a certain context will tend to be performed more often in that context, and actions that are punished in a situation will tend to be avoided in similar situations.

• Like classical conditioning, operant conditioning is also a type of associative implicit learning. But in this case, a 3-way association is being learned between the context, the action, and the reward.
• People exploit the principles of operant conditioning every day when they try to shape the behavior of others, especially children. The teacher who praises a young student for correctly reading a new word and the parent who punishes a child for not finishing his or her chores are both relying on operant conditioning to try to shape the child’s behavior.

• The original research on operant conditioning was published in 1898 by Edward Thorndike, who put hungry cats inside what he called a puzzle box and measured how long it took them to escape to get to a dish of food that was just outside. Inside each box was a device that would open the door to the box if pressed or pulled in the right way.

• Initially, the cats moved around relatively randomly, clawing at the box and meowing. But eventually, they would accidentally hit the unlatching device, the door would open, and they would be able to escape and reach the food.

• The critical test was what would happen if Thorndike kept putting the cats back in the same box. And he found that they gradually got faster and faster at escaping. After 5 or 6 trials, the cats learned to go straight to the lever and push it, allowing them to escape within just a few seconds.

• Thorndike hypothesized that escaping the box and getting food was reinforcing the behavior of pressing the lever relative to all the other actions that the cat could perform inside the box. And with each successful escape, that behavior got more and more reinforced and therefore more likely to be performed.

• Thorndike summarized this idea in his law of effect, which basically states that we learn to do what gets rewarded and to avoid doing what gets punished.
Operant conditioning is typically classified into 4 major types: positive reinforcement, negative reinforcement, positive punishment, and negative punishment. As expected, reinforcement means that something desirable is happening, while punishment means that something undesirable is happening. But the terms “positive” and “negative” don’t have their normal meaning of good and bad in this context; rather, positive means that something is being added, while negative means that something is being taken away.

In positive reinforcement, something is being added that is desirable. If taking a specific action leads to getting something that you like, that would be positive reinforcement. An example is giving children a treat when they finish their homework; the children are getting something they like as a result of a particular behavior, so that behavior is getting reinforced.

During negative reinforcement, on the other hand, taking an action leads to something unpleasant being removed. For example, suppose that the children’s reward for finishing their homework is that they don’t have to do the dishes. The behavior of finishing the homework is still being reinforced, but the reward is based on removing something unpleasant.

Positive punishment refers to actively punishing a specific behavior by adding something unpleasant. An example is making a child do the dishes because he or she used vulgar language. The hope would be that doing so would reduce the frequency of that vulgar language in the future.

Negative punishment involves removing something pleasant as a punishment for some behavior. Think of taking away TV privileges because of the foul language in the hopes of discouraging that behavior.
Learned Helplessness

The principles of operant conditioning have had an enormous influence in the real world in a variety of fields. Many parents apply these principles almost instinctively in the way they raise their children, and teachers are trained to reinforce desirable behaviors in the hopes of helping students succeed.

Operant conditioning has also been used to explain, and potentially treat, many psychological and social problems, including clinical depression, addiction, and weight management.

Some of this work was inspired by findings of learned helplessness in animals. Some of the most famous work in this area was done by Martin Seligman and Steven Maier.

- One group of animals could avoid a shock by pushing a lever, and they quickly learned to do so. This is an example of negative reinforcement. But another group of animals were not able to avoid the shock during the training phase.

- Then, both groups of animals were put in a new situation in which they could escape a shock by jumping over a barrier. The animals who had been able to press a lever to avoid the shock during the training phase also learned to jump over the barrier. They tried different actions until they finally hit on jumping over the barrier. And once that behavior was reinforced, they quickly learned to do it on future trials.

- But the other group of animals, who had not been able to avoid the shock during the training phase, didn’t learn to jump over the barrier, even though it would have worked. Rather, they passively suffered through the shocks without trying anything to avoid them.

The standard interpretation is that this second group of animals had learned something harmful—that they couldn’t avoid shocks no matter what they did. As a result, they didn’t even try to avoid the shocks during the second phase of the experiment. They had learned that they were helpless.
SUGGESTED READING

Eichenbaum and Cohen, *From Conditioning to Conscious Recollection.*

QUESTIONS TO CONSIDER

1. Do you think it’s significant that implicit memories are unconscious? Suppose that you became consciously aware of all the implicit learning going on in your brain. How would that affect you?

2. What are some examples of when you’ve been conditioned in your life?
Learning any complex motor skill is difficult. The first time you hit a tennis serve or golf ball, or tied your shoe, it required all of your effort and concentration—and you still probably didn’t do very well. But with enough practice, you eventually learn to perform the skill kind of automatically. And when you do, it doesn’t even require your full attention. How do you go from being a complete novice at a skill to getting pretty automated so that you can perform other tasks at the same time? That’s skill acquisition—the topic of this lecture.
Skill Acquisition

• A standard way that psychologists think about skill acquisition is as converting explicit, declarative knowledge into an implicit, procedural skill. How do we go from knowing that to knowing how?

• Explicit, declarative knowledge is knowledge about a skill that you can verbalize and talk about—declare. It’s the book knowledge and verbalized instructions about how to perform a skill. But actually doing a skill requires implicit, procedural memory. Just because you can talk about how to do a skill, that doesn’t mean that you can actually do it. Somehow you need to convert the declarative knowledge into a procedural skill that you can actually execute. And that takes practice and time.

• Imagine that you are just starting to learn to play the piano and that your first lesson is how to play a D major scale. The first time you do this, you will be pretty slow. But the second time you do it, you will probably be a little bit faster. And after about a week of practice, you will be much faster. You’re not going to be a skilled pianist after just a week of practice, but you will be dramatically better than you were on the first day.

When learning a complex skill, such as piano, tennis, or golf, the most dramatic improvements will be made in the first few days and weeks of practice.
If you continue to practice, then you’ll still continue to improve. You’ll still get faster at playing that musical scale. But the rate of your improvement will slow down. When you’re practicing a complex skill, you’ll improve a lot initially, but it becomes more and more difficult to get better as you become more and more skilled. You reach a plateau, and it takes more and more practice to make even small improvements. This characteristic pattern that is observed when people are learning new skills is called the power law of practice.

**Stages of Skill Acquisition**

Paul Fitts and Michael Posner came up with a very influential theory that proposes that we go through 3 major stages over the course of skill acquisition: the cognitive stage, the associative stage, and the autonomous stage.

1. The cognitive stage is dominated by cognition—that is, by thinking, or by explicit, declarative knowledge.

   Suppose that you’ve never played golf and that you take a lesson. The golf pro will probably start out by giving you some verbal instructions, such as “keep your left arm straight when you swing.” Now you have a bunch of verbal instructions that you will dutifully try to execute. In fact, you may try to memorize some of the verbal instructions or even write them down. And you may consciously and deliberately rehearse the verbal, declarative knowledge that the pro told you as you’re trying to hit a golf ball.
One of the key characteristics of the cognitive stage is that it’s cognitively demanding; that is, it requires all of your attention. So, you can’t really do other things when you’re in the cognitive stage. All of your attention has to be focused on performing the task and rehearsing the facts that you’ve committed to memory.

Notice that there’s a big difference between knowing the declarative knowledge associated with the skill and being able to execute that skill. Having the declarative knowledge is different from having the skill; you could have one and not the other.

The associative stage involves tweaking the skill, associating it with different responses, and hopefully improving. It involves figuring out what works and what doesn’t and using that feedback to slowly get rid of actions that lead to errors.

Suppose that you’ve been taking tennis lessons for a while and you’re trying to improve your serve. You go to the court and hit a bunch of serves. As you practice, you begin to fine-tune your serve by making changes that lead to better results.

You’re associating tweaks with outcomes, or results. And with additional practice, you start to figure out what tweaks work and what tweaks don’t work. For that to happen, you need to be getting feedback. That feedback could come from another person, but it doesn’t have to. You just need to be able to observe what works and what doesn’t.
The autonomous stage is the point at which the skill can be performed really well without having to think about it.

Think of the skilled golfer who can hold a conversation while hitting golf balls at the range. Unlike the cognitive stage, which requires a lot of attention, the autonomous stage doesn’t. Performing the skill is no longer nearly as cognitively demanding. In this stage, there is less dependence on verbalization and declarative knowledge.

Furthermore, declarative knowledge about the skill may actually become less available the more skilled you get. Maybe when you were taking lessons initially, you memorized all these things about the golf swing and could even recite them from memory. But once the skill gets automated, you may actually forget some of the declarative knowledge that you used to rely on.

Getting feedback is crucial during the associative stage of skill acquisition, but this is not the case during the autonomous stage. Musicians and athletes at this stage of skill acquisition would typically know what happened even if they weren’t getting much feedback.
How Skill Acquisition Happens: A Theory

- When practicing, how do we move from the cognitive to the associative stage and from the associative to the automatic stage? In other words, how do we transform declarative knowledge—the book knowledge and verbalized instructions about how to perform a skill—into a procedural skill?

- One of the most influential answers to this question was developed by John Anderson, who proposed that the nature of our representation of procedural skills is very different from our representation of declarative knowledge. In particular, he argued that we represent procedural knowledge using production rules, or associations between some conditions and some actions.

- You can think of a production rule as an if-then association: If the conditions are satisfied, then perform the action. Critically, this association is not explicit or conscious or declarative; rather, the association is automatic, unconscious, and implicit.

- When certain conditions are satisfied, then a certain association fires automatically, and the actions associated with those conditions are automatically and immediately executed. You don’t have to consciously decide to take those actions. That’s what makes it implicit and procedural, rather than declarative.

- For example, when you walk, you’re not usually thinking about how to walk; instead, it’s an automatic set of associations. That’s what production rules are: automatic associations. Walking is not conscious; it’s an implicit, unconscious, procedural skill.
• The idea is that your ability to walk is stored as a big set of automatic production rules—the automatic associations between conditions and actions. And these production rules are stored in a procedural memory system, which is completely separate from the explicit, declarative memory system.

• According to Anderson, the key question is how to convert declarative knowledge into production rules. Suppose that you read a book about how to hit a tennis serve. How do you convert that declarative knowledge into some automatic associations that are stored in procedural memory and that will fire automatically when you want to hit the ball?

• Anderson refers to the conversion process as knowledge compilation, in which you compile declarative knowledge and turn it into procedural knowledge. In computer science, a compiler takes a high-level description of the program you want to run and transforms it into an executable form. In this case, the high-level description is in English rather than a programming language, and the executable form is a set of production rules rather than a computer’s machine code—but the basic idea is the same.

• According to Anderson, as we’re learning a skill, we’re taking a high-level declarative description of what we want to do and converting it into a form that our motor system can actually execute. How do we transform explicit, declarative knowledge into implicit production rules? How do we compile our knowledge? Anderson proposed that there are 2 major stages: proceduralization and composition.

• Proceduralization involves taking an individual piece of declarative knowledge and converting that piece into a single production rule—an automatic if-then association between conditions and actions.
• For example, suppose that you’re trying to teach a child how to tie his or her shoelaces and you start by telling him or her what to do: “First, cross that right lace underneath the left lace and then form a loop with that right lace. Then, wrap the left lace around the base of that loop and push it through and out.”

• The first step is to turn those individual pieces of declarative knowledge into individual production rules—that’s proceduralization. Consider the first part of the instruction: Cross the right lace underneath the left lace. What would the production rule corresponding to that instruction look like?

• The production rule is just an automatic association between a set of conditions and a set of actions. The actions in this case correspond to a set of motor commands that will grab the right lace and slide it underneath the left lace. The conditions specify when those actions should be performed, such as having the goal of tying your shoes, looking at your shoes, and seeing that they’re untied. Under those conditions, you should perform the action of crossing the right lace underneath the left.

• You proceduralize that first piece of declarative knowledge by creating an automatic association between those conditions and those actions: If you have the goal of tying your shoes, you’re looking at your shoes, and you see that they’re untied, then execute the motor commands to grab the right lace and slide it underneath the left lace.

• That association is implicit, automatic, and procedural. It’s not declarative anymore. You’re not talking yourself through the process; your hands are just doing it.

• The next step is to proceduralize each of the other pieces of declarative knowledge. So, if the next instruction was to form the loop, then you would create an automatic production rule to
perform that action. The conditions might specify that you’re tying your shoes and you’ve already crossed the right lace under the left one, and the actions would be motor commands to form the loop.

- This process continues for each of the other instructions for tying shoelaces. You create separate production rules corresponding to each piece of declarative knowledge.

- The second part of knowledge compilation is composition, which involves combining separate production rules together into a single, more complicated production rule—in other words, grouping them together. When you get good at tying your shoes, you don’t do it piece by piece; rather, you perform the whole skill as an integrated, fluid set of motions. Once you’ve composed this master production rule for shoe tying, it will handle the whole job in one fell swoop.

SUGGESTED READING

Anderson, “Acquisition of Cognitive Skill.”
———, Cognitive Skills and Their Acquisition.
Fitts and Posner, Human Performance.

QUESTIONS TO CONSIDER

1. Do you think the cognitive stage or the associative stage is more important when acquiring a skill?

2. Psychologists typically treat learning a sport and learning an instrument similarly (as examples of motor skill learning). Can you think of any important differences between them?
THIS LECTURE IS ABOUT ONE OF THE LEARNING BRAIN’S GREATEST ACHIEVEMENTS: learning how to speak and understand a language. Natural languages are arguably the most complicated of all human inventions. They involve hundreds of thousands of words that are formed according to complex rules that often include hundreds of exceptions. And the words themselves have to be combined according to sophisticated syntactic rules that the world’s top linguists still don’t completely understand. Yet toddlers across the world learn these amazingly complicated inventions.
If you start learning a language as an adult, it’s very unlikely that you’ll ever get as good as someone who learned that language as a child.

In general, people need to start acquiring a language before age 10 to 12 if they ever want to speak it like a native. Those early childhood years are therefore often referred to as a critical, or sensitive, period for language acquisition.

It’s not about how long you work on the language; it’s about when you start acquiring it.
The Problem of Language Acquisition

• All of us comprehend and generate millions of different sentences, and we do this effortlessly—and very quickly. This is true even though many of the sentences that we produce and many of the sentences that we hear are completely novel. We know more than 100,000 words in our native language and are constantly combining these words in novel ways without even thinking about it. And this ability is unique to humans; no other species does this.

• The problem of language acquisition—how challenging the task of acquiring a natural language is—can be illustrated by walking through some of the obstacles that babies have to overcome to learn their native language.

• First, they have to realize that not all sounds are language. They need to distinguish language sounds—that is, speech—from all the other sounds in the environment, such as the sounds of the doorbell ringing and a dog barking. This is the first obstacle in language acquisition: just figuring out what the target is. What are the sounds that babies need to focus on to start learning a specific language?

• Let’s say that a baby has figured out that some of the weird sounds that come out of his or her parents’ mouths correspond to a kind of communication. And the baby begins focusing on them and trying to figure them out. That’s a very far cry from actually understanding what is being said, much less being able to produce language. And before a baby can understand what it means, he or she needs to be able to recognize the sounds that make up the words.

• Every language has roughly 40 to 100 different language sounds that get combined to form the words of the language. Just as we combine 26 different letters in different ways to spell words, we also combine a relatively small set of language sounds in different
ways to pronounce words. These basic, atomic language sounds are called phonemes. And we all need to recognize the phonemes in someone’s speech before we can figure out what the person is saying.

- For example, when you hear the word “cat,” you need to somehow chop this continuous stream of noises into component phonemes: “cuh,” “ah,” and “tuh.” And even if you have done that, you also need to figure out which phonemes are grouped together in the same word and which phonemes are in different words. That’s actually very difficult, because when people speak, all of the words glide together. It’s just a continuous stream of phonemes, and it’s not at all clear where the word boundaries are.

- That’s another major problem that babies have to overcome: Once they have figured out what the language sounds are and recognize the individual phonemes, they still have to chop the sequence of phonemes up into words.

*English speakers have adopted the convention of producing the sound “apple” when they want to refer to a crisp, spherical fruit that grows on trees and is usually red. But to a baby who is learning English, the sound of the word “apple” doesn’t really provide any clues about what the word means.*
• Let’s say that they’ve done all that. They still need to figure out what the words mean. And for the vast majority of words, the sound doesn’t give any clue about its meaning. That’s because the mapping from the sound of a word to its meaning is usually completely arbitrary; it’s just a cultural convention that all the speakers of a language adopt to allow them to communicate.

• Worse yet, the same sound can mean different things, and different sounds can mean the same thing. For example, the word “bank” can be used to refer to a financial institution or to the side of a river. Conversely, the words “car” and “automobile” refer to the same thing. Such irregularities make the task of learning word meanings very difficult.

• But let’s say that you have distinguished language sounds from other sounds, parsed language sounds into individual phonemes, figured out where the word boundaries are, and even begun to figure out what some of the words mean. You still have to figure out the grammar of your language. How do you put different words together into phrases? How do you combine phrases into sentences in a grammatical way?

• And that grammatical knowledge has to generalize. In other words, you can’t just imitate and repeat back sentences you’ve heard in the past; you have to learn general-purpose grammatical rules that you can apply to novel sentences that you’ve never heard before.

• Children are learning a lot about language in the first few years of life. And they do all of this without a lot of feedback. In other words, adults don’t usually correct their children’s grammar or pronunciation. Psycholinguists who have tried to correct their own children’s grammar found that providing explicit feedback when the child makes a mistake doesn’t help him or her acquire language
any faster than other children do. Apparently, children simply correct themselves over time. They implicitly learn the rules of their language despite the lack of feedback.

Genetic Wiring and Linguistic Universals

• The task of acquiring a language is extremely difficult, yet all normal human children acquire natural language—and they do so despite the fact that they aren’t getting much feedback about how they’re doing. All these considerations led scientists to propose that human beings must in some sense be born to learn language. In other words, language learning is genetically wired into the brains of all normal human beings from birth.

• Babies automatically work on figuring out how their language works, what sounds correspond to what words, what those words mean, and how those words get put together into grammatically acceptable phrases and sentences.

• The basic argument is that if we weren’t genetically wired to acquire language, then there is no way that babies could do it. The task is just too daunting.

• Babies in different parts of the world have to learn different languages. American babies are not specifically wired to learn English, and French babies are not genetically wired to learn French.

• The claim is that human beings are genetically wired to learn whatever natural language they’re exposed to, whether that language is English, French, or one of the roughly 7000 other natural languages spoken in the world today.
• But that only works if all those languages share some common principles that babies everywhere can expect and exploit. And it turns out that all languages do share some commonalities.

• For example, all natural languages are based on words. And those words are based on combinations of specific sets of phonemes. Those words are divided into specific parts of speech, such as nouns and verbs. And those parts of speech help determine how words are put together into phrases and sentences.

• These kinds of common principles are sometimes called linguistic universals, meaning that they’re shared by all the world’s natural languages. Some languages tend to put the verb at the end of the sentence while others tend to put it in the middle, but regardless of the language, there will be a verb. And that linguistic universal constrains the language acquisition problem and makes it more tractable.

Language Development

• What do we see when we actually observe children trying to acquire language? Let’s start at the level of just distinguishing the phonemes of a language.

• Different languages use different phonemes. For example, English has phonemes corresponding to the sounds “ull” and “err.” That’s what distinguishes the word “light” from the word “right.” Japanese, on the other hand, does not have these 2 separate phonemes; rather, it has a single phoneme that’s somewhere in the middle. This is why adult Japanese speakers often have a difficult time hearing the difference between the word “light” and the word “right.” And there are plenty of phonetic differences in other languages that English speakers have a difficult time hearing.
• Babies have to be prepared to learn any language, and it turns out that they are able to hear the subtle phonetic distinctions that are present in every language. Six-month-old infants can often hear phonetic distinctions that adults actually have a difficult time noticing. For example, a baby in Japan can tell the difference between “light” and “right” even though that baby’s parents might not be able to.

• Research has shown that babies can hear the phonetic distinctions in any natural language. But as they get more and more exposure to their native language, their speech perception gets specialized to that language. And sounds that correspond to different phonemes in that language begin to sound more distinctive, while different sounds that correspond to the same phoneme begin to sound more similar.

• Some of the major stages of language development that children go through include the holophrastic stage, sometimes called the 1-word stage; the telegraphic stage, sometimes called the 2-word stage; and the stage at which they start learning the syntax, or rules, of their grammar.

  ♦ In the holophrastic stage, children are producing 1-word utterances, such as “mama” and “daddy.” One key feature of this stage is evidence of both undergeneralization and overgeneralization. Undergeneralization occurs when a child uses a word in a more restrictive sense than is appropriate. For example, the word “dog” could refer to millions of animals around the world, but a child in this stage may use “dog” only to refer to his or her own dog. Overgeneralization would be using the word “dog” to refer to cats as well as dogs.

  ♦ In the telegraphic stage, children can pretty much communicate anything they want to very succinctly. Even though there is limited linguistic ability, children in this stage can communicate extremely effectively using simple 2-word utterances, such as “dog bark” and “drink milk.”
Another important milestone is learning the complex grammatical rules of the language. To take just one example, children need to learn how to form the past tense of verbs. In the past tense in English, there are 2 different kinds of verbs: regular verbs, where you form the past tense by adding “‑ed” (Today you “laugh” while yesterday you “laughed”); and irregular verbs, where you don’t form the past tense by adding “‑ed” (Today you “go” while yesterday you “went”).

If you track the correct use of irregular past tense forms (such as “went”) as a function of a child’s age, children get worse before they get better at using irregular past tense forms as they get older.

The U-shaped acquisition curve supports the hypothesis that children are beginning to learn general-purpose rules and apply them to other words.

**SUGGESTED READING**

Clark, *First Language Acquisition.*

———, *Language in Children.*

Pinker, *The Language Instinct.*

**QUESTIONS TO CONSIDER**

1. Do you think the way we learn a language is fundamentally different than the way we learn other skills?

2. Do you think we learn a second language in the same way we learn our native language? What are some similarities and differences?
This lecture is about the neural mechanisms underlying implicit learning. How is simple nonassociative learning, such as habituation and sensitization, actually implemented at a neural level? How does the brain change during classical and operant conditioning?
Neural Mechanisms Underlying Nonassociative Learning

• Many of the early insights in implicit memory came from studying the sea snail *Aplysia californica* (pictured below), which exhibits many simple implicit learning mechanisms. For example, it exhibits habituation to being touched. Initially, it quickly withdraws its gill when it’s touched, but if it’s touched repeatedly and gently, it eventually learns to ignore the touch and stops withdrawing its gill. It also exhibits a simple form of sensitization, in which its gill withdrawal reflex gets stronger over time under the right circumstances.

• What changes in the brain when we learn? Is the newly learned information stored in new brain cells that grow in response to the learning, or are new connections created between existing neurons? Is there a specific place in the brain that is critical to implicit learning, similar to the way the hippocampus and medial temporal lobes are critical for explicit learning?

• Eric Kandel and his colleagues started working on these kinds of questions by studying the gill withdrawal reflex in *Aplysia*. And those studies eventually led to the Nobel Prize in Physiology. They began by mapping out the exact neural circuit involved in the gill withdrawal response. Because the nerve cells in *Aplysia* are big and easily identifiable, they were able to stimulate and record from individual neurons to see if they were involved in this reflex response.
• They discovered that the circuit was always the same. They could identify the same neurons in different animals, and the neurons were always connected in the same way. And they could easily identify specific neurons and repeatedly return to study them, both before and after learning, even in different animals.

• How does this circuit change after learning? First consider habituation, one of the simplest forms of implicit learning. *Aplysia* has a gill that it uses for breathing and a siphon that it uses to expel water. When the animal is at rest, the gill and siphon are often extended outside of the body. But if the siphon is gently touched, the animal will withdraw them in a defensive reaction—the gill withdrawal reflex. But if you repeatedly touch the siphon and nothing bad happens to the animal, it eventually gets used to it and stops withdrawing.

• Kandel and his colleagues carefully examined the neural circuit of the gill withdrawal reflex before and after habituation to try to figure out what had changed that might account for the change in behavior. And at first, they didn’t see much. All the same neurons were there after learning as had been there before. No neurons had grown, and no neurons had been removed.

• Furthermore, the number and location of connections between the neurons appeared to be unchanged. The neurons that had been connected before habituation were still connected after habituation. And there weren’t any new connections that hadn’t been there before.

• So, why did the snails behave any differently? Kandel and his colleagues discovered that the neurons in the circuit reduced the strength of their signals. Specifically, they released less neurotransmitter than they did before habituation.
• Neurotransmitters are chemicals that neurons use to communicate with each other. Essentially, when a neuron wants to send a signal to another neuron, it releases a bunch of neurotransmitter molecules in the synapse, the very small space between one neuron and the next. The neurotransmitter molecules then move across the synapse and bind to special receptor molecules on the next neuron and turn them on.

• When those receptors get turned on, they might trigger the next neuron to fire and send a neurotransmitter signal to another neuron—and so on. That’s the way information gets sent through the neural circuits in your brain. All of your perceptions, decisions, and actions are based on neurons firing and triggering other neurons to fire.

• Before habituation, touching the siphon leads a bunch of neurons to fire and release a lot of neurotransmitter molecules. First, sensory neurons in the siphon fire in response to the touch itself. These sensory neurons are connected to motor neurons that can withdraw the gill, and when the sensory neurons fire, they release a bunch of neurotransmitter molecules into these synapses. The neurotransmitter molecules bind to receptors on the motor neurons and turn them on. And that causes the motor neurons to start firing vigorously and leads to the withdrawal of the gill.

• But Kandel and his colleagues found that after repeated gentle touching, the sensory neurons in the siphon started releasing less and less neurotransmitter. As a result, the receptors on the motor neurons weren’t turned on as much, and the gill withdrawal response became smaller and smaller. That was the neural basis of habituation: reduced neurotransmitter release. And similar findings have been reported in many other species.
The snail’s habituation to being touched usually only lasts a few minutes. So, if you wait 15 minutes and then touch the siphon again, the snail will withdraw its gill just like it used to before learning. But Kandel and his colleagues found that if they kept touching the siphon repeatedly over the course of a few days, then the habituation would last much longer. In that case, they could touch the animal’s siphon more than 3 weeks later and it still wouldn’t withdraw its gill very much. In other words, the animal had learned a long-term implicit memory.

The human brain contains nearly 100 billion neurons, or nerve cells. And because neurons tend to make about 1000 connections each, the total number of connections is around 100 trillion. To put that number in perspective, there are probably more neural connections in your brain than there are stars in the Milky Way galaxy.
Craig Bailey and Mary Chen investigated what makes the memory last longer by carefully counting the number of active zones on neurons—that is, the specific regions at the end of the neurons where they made synaptic connections with other neurons. They did this both before and after habituation. And they found a profound structural change.

After long-term habituation, the animals had fewer than half as many active zones as before habituation. Apparently, the animals had pruned away a lot of the synaptic connections supporting the gill withdrawal feedback.

In addition to habituation, sensitization—in which repeated exposure to a stimulus makes you respond more and more—is another kind of nonassociative memory. Scientists also studied this kind of learning in *Aplysia*. Although repeated, gentle touching of the siphon leads to habituation, repeated shocks lead to sensitization; that is, after being shocked repeatedly, the animal will exhibit a larger-than-normal gill withdrawal response if it’s touched afterward, even if now there is no shock. It’s as if the animal is now very wary of any kind of touch.

Implicit learning occurs in the same neural circuits that control the behavior that is changing. This is fairly different from explicit learning, in which a specific region of the brain—the hippocampus—is dedicated to that function specifically.
• The same neural mechanisms that underlie habituation also seem to be at work during sensitization, but in the opposite direction: Whereas short-term habituation leads to a decrease in neurotransmitter release, short-term sensitization leads to an increase in neurotransmitter release, and while long-term habituation is associated with a decrease in the number of synaptic connections, long-term sensitization is associated with an increase in the number of connections.

Neural Mechanisms Underlying Associative Learning

• Next, let’s consider associative learning, such as classical and operant conditioning. What was changing in the brains of Pavlov’s dogs when they learned to associate the sound of experimenters with the reward of food?

• One of the key ideas to come out of studies on conditioning is the idea of reward prediction error. We tend to learn associations between stimuli and rewards, or between behaviors and rewards, when we fail to predict those rewards.

• Consider the phenomenon of blocking: If you’ve already learned an association between 2 stimuli, then that existing association can block the learning of other associations. For example, if you’ve already learned an association between seeing a red light and hearing a fan, then you might not learn an association between a green light that starts coming on later that also predicts the fan. In that case, the green light does not become associated with the fan, because the red light could already predict it. As a result, there was no prediction error and no new learning.
• In one of the most exciting neuroscientific discoveries of the last 25 years, Wolfram Schultz found what now appears to be the neural basis of this kind of prediction error. He was studying neurons in a small part of the brain called the ventral tegmental area (VTA), which is in the midbrain at the top of the brain stem.

• Schultz had implanted electrodes in the VTA of some monkeys, and he was recording the activity of dopamine neurons—which use the neurotransmitter dopamine to send signals to other neurons—in that brain area while the monkeys were performing a learning task.

• The monkeys were performing a basic conditioning task. Specifically, if they pressed a lever after a light flashed, then they would get a squirt of good-tasting juice, which served as a reward. Schultz recorded neural activity in the VTA while the animals learned to press a lever so that he could watch how VTA neurons behaved before and after learning.

• When the monkeys first started doing the task, Schultz noticed that the VTA neurons tended to fire when the monkey got a juice reward. He saw a big spike of neural activity as the VTA neurons fired and released dopamine. But once the monkeys figured out that they would get the juice as long as they pressed the lever when the light came on, then the VTA neurons stopped firing in response to the juice.

• That’s exactly what you would expect a reward prediction error to look like in the brain. These neurons fire a lot when they get a reward that they weren’t expecting and don’t fire when they get a reward that they were expecting. In other words, the neurons fire in response to a reward prediction error.
• After the monkeys had learned the task, the VTA dopamine neurons started firing in response to the light rather than the juice. Like Pavlov’s dogs, the VTA neurons in Schultz’s experiment initially fired in response to the juice reward, but after conditioning, they started firing in response to the stimulus that predicted the juice: the flash of the light.

• In addition to the midbrain dopamine system, another neural mechanism that plays a critical role in associative learning, and is also critical in many other types of learning, is long-term potentiation (LTP).

• In 1949, Donald Hebb wrote *The Organization of Behavior*, in which he laid out a theory that tried to connect what psychologists knew about behavior with what neuroscientists knew about the brain. In particular, he proposed an idea that has come to be known as Hebbian learning: If the activity of one neuron repeatedly leads to the firing of another neuron, then the synaptic connection between them will get stronger. Put simply, neurons that fire together, wire together.

• More than 20 years after Hebb originally proposed this idea, Tim Bliss and Terje Lømo discovered empirical evidence that Hebb was right. Specifically, they found that if they artificially stimulated a neural circuit with high-frequency electrical activity, the strength of the synaptic connections in that pathway got stronger. Furthermore, they found that the strength, or potentiation, of those synaptic connections lasted for days or even weeks, so they referred to the phenomenon as long-term potentiation (LTP).

• A few years later, Gary Lynch and his colleagues demonstrated that it was also possible to induce the long-term depression (LTD) of synaptic connections. In that case, the synaptic connections get weaker rather than stronger.
• It seems likely that LTP and LTD play an important role in long-term associative learning. But just because artificial stimulation leads to synaptic changes, that doesn’t necessarily mean that these mechanisms play a role in real-life learning.

• To test that hypothesis, Richard Morris and his colleagues tested rats’ ability to learn before and after being injected with a drug that blocks LTP. Specifically, the rats had to perform the Morris water maze task, which involves learning where a hidden platform is in a pool of opaque water.

• Normally, rats swim around until they stumble upon the platform but then quickly learn its location and swim straight for it when they’re put back in the pool. But after being injected with the LTP-blocking drug, the rats were significantly impaired at learning the platform’s location, suggesting that LTP is playing a role in real-world learning.

• LTP and LTD have been found in numerous parts of the brain, but they have been most studied in the hippocampus—which is crucial for explicit learning. These are basic neural mechanisms that could play a role in both implicit and explicit learning.

SUGGESTED READING

Kandel, In Search of Memory.
Schultz, “Predictive Reward Signal of Dopamine Neurons.”
Squire and Kandel, Memory.
QUESTIONS TO CONSIDER

1. What do you see as the major advantages and disadvantages of studying learning in animals when trying to understand human learning?

2. The neural mechanisms that underlie human learning are thought to be quite similar to those that underlie animal learning. So, why do you think humans learn so much more than animals do?
HOW SHOULD YOU PRACTICE TO GET BETTER AT A PARTICULAR SKILL? UNFORTUNATELY, the approaches to training that are used by most coaches are based largely on intuition and trial and error rather than on sound scientific evidence, and many of our intuitions about effective practice may actually be undermining our improvement. This lecture will focus on 3 key ideas about practice that have been scientifically demonstrated to be effective in the acquisition and long-term retention of skills: space, challenge, and randomize (SCoRe).
A Misconception about Effective Practice

• Many people believe that whatever method of practice leads to the most immediate improvement must be the most effective method. For example, the tennis player who repeatedly hits crosscourt forehand after crosscourt forehand during practice may begin to get in a groove with that shot and quickly improve his or her ability to hit it consistently and accurately. Unfortunately, the confidence that one feels during practice doesn’t always translate into better performance during a match.

• To understand why this is, it’s important to distinguish long-term learning from short-term performance. In most cases, the goal of practice is long-term learning—that is, improvement that lasts and that will be apparent in any context. The tennis player on the practice court would like to see a lasting improvement in his or her overall game that’s apparent whether he or she plays on hardcourt or clay and no matter what opponent he or she faces.

• However, we often choose practice methods based not on how much they improve our long-term learning, but rather based on how much they improve our short-term performance—that is, our ability to perform the skill in the context of the current practice session. For example, it’s much easier to groove a tennis swing when repeatedly hitting the same shot rather than intermixing shots, so short-term performance during the practice session will likely be better.

• It’s only natural to assume that if our short-term performance is getting better, then our method of practice must be paying off, and our long-term learning will also be maximized. But it turns out that our intuition is wrong.

Vince Lombardi famously said, “Practice doesn’t make perfect. Perfect practice makes perfect.” But what constitutes perfect practice?
In fact, training methods that are most effective for long-term learning tend to introduce difficulties during practice that actually make short-term performance worse.

• Dominic Simon and Robert Bjork performed an experiment that illustrates this point. They asked people to learn 3 different sequences of key presses on the number pad of a keyboard. Half the participants practiced one sequence over and over before moving on to another sequence. The other half practiced one of the sequences once and then practiced a different sequence once, and so on, in an unpredictable, random order. Both groups returned the next day and were tested again to assess their longer-term learning.

• Predictably, during the practice session, people who got to practice each sequence over and over in separate blocks did better than people who practiced the sequences in a random order. The people in the blocked condition also predicted that they would continue to do well when tested the next day. But they were wrong. In fact, the people who practiced the sequences in an unpredictable order did much better the following day.

• There are 2 important lessons we can draw from this study:

  1. Long-term learning can be significantly improved by introducing changes that actually make short-term performance more difficult rather than easier. Bjork refers to these kinds of changes as desirable difficulties.

  2. Our intuitions about which training method will be most effective for long-term learning are not reliable. Most people assume that a training method that leads to rapid improvement during training will also lead to lasting improvements. They therefore gravitate toward such methods. Unfortunately, those methods typically don’t actually maximize long-term learning.
• If our intuitions about effective practice are wrong, then how should we practice? The 3 most important principles of effective practice can be summarized in the acronym SCoRe: space, challenge, and randomize. Each of these ideas can be seen as a kind of desirable difficulty; that is, each makes short-term performance more difficult, but that short-term difficulty is actually desirable because it leads to better long-term learning.

Space

• To maximize long-term learning, practice should be spaced out, or distributed, over time rather than crammed into a short period.

• Carol-anne Moulton and colleagues demonstrated the advantages of spaced practice in people training to be surgeons. Thirty-eight surgical residents received 4 training sessions on a specific type of microscopic surgery that required connecting very small blood vessels together. Half the residents received all the training in one day, which was the standard approach used in the residency program. The other half of the residents received one training session each week for 4 weeks. So, both groups received the same amount of training, but one group’s training was spaced while the other group’s training was not.

• One month after the final training session, all of the residents were asked to perform the surgery on a live rat while experts who did not know about the experiment observed. The residents whose training was spaced performed much better. They all completed the surgery successfully, while some of the residents in the other group did not. Furthermore, their surgically repaired blood vessels were more stable, and the experts rated their performance as being significantly better.
There are a few potential reasons why spacing helps. One idea is that people are more engaged and attentive after a delay. If you’ve just spent the past 2 hours practicing your golf putting, it might be tough to remain focused for another hour of the same kind of work. But if you take a break and space your practice, then you can often return more energized and be more productive in your third hour.

Another reason spacing might help is that practicing a skill at different times can make it less dependent on any specific practice context. For example, suppose you’re hitting golf balls. In one practice session, the wind is blowing into your face, and hitting the ball lower leads to better results because it keeps the ball below the wind. But then you take a break, the wind shifts, and now it’s with you during your next practice session. Now hitting the ball higher might lead to better results because the ball can ride the wind. In this case, spacing your practice helped you learn to hit shots in 2 different types of conditions, both of which you’re going to encounter when playing real rounds of golf.

Space your practice to maximize long-term learning. For example, athletes benefit more from practicing for 30 minutes every day than from practicing for 4 hours once a week.

Challenge

Research suggests that your practice will be more effective if you deliberately challenge yourself. If you can identify specific challenging areas to work on, set specific goals within those areas that are difficult—but not impossible—to achieve, and
systematically work to achieve those goals, then you’ll improve faster than if you spend the same amount of time practicing without challenging yourself.

- One study that illustrates the benefits of deliberately challenging yourself was conducted by Nina Keith and Anders Ericsson, who recruited 60 university students who had several years of typing experience. They gave them all a bunch of typing tasks, measured how quickly they could perform simple perceptual and motor tasks, and interviewed them to find out how they learned to type. They reported 2 interesting results.

- First, perceptual and motor processing speed didn’t make a difference. You might expect the people who were really fast at perceiving visual stimuli or who could press a button very rapidly would have a significant advantage and would be the fastest typists, but they weren’t. In fact, perceptual and motor processing speed didn’t correlate with typing speed at all.

- Second, they found that what really mattered was deliberate, challenging training. Specifically, the fastest typists had 2 common characteristics: They had taken a formal typing class that included deliberate typing goals and challenged themselves to type as fast as possible during their daily typing tasks. Neither characteristic alone was sufficient to identify the fast typists.

★ If you want to get better at any complex skill, you need to be systematic and deliberate in the way you practice. Rather than practicing things that you’re already good at, deliberately challenge yourself and stretch your abilities when you practice. ★
Randomize

• Most complex skills involve multiple parts, each of which must be mastered. For example, tennis requires being able to hit forehands, backhands, volleys, and overheads. Random practice refers to mixing the practice of different parts of a skill, rather than practicing each part separately.

• In the experiment on learning sequences of key presses on a number pad, the group that practiced the sequences in an unpredictable order was using a random practice schedule: After practicing one sequence, they would practice a different one, in a random order. The other group’s practice was blocked, rather than being random; that is, they practiced a single sequence over and over before switching to another sequence and practicing that one over and over.

• Although the short-term performance of the group that used random practice was worse than the other group, the next day the random practice group performed much better than the other group. So, if your goal is long-term learning rather than short-term performance, random practice is better than blocked practice.

• Many people find this result counterintuitive. After all, isn’t it better to break down a complex skill into separate parts and practice each part separately without interference from all the other parts? Although that is a very common way to practice and although it does improve short-term performance, random practice is better for long-term learning.

• One potential explanation for why is that when you actually have to perform the real skill later, you’ll typically have to perform all the subparts in an unpredictable order. Using random practice therefore better prepares you for the real execution of the skill. For
example, when playing in a real tennis match, you’ll be forced to intermix forehands and backhands in an unpredictable order. And it turns out that it’s better to practice that way, too. As athletes often say, you should practice the way you play.

* In addition to randomizing the order of practice, it’s also helpful to randomize the conditions of your practice. If you always practice under the same, predictable conditions, then your learning can become strongly tied to those conditions. For example, if you always hit golf balls at the same driving range, then you may limit the generality of your learning. When it comes time to use those skills in a real competition, you could find that you haven’t mastered them as well as you thought you had.

* Robert Kerr and Bernard Booth conducted a study that illustrates the benefits of randomizing practice conditions. Two groups of children practiced tossing beanbags at a target. Half the children always tossed to a target that was 3 feet away, while the other half of the children tossed to targets that varied in distance but were never 3 feet away. After training, both groups of children tossed beanbags at a 3-foot target.

* Incredibly, the children who practiced at varying distances actually performed better than the children who had trained exclusively at the 3-foot distance. Clearly, randomizing your practice can be a very powerful approach.

★ As you try to learn new skills, mix up your practice rather than working on an isolated part of the skill for an extended period of time. ★
Qualifications on SCoRe Recommendations

• It’s important to recognize that not all difficulties are desirable. In particular, the level of difficulty needs to match the ability of the learner. There is nothing wrong with novice tennis players practicing forehand after forehand while they try to learn the basics of the grip and swing. Similarly, although it’s fine for an intermediate golfer to practice hitting a large green from 100 yards away, that’s probably not challenging enough to stretch a professional golfer. The point is that people at every skill level need to introduce difficulties during practice that are challenging but also manageable.

• Spacing and randomizing can also be taken too far. For example, spacing becomes ineffective if the delay between practice sessions is so long that the learners have forgotten what they previously learned. And although randomizing practice conditions is helpful, there is no need to include conditions that you would never actually encounter in real life. For example, although it’s helpful for a basketball player to practice shooting from a variety of different distances to the hoop, there is no need for the player to practice shots from 200 feet away.

• It’s important to realize that the goal is not always long-term learning. Sometimes, the goal is short-term performance. For example, the musician who is preparing for a recital tomorrow is more worried about short-term performance than long-term learning. And in this kind of case, spacing and random practice may not be the ideal way to prepare.
SUGGESTED READING

Ericsson and Pool, *Peak*.
Schmidt and Lee, *Motor Control and Learning*.
Schmidt and Wrisberg, *Motor Learning and Performance*.

QUESTIONS TO CONSIDER

1. What new skill would you like to acquire? How might you apply what you learned in this lecture to help you acquire that new skill faster?

2. Have you identified any effective practice strategies of your own that were not discussed in this lecture?
ACQUIRING NEW KNOWLEDGE AND DEVELOPING NEW SKILLS CAN BE BOTH helpful and fulfilling, but in some cases—specifically, addiction—our sophisticated learning mechanisms can actually work against us and lead us to learn habits that harm us more than they help us. Addictive drugs can hijack learning mechanisms so that instead of learning valuable skills and habits, such as speaking a language or playing an instrument, the addict learns extremely strong associations with drug taking that turn that harmful behavior into a habit that can be extremely difficult to break. ●
Key Features of Addiction

- Addiction refers to continuing to compulsively engage in a behavior despite the fact that doing so has significant negative consequences. Often the behavior is using an addictive substance, such as nicotine, alcohol, or painkillers, and the consequences could range from significant health problems, to broken relationships, to losing a job.

- Some people manage to use drugs without significant negative consequences in their life. Think of the social drinker who never becomes an alcoholic. That would be considered drug use, but not drug abuse. And without abuse, it wouldn’t be considered a true addiction.

Most people have either struggled with an addiction or know someone who has. Maybe you know a long-time smoker who has repeatedly tried to quit but just hasn’t been able to kick the habit.

If you’ve never been addicted yourself, it can be difficult to understand. Don’t these people see how harmful their addiction is, not only to them, but also to those around them? Don’t they have any willpower? Why don’t they just quit?

The challenge of overcoming an addiction involves both psychological and neural mechanisms.
• Although most addictions involve taking drugs, many scientists believe that some other behaviors should also be considered addictions. An example is pathological gambling, which involves compulsive behavior and can have significant negative consequences.

• Many scientists believe that people can also become addicted to playing video games or surfing the internet. But for those behaviors to be classified as addictions, the person would have to pursue them obsessively despite truly significant negative consequences.

• But obsessive behavior and negative consequences aren’t the only symptoms of addictions. Addictions are also characterized by dependence and by craving.

• First, addicts depend on their drug or behavior to feel normal, both psychologically and even physically. For example, as heroin addicts continue to regularly take heroin, their body comes to expect the drug and begins to make physical changes to compensate for the drug and to neutralize its effects. As a result of these physical changes, heroin users need to take more of the drug to have the same effect that a smaller dose used to have. That’s called tolerance, and it’s a clear sign of physical dependence.

• Another clear sign of physical dependence is withdrawal. If addicts stop taking their drug for a while, they will typically start to feel unpleasant side effects that are the mirror opposite of the positive feelings produced by the drug. The addict’s body is expecting the drug to be present and has therefore compensated in an effort to neutralize the drug’s effects, and those very compensations can lead to symptoms of withdrawal if the drug is withheld.
• For example, alcohol is a sedative that tends to suppress neural activity. In alcoholics, the body compensates for these effects by exciting neural activity more than normal. This extra excitatory activity means that when alcoholics drink alcohol, their neural activity doesn’t look as suppressed as it would in nonalcoholics who are drinking. That’s another aspect of alcoholics’ tolerance to alcohol.

• But when alcoholics stop drinking, their body is still generating more than normal neural activity, but now there’s no alcohol to suppress it. Alcoholics therefore starts to feel withdrawal symptoms such as anxiety and shakiness that are caused by too much neural excitation. In severe cases, victims might even experience dangerous seizures and delirium that require medical attention.

• The same is true for other drugs. Opiate drugs, such as heroin and prescription painkillers, tend to produce a sense of euphoria and also cause constipation. So, when they’re withheld, the addict might experience withdrawal symptoms such as agitation and diarrhea—the mirror opposite of the effects produced by the drug.

• Another key characteristic of addiction is craving. Drug addicts experience extremely strong urges to obtain and use their drug of choice. Of course, everyone experiences cravings now and then, such as for a candy bar when checking out at the grocery store. You might even give in to those kinds of cravings sometimes.

• But the cravings of addicts are different. Addictive cravings are so strong that they completely consume the addicts, making it difficult to think about anything else. These are the kind of drives that lead addicts to lie, beg, steal, or do almost anything else to get their drug. They’re so obsessed with the need for the drug that they don’t consider the long-term consequences in terms of school, work, or family. Getting the drug is all that matters.
How Addiction Reflects Pathological Learning

• One of the key features of associative implicit learning, such as classical and operant conditioning, is that over time, unconditioned stimuli can become strongly associated with a reward or behavior. Pavlov’s dogs learned to associate getting fed with hearing the sound of experimenters entering the room.

• Another key feature is that learning in these situations depends on making a prediction error. If you’ve already learned an association between a stimulus and a reward and the reward arrives after the stimulus just as you predicted, then there’s no prediction error. You were already expecting the reward, so you don’t need to learn something new.

• However, if you get the reward when you weren’t expecting it, then there is a reward prediction error—you failed to predict the reward when it showed up. And that means you should try to learn so that you can better predict rewards in the future. That’s when you learn new associations between whatever stimuli are in the environment and the reward you just received.

• The activity of neurons in the ventral tegmental area (VTA) tends to track this kind of reward prediction error. These neurons fire when an unexpected reward arrives, but not when a reward shows up that was predictable. Furthermore, these neurons start to fire in response to nonrewarding stimuli that have been associated with a future reward.

• The VTA neurons release the neurotransmitter dopamine when they fire. This signals that an unexpected reward has arrived or is on the way; that is, it signals reward prediction error. It also signals the need for new learning.
• When the VTA neurons fire and release dopamine, the organism strengthens associations between the reward and whatever stimuli are present that predict that reward. And the next time it encounters those same stimuli, it will tend to predict that a reward is on the way.

• In addition to signaling that an unexpected reward is on the way, dopamine also seems to be important in motivating you to pursue the reward. It makes you want it.

• Some of the best studies on dopamine’s role in motivation use genetic engineering, which involves manipulating the DNA of organisms, especially mice, so that those organisms have specific genetic properties.

• For example, scientists might knock out a specific gene or change the form of a gene. Scientists have used this approach to create mice that tend to produce abnormally high levels of dopamine as well as mice that produce abnormally low levels of dopamine. The findings from these studies tell us a lot about the role of dopamine in motivation.

• For example, mice that are genetically engineered to produce high levels of dopamine seem to have abnormally strong motivation to get food. Conversely, mice that have been genetically engineered to have abnormally low levels of dopamine show a complete lack of motivation. They won’t even walk across their cage to get food when they’re hungry. In fact, they actually have to be hand-fed or they’ll starve.

• How does all of this relate to addiction? All addictive drugs lead to an artificially large burst of dopamine. And that large burst of dopamine is what makes the drugs so addictive.
Dopamine plays a central role in motivation, in addition to its role in signaling reward prediction error and the need for new learning. And that combination of functions makes a lot of sense.

Imagine an animal that has just smelled a new source of food that it didn’t previously know about. It would be helpful to that animal’s survival if it were motivated to find that food and to learn its location.

And that’s exactly what the dopamine system does. The smell of food signals a reward prediction error. The animal had not been predicting a reward, but once it smells the food, it realizes that its prediction had been wrong: Food is actually likely on its way.

That reward prediction error is accompanied by the release of dopamine, which triggers new learning, which will help the animal remember this food source in the future; and wanting, which motivates the animal to look for and find the food.

• For example, cocaine is a dopamine reuptake inhibitor, which means that it prevents the brain from removing dopamine after it’s been released by dopamine neurons. And that means that whenever dopamine is released, its effect will last longer and will therefore be magnified.
• Other addictive drugs also lead to increased dopamine levels, but in different ways.

  ♦ Methamphetamine produces even higher levels of dopamine than cocaine does, and it’s also even more addictive.

  ♦ Nicotine binds to special receptors on the VTA dopamine neurons and makes them fire more than normal, leading to increased dopamine release.

  ♦ Alcohol and opioids turn off neurons that normally inhibit the VTA dopamine neurons, which means that the dopamine neurons fire more than normal.

• To understand why that large burst of dopamine makes drugs so addictive, consider what happens when a heroin addict shoots up or a chain smoker takes a puff: The drug induces an artificially large burst of dopamine, and the brain interprets that dopamine burst as meaning that an unexpected reward has arrived or soon will.

• Notice that the reward for drug addicts actually isn’t unexpected. If they are chronic users, they know very well what to expect from taking their drug of choice. In fact, they’ve probably developed a tolerance to their drug so that the rewarding effect isn’t as strong as it used to be.

• So, the dopamine burst in this case isn’t caused by an unexpected or better-than-normal reward; it’s caused by the drug messing with the brain’s machinery and artificially creating a dopamine burst.

• But the brain doesn’t know that—so it behaves the way it always does when it gets a dopamine burst. It interprets it as meaning that an unexpected reward is on its way and does 2 things: First, it triggers wanting or motivation. (This is not regular wanting, but the pathological craving that addicts report feeling.)
• The brain’s second response is to learn: Dopamine normally signals a reward prediction error and the need for more learning. Specifically, the brain learns associations between whatever environmental cues happen to predict the reward and the behavior that led to it. In this case, the behavior being reinforced is taking the drug.

• The environmental cues that predict the reward are anything in the environment that tends to predict drug taking, such as the sight of a pack of cigarettes for a chain smoker, the street corner where the user buys heroin, or the people with whom the user typically does drugs. Anything and everything that is reliably associated with drug taking constitutes an environmental cue that the brain will associate with that behavior.

• Worse yet, the dopamine neurons will start to fire in response to the cues that predict the reward, rather than the reward itself, so the addicts’ dopamine neurons start firing whenever they encounter an environmental cue that they’ve associated with drug taking. For example, the chain smoker starts experiencing a dopamine burst whenever he or she sees a cigarette. Anything in the environment that the addict associates with drug taking eventually triggers a dopamine burst itself.

• For chronic drug users, almost everything in their daily environment is associated with drug taking—and therefore trigger craving and an overwhelming urge to seek out and use the drug. So, it’s virtually impossible for the addict to avoid encountering these cues and experiencing the extremely powerful cravings that end up controlling their behavior. And every time the addict gives in to their cravings and takes their drug, another dopamine burst is released, and the associations are strengthened even more. It’s a vicious cycle—one that can be extremely difficult to break.
SUGGESTED READING

Erickson, *The Science of Addiction.*
Kuhar, *The Addicted Brain.*
Kuhn, Swartzwelder, Wilson, Wilson, and Foster, *Buzzed.*

QUESTIONS TO CONSIDER

1. What do you see as the key similarities and differences between addiction to a drug and addiction to a behavior, such as gambling?

2. Think of someone you know who is addicted to alcohol, smoking, or some other drug or behavior. Does what you learned in this lecture change your view of that person and his or her addiction in any way? If so, how?
Starting with this lecture, the course will turn to yet another aspect of learning and memory: working memory. In this lecture, you will discover what working memory is, the central role that it plays in virtually all cognitive tasks, and the fact that it depends on different brain systems than long-term memory does. You will also be introduced to a simple model of working memory. In this lecture, you will learn about the phonological loop component of this model, while the next lecture will address the other components of working memory as well as some of the neural mechanisms that have been discovered.
Working Memory and Cognition

- Working memory is the cognitive system that allows you to temporarily store information for short periods of time, maintain that information over a delay, and process that information in the service of whatever you’re currently trying to do.

- Working memory is a kind of temporary, or short-term, memory. In fact, psychologists often use the terms “short-term memory” and “working memory” interchangeably to refer to the same cognitive process. But working memory has become the preferred term because it conveys the idea that the system is actively engaged in working with information. It’s not just a passive storage system; it’s actively used for processing information.

- Another important characteristic is that working memory has a much more limited capacity than long-term memory, which holds hundreds of thousands of words, countless facts about the world, and thousands upon thousands of personal episodes from your life.

- The capacity of your long-term memory is virtually unlimited. Our brains are finite, so there must be some upper limit on how much information we can store in long-term memory, but nobody seems to have reached it in our limited lifespans.

- In contrast, the capacity of working memory is severely limited. For example, suppose that you were asked to close your eyes and add 625,488,561 and 37,290,417 in your head. It’s pretty unlikely you’d be able to remember the numbers, much less add them together. And that’s not because you can’t add big numbers; if you were able to do the addition on paper, you’d probably find it pretty easy. The problem is that the capacity of your working memory is limited; you can only store so much information at a time.
• Working memory plays a crucial role in virtually any cognitive task you can think of. When you’re holding a conversation with someone, you need to temporarily store what he or she is saying, process that information, and retrieve it later in the conversation. When you’re cooking dinner, doing your taxes, playing an instrument, reading, writing, or driving, you’re using your working memory.

• People with greater working memory capacity tend to perform better on a wide range of cognitive tasks. They perform better on tests of reading comprehension and reasoning, and they get better grades and higher standardized test scores. In fact, working memory capacity is one of the best predictors of intelligence, at least as measured by IQ tests. This is further evidence that working memory is important to cognition in general.

• Working memory is important, but so are long-term explicit and implicit memory. What’s the relationship between working and long-term memory?

• Human beings use many different memory systems. For example, explicit memory is fundamentally different than implicit memory and depends on different neural substrates. And even within explicit memory, we distinguish between semantic memory for facts and episodic memory for personal events that are tied to a specific time and place.

• Working memory is itself a distinct memory system. In fact, some of the evidence for that claim comes from the amnesiac patient Henry Molaison, whose explicit long-term memory was profoundly impaired but whose working memory was normal.
• This is an example of a single dissociation, in which damage to one part of the brain causes a deficit in one process, but not another. In this case, damage to the hippocampus and other medial temporal lobe structures leads to impairments in long-term memory, but not working memory.

• You might think that evidence like that proves that long-term memory and working memory depend on different underlying systems. But there’s a potential alternative explanation. Suppose that the long-term memory tasks are just more difficult than the working memory tasks. Then, you might perform worse on the long-term memory tasks even if they depend on the same neural systems as the working memory tasks.

• We can rule out this alternative explanation by finding another brain-damaged patient who exhibits the opposite dissociation—a patient whose long-term memory is normal, but whose working memory is dramatically impaired. One such patient is referred to by his initials, KF, to protect his anonymity.

• KF had a pretty severe motorcycle accident that led to brain damage. But the damage was not in the medial temporal lobes, and his long-term memory was fine. But his working memory was dramatically impaired. In particular, whereas most people can remember 6 or 7 digits after a brief delay, KF could only remember about 2.

• KF’s problems were the opposite of Henry Molaison’s. This is a double dissociation: 2 patients who exhibit single dissociations but in opposite directions. One patient is impaired on task A but not task B, while the other patient is impaired on task B but not task A.
• The great thing about double dissociations is that you can’t explain them away based on a difference in task difficulty. For example, suppose that working memory and long-term memory depend on the same neural system and the only reason that Henry Molaison is more impaired on long-term than working memory tasks is because the long-term memory tasks are more difficult. In that case, you should never see a patient like KF who exhibits the opposite dissociation and is selectively impaired on the tasks that are assumed to be easier. The only way to explain both dissociations is if working memory and long-term memory depend on different underlying systems.

The Phonological Loop

• Alan Baddeley and Graham Hitch proposed a theory of working memory—called the multicomponent theory—that has become one of the most influential theories in all of cognitive psychology, probably because it is relatively simple and yet manages to explain a wide variety of empirical phenomena.

• One of the key assumptions of this theory is that working memory consists of multiple, separable components. So, just as working memory should be distinguished from long-term memory and explicit memory should be distinguished from implicit memory, Baddeley and Hitch argued that working memory should be subdivided into separate functional components.

• Originally, they proposed 3 components: a phonological loop, a visuospatial sketchpad, and a central executive. But in 2000, Baddeley argued for the addition of an episodic buffer component.
• The phonological loop is the component of working memory that is responsible for the temporary storage and rehearsal of linguistic information. For example, if you are asked to remember a few random words, such as “ball,” “truck,” “mirror,” and “star,” and then a few seconds later are asked to say those words, you would be using your phonological loop to hang on to that information temporarily.

• You could imagine different ways of storing those words. You could store images of what the words look like based on the shapes of the component letters. You could also imagine storing representations of the words’ meanings. But a key assumption of the phonological loop is that you store the words in a sound-based format.

• Phonemes are the atomic units of distinctive speech sounds in a language, such as the “cuh,” “ah,” and “tuh” sounds in the word “cat.” The assumption is that when we’re storing language in working memory, we’re storing phonemes, or language sounds. That’s why it’s called the phonological loop.

• This phenomenon is sometimes called the phonological similarity effect. When we have to temporarily store words that are phonologically similar—in other words, that sound alike—we typically do worse than if we’re trying to store words that sound different.

• But what’s really interesting is that we only have trouble with items that sound alike, not with items that look alike or items that have similar meanings.

• For example, consider the word “bough,” as in the bough of a tree. The spelling of the word is very similar to “cough,” “dough,” and “through,” which all end in “-ough” and only differ in the first letter or 2. Those words look very similar, but they sound completely different.
• People don’t have any trouble storing words like this in working memory. So, visual similarity doesn’t cause the same problems that phonological similarity causes.

• Likewise, semantic similarity also doesn’t cause problems; that is, people have no problem storing words that have similar meanings in working memory. So, if you were given the list “huge,” “long,” “tall,” “big,” and “wide,” you probably wouldn’t have any problem holding on to those words. And the fact that the words are semantically related might actually make it easier to remember them.

• So, phonological similarity impairs working memory, but visual and semantic similarity don’t. This suggests that when we store verbal information in working memory, we’re storing the sound of the information, not what it looks like and not what it means. And that’s exactly what the phonological loop model assumes.

• The other key assumption of the phonological loop model corresponds to the “loop” in the model. The model assumes that people have access to an articulatory loop that they can use to rehearse the sound-based representations stored in working memory. Whatever language sounds you can say in about 2 seconds, you can rehearse and refresh using this loop.

• The reason it’s called an articulatory loop is because the assumption is that you articulate the information in working memory. In other words, you say it to yourself—not necessarily out loud; you might do it subvocally. But the assumption is that you are using some of the same mechanisms that you use when you speak. You’re just speaking to yourself. And doing that reactivates and refreshes the sound-based representations that are in working memory so that you can hang onto them a little bit longer.
• The model also assumes that if you’re trying to store language-based information in working memory but that information isn’t already in a sound-based format, then you’ll use the articulatory loop to say it to yourself and convert it into a sound-based format.

• For example, suppose that you are asked to remember a few words in your working memory, but instead of saying them out loud, you are only allowed to read them on a piece of paper or on a computer screen. The words are presented in a visual format, not a phonological format.

• The model assumes that you will use your articulatory loop to say the words to yourself and convert them into a phonological format. And that’s the format that they’re stored in. So, even though the words were presented visually, they are stored phonologically.

• These assumptions about the articulatory loop make a number of testable predictions. And the phonological loop model correctly predicts that similar-sounding items will be more difficult to remember and that making people talk out loud will impair their memory. It also correctly predicts that phonological similarity effects will disappear when people talk out loud, but only if items are presented visually.

• Furthermore, based on the assumption that the articulatory rehearsal loop can only hold about 2 seconds of speech, this model predicts that people should be able to remember more short words than long words. The reason is that you can say more short words in a 2-second window than you can long words. And that means you can rehearse more short words than long words, and every rehearsal refreshes the item in working memory.
• This finding even extends to how fast people speak. If you measure people’s speed of speech—that is, how many words they typically produce per second—you’ll find that it’s a very good predictor of their working memory capacity.

• It also suggests that working memory capacity might not be innate, but can be influenced, and potentially even improved, by experience. In fact, an entire future lecture will be dedicated to this fascinating topic.

SUGGESTED READING

Baddeley, *Working Memory, Thought, and Action*.
Baddeley, Eysenck, and Anderson, *Memory*.
Gathercole and Alloway, *Working Memory and Learning*.

QUESTIONS TO CONSIDER

1. Some psychologists view working memory as the currently activated part of long-term memory. What do you see as the strengths and weaknesses of this theory?

2. Psychologists used to think that information had to be stored in working memory before it could be stored in long-term memory. But Patient KF had relatively normal long-term memory despite very impaired working memory. Do you think KF’s profile demonstrates that psychologists were wrong?
In the previous lecture, you were introduced to one of the most famous theories of cognitive psychology—namely, Alan Baddeley’s multicomponent theory of working memory, which assumes that working memory can be broken down into component parts. One part is the phonological loop, which you learned about in the previous lecture. This simple model can explain many phenomena related to working memory for language-based information, including effects of phonological similarity, word length, and speed of speech. In this lecture, you will learn about the other components of Baddeley’s model: the visuospatial sketchpad, the central executive, and the episodic buffer.
The Visuospatial Sketchpad

- The visuospatial sketchpad is a separate component of your working memory system that’s devoted to temporarily storing visuospatial information. So, just as the phonological loop is devoted to storing language sounds, the visuospatial sketchpad is devoted to storing visual and spatial information.

- For example, look around wherever you are right now and store a visual image of what your environment looks like. Now close your eyes and bring that visuospatial image to mind. That’s your visuospatial sketchpad at work, temporarily storing that visuospatial information while your eyes are closed.

- Information can get into your sketchpad in 2 different ways. One way is by perception. When you looked around and formed an image of your local environment, you were putting that information into your visuospatial sketchpad using visual perception.

- The other way is to retrieve information from long-term memory. For example, if you close your eyes and bring to mind the image of your best friend’s face or of the house you grew up in, then you’re using your visuospatial sketchpad again. But this time, the information in the sketchpad wasn’t directly perceived from the environment; rather, it was retrieved from your long-term memory.

- Why did Baddeley assume that working memory is divided up into these separate components? Maybe we have a single, unitary working memory system that we use to temporarily store any kind of information, whether it’s phonological or visual or spatial. So how do we know that the visuospatial sketchpad is different from the phonological loop?
Some of the best evidence came from an experiment conducted by Lee Brooks, who asked people to perform 2 working memory tasks: one that would tap visuospatial working memory and one that would tap phonological working memory. And he asked them to perform each task in 2 different ways. In one version of the tasks, he asked people to respond verbally—that is, by speaking their answers. In the other version, he asked people to respond spatially, by pointing to their answers on a piece of paper.

His idea was that if we really do have separate working memory systems for storing sounds versus sights, then using a vocal, sound-based response might interfere with sound-based working memory, whereas using a visuospatial, pointing response might interfere with visuospatial working memory.

Essentially, if making the response requires using some of the mechanisms that are being used during the working memory task, then that might cause problems, because you're trying to use those mechanisms to do 2 different things at the same time.

In both tasks, you have to remember something in your working memory and then walk through that representation, making judgments about different parts of it. The difference is whether you have to remember a visuospatial representation of what a letter looks like or remember a phonological representation of what a sentence sounds like.

Brooks asked his participants to perform both of these tasks in 2 different ways: You either respond vocally, by saying “yes” or “no” out loud; or spatially, by pointing to the correct answers on a sheet of paper with a bunch of “yes”/“no” pairs written on it.

Brooks found that the 2 response types had opposite effects on the 2 tasks. First, in the visuospatial working memory task, he found that people are faster if they get to say “yes” or “no” out loud and
slower if they have to point to the “yes” or “no” on the paper. In this case, there is an interference from having to point. Pointing—that is, making a visuospatial response—interferes with visuospatial working memory.

• You might think that talking is just easier than pointing and that people would always be faster when they get to say their responses. But Brooks found the opposite pattern for the sentence task: People were faster when they pointed to the response on a piece of paper and slower when they spoke their responses out loud.

• For the visuospatial working memory task, pointing interferes, but for the phonological working memory task, speaking interferes. That is a double dissociation, which means that the 2 tasks must depend on different underlying systems. After all, if they depended on the same system, then they should be affected in the same way, not opposite ways.

• And those 2 systems are visuospatial working memory and phonological working memory. Brook’s experiment provides evidence that we really should distinguish these 2 types of working memory, just as Baddeley’s multicomponent theory assumes.

The Central Executive

• Think about the central executive officer (CEO) in a company. This person delegates responsibilities to other people, monitors how things are running, and makes sure that everything’s getting taken care of. And that’s exactly what Baddeley’s central executive is assumed to do in our mind—delegate responsibilities to specific cognitive processes, monitor how our mental processing is going and whether we’re making progress on our goals, and make sure we’re doing what we need to be doing.
• Imagine reading a technical book or manual to learn some useful information, such as how to program your universal remote control. Doing so requires all kinds of cognitive processing. You have to use vision to recognize the letters and words on the page, semantic memory to retrieve the meaning of the words you read, and language skills to put the words together and figure out the ideas that are being conveyed.

• Beyond those basic cognitive processes, you also have to control those processes and decide what to do when. That’s the function of executive control. It’s the system that tells vision to read a particular word and that tells language to comprehend a particular sentence. And if you get distracted and your mind starts to wander, executive control is what notices and gets you back on track. It’s overseeing and managing the other cognitive operations.

• In the case of working memory, it might tell the phonological loop to rehearse some words, or it might tell the visuospatial sketchpad to remember the spatial sequence of buttons that you have to push to program your universal remote control.

• And there is evidence that our brain includes a system devoted to this kind of central executive function, as Baddeley’s theory assumes. Recall that our cerebral cortex is divided into 4 lobes: the temporal lobe, the occipital lobe, the parietal lobe, and the frontal lobe. The posterior part of the frontal cortex handles motor control, but in front of that is a region called the prefrontal cortex—and damage to this part of the brain often leads to impairments in executive control.

• In particular, neurological patients with damage to the prefrontal cortex act as if their CEO isn’t working right; that is, they have a difficult time controlling their behavior, focusing on the things they want to focus on, and avoiding distraction.
These patients also commonly exhibit perseveration, which is a pathological form of persevering—sticking to something and continuing to pursue it—in which patients continue with a behavior even after it’s no longer appropriate.

One famous task that’s used to test for perseveration is the Wisconsin card-sorting test, in which you are shown a sequence of cards and asked to sort them. For example, if you’re sorting by suit, then you need to put the spades in one pile and the hearts in another pile. If you’re sorting by number, then you need to put the 7s in one pile and the 4s in another pile.
• You are not told what you should be sorting by. But the test administrator tells you whether you’re right or wrong as you sort each card. Initially, you have to try a few things to see whether you’re sorting correctly. But pretty quickly, you’ll get the hang of it and have no problem sorting the cards.

• But then, the administrator will unexpectedly change the sorting rule without telling you. So, if you were sorting by suit, the administrator will change it so that you have to sort by number instead. Naturally, you will make a few mistakes, but pretty quickly you’ll realize that the rule has changed, so you’ll try sorting by number and get back on track.

• But patients with damage to the prefrontal cortex will keep sorting by suit; that is, they’ll perseverate in their previous behavior even though it’s no longer appropriate. This is a problem with executive control. The patients have a difficult time inhibiting a behavior that was working well and trying something else instead.

• The prefrontal cortex looks a lot like Baddeley’s central executive component. Like the CEO of a company, our prefrontal cortex oversees and controls our behavior, deciding what to pay attention to and what to ignore, what to do and what to avoid doing, and when to store information into working memory and when to retrieve it.
The Episodic Buffer

• Originally, the phonological loop, the visuospatial sketchpad, and the central executive were the only 3 components in Baddeley’s model of working memory. And although these components were able to explain a variety of empirical phenomena, Baddeley began noticing some weaknesses in the model’s explanatory power that ultimately led him to add a fourth component, which he called the episodic buffer.

• Like long-term episodic memory, the episodic buffer is assumed to store personal episodes in memory. These episodic memories integrate multiple different types of information. They can contain visual information, spatial information, and phonological information from perception. Critically, these memories can also incorporate information from long-term memory.

• The episodic buffer is where all these different types of information get put together into a unified, integrated representation. Psychologists sometimes refer to this function as binding.

• But there are also critical differences between the episodic buffer and long-term episodic memory. First, the episodic buffer is short-term, so information in the buffer must be rehearsed or it will quickly fade away. In addition, the capacity of the episodic buffer is assumed to be limited, whereas long-term episodic memory is assumed to have almost unlimited capacity. In particular, the episodic buffer is assumed to have a capacity of about 4 chunks (or meaningful units) of information.

• For example, if you are asked to remember a random sequence of letters, such as K B J O D T, the letters themselves are meaningful units, or chunks, and you can probably remember about 4 at a time without doing any rehearsal.
• But suppose you are asked to remember the letters FBI, CIA, and MIT. Now the letters are grouped into 3 meaningful units, or chunks. So, even though you were actually given a total of 9 letters, you can probably remember all of them because you can easily recall the 3 chunks. And from those chunks, you can extract all the component letters.

• This is also the explanation for our superior memory for a meaningful sentence compared with a random sequence of unrelated words. In the case of the sentence, the component words can be grouped together into meaningful chunks, and those chunks can then be stored in the episodic buffer for later retrieval. The unrelated words can’t be grouped in that way, so they aren’t remembered as well.

• And that finding has practical implications for us when we’re trying to remember information in our working memory. If we can find a way to group the information into meaningful chunks, then we’ll be more likely to remember it than if we treat every piece of information as independent and unrelated to all the others.

SUGGESTED READING

Baddeley, *Working Memory, Thought, and Action*.

QUESTIONS TO CONSIDER

1. Which of the components of Baddeley’s working memory model do you think is most important in real life?

2. Do you think it’s adaptive to have separate working memory components devoted to storing phonological versus visuospatial information? Why not just have a single, unified working memory system?
YOUR BRAIN CAN STORE INFORMATION INTO WORKING MEMORY WHEN NECESSARY, rehearse and refresh that information to keep it active, and retrieve the information when it needs it to make a decision or choose an action. How does it do this? Is there a specific part of the brain that’s devoted to working memory? Is the distinction between phonological working memory and visuospatial working memory reflected in brain organization? Are there specific neurons that fire when you’re holding information in working memory and that don’t fire when you’re not? These are the kinds of questions that will be addressed in this lecture.
In the early 1970s, Joaquin Fuster and Garrett Alexander made one of the first and most important discoveries about the neural basis of working memory. They were recording from neurons in a monkey’s brain while the animal performed a delayed response task—specifically, the monkey watched the experimenters put a piece of apple into one of 2 holes in front of the animal’s cage.

The holes were then covered, and a blind was lowered between the animal and the holes. Then, there was a delay of anywhere from 15 seconds to a little more than a minute. After the delay, the blind was removed, which allowed the animal to reach out through its cage into one of the covered holes.

If it reached into the hole with the apple, then it got to eat the apple. If it reached into the other hole, then the experimenters showed the monkey where the apple really was but didn’t let the animal have it. Monkeys are smart, and they quickly figured out the task and began consistently reaching into the hole containing the apple.

Even though this task is simple, it very clearly requires working memory. First, the holes are covered, so the monkey can’t see the apple. In addition, the experimenters moved the apple around randomly, so guessing wouldn’t work. The monkeys had to store the location of the apple in working memory on every trial and hang onto that information across the delay. And that’s exactly what they did.

While the monkeys were doing this, Fuster and Alexander were recording from neurons in their brain. And they found a bunch of neurons that fired continuously during the delay period and then stopped firing after the animal made its response.
• Keep in mind that nothing was happening during the delay period. The blind was down, and the monkey couldn’t even see the holes, much less the apple. Yet a bunch of neurons were firing like crazy. Fuster and Alexander hypothesized that the activity in these neurons corresponded to the monkey’s working memory of the apple’s location.

• These neurons were in the prefrontal cortex. Recall that the cortex is the thin layer of gray matter around the outside of the brain, and the prefrontal cortex is the cortex in the front of the brain.

• Fuster and Alexander’s results suggested that the prefrontal cortex is critical for working memory. And that idea also makes sense given Alan Baddeley’s working memory model and the central executive component, which controls our attention and decides to keep some information active while letting other information fade away.

• The part of the brain that is associated with the central executive is the prefrontal cortex. According to Baddeley’s theory, we should expect to see neural activity in the prefrontal cortex during working memory tasks. And we do.

• Subsequent research has begun to tease apart what these prefrontal neurons do in more detail. One very important line of work was conducted by Patricia Goldman-Rakic and colleagues. Like Fuster and Alexander, Goldman-Rakic’s team recorded from prefrontal neurons while monkeys performed a delayed response task.

• But instead of asking monkeys to remember which of 2 holes an apple was hidden in, they required the monkeys to remember the location where a visual stimulus, such as a square, flashed on a screen. The square could appear in any of 8 different locations and, just like in Fuster and Alexander’s experiment, the monkey had to remember that location across a delay.
• This task is a little more difficult, but the monkeys did eventually learn to do it quite well. And like Fuster and Alexander’s study, Goldman-Rakic’s team found a bunch of prefrontal neurons that fired vigorously during the delay. But they also found that many of the neurons were location-specific.

• For example, one neuron was active whenever the monkey was trying to remember that the square had been in the upper-right corner of the display, and a different neuron was active when the monkey was trying to remember that the square had been in the lower-left corner. But the neural responses were consistent: The same neurons always fired when the monkey was remembering “upper-right,” and a different set was always active when it was remembering “lower-left.”

• In other words, these prefrontal neurons have very specific duties in spatial working memory. They don’t all contribute to remembering all locations. Instead, each of them is responsible for remembering a specific location and doesn’t actually participate in remembering other locations.

• And it turns out that it’s not just the prefrontal cortex that’s involved in working memory. Subsequent experiments have demonstrated neural activity during the delay period in a number of more posterior parts of the brain. And the posterior brain area that is activated is typically the area that represents the kind of information being remembered.

• For example, we tend to represent spatial information in the parietal cortex, which is toward the top of the back half of the brain. Patients with damage to this part of the brain often exhibit a deficit called visuospatial neglect, in which they neglect, or fail to pay attention to, one side of space. They might not read the text on the left side of a page, for example. Clearly, the parietal cortex is
crucial for representing the space around us. And it turns out that when we store spatial information in working memory, neurons in that area of the brain are active during the delay.

- Based on results like this, one popular hypothesis is that when we need to store information in working memory, we activate the same brain regions that we normally use to represent that kind of information during perception. If we use the parietal cortex to represent spatial information during perception, then we use that same area to store spatial information in working memory. And the same principle is thought to apply to auditory information, linguistic information, and so on.

Applying Animal Results to Humans

- Monkeys may be smart, but we’re smarter, and our working memory abilities are also significantly better. So, it’s important to test whether the results found in monkeys also apply to human beings.

- Around 1990, scientists developed some methods for measuring human brain activity without having to crack open the skull. These so-called neuroimaging methods have revolutionized the study of the human mind and brain. They’ve also revolutionized the study of the neural basis of working memory in human beings.

- One of the first neuroimaging studies of working memory in humans was conducted by John Jonides and Edward Smith, who used a technique called positron-emission tomography (PET). Using this technique, Jonides and Smith estimated brain activity while human participants performed 2 different working memory tasks: one that required people to remember verbal information and another that required people to remember spatial information.
• By comparing the brain activity patterns in the 2 tasks, Jonides and Smith could identify the neural correlates of working memory in humans. They could also test whether remembering different kinds of information activates different regions, both in posterior areas and in the prefrontal cortex.

• They found that verbal working memory activated an area in the left prefrontal cortex and a posterior area in the left hemisphere that is commonly associated with language processing. And that’s exactly what you would expect based on the animal studies.

In a typical PET study, participants are injected with a very low dose of a radioactive tracer, which follows the blood supply wherever it goes, including into the brain. Furthermore, more blood gets sent to brain areas that are particularly active, so more of the tracer goes to active brain areas than to brain areas that are inactive.

Because the tracer is radioactive, it decays and leads to the emission of particles called positrons. The emission of those positrons can be detected by a special scanner that can determine where the positrons came from in the brain. Putting this all together, a picture of brain activity can be created based on positron emission.
• In short, the results of this PET study suggest that the neural mechanisms underlying working memory in human beings share some important similarities with the mechanisms used by monkeys.

• But are the prefrontal regions involved in working memory general-purpose ones, or are different areas of the prefrontal cortex engaged when people have to hold on to different kinds of information? To address this question, Jonides and Smith performed a PET study in which participants had to try to remember spatial information.

• Once again, they found that working memory activated both prefrontal and posterior brain regions. They also found that the posterior brain regions were areas associated with representing and processing spatial information. So, consistent with the animal studies, posterior brain areas involved in temporarily storing information were some of the same areas normally involved in representing and processing that information.

• Furthermore, the spatial working memory task activated a completely different part of the prefrontal cortex compared with the verbal working memory task. In fact, it was on the other side of the brain entirely. The verbal working memory task activated the left prefrontal cortex, while the spatial working memory task activated the right prefrontal cortex.

• This has important implications for our understanding of what the prefrontal cortex is doing during working memory. Apparently, there’s not a single prefrontal region that performs exactly the same function regardless of what you’re trying to store in working memory; instead, different parts of the prefrontal cortex participate in working memory for different types of information.

• One hypothesis for what these prefrontal regions are doing is the idea that the prefrontal cortex provides top-down excitation of posterior brain regions during working memory tasks.
• Consider what happens when you perceive an orange. Nerve cells in your eyes send signals into the brain that cause other nerve cells to fire. And those cells cause still other cells to fire, and so on. So, the neural activity is driven by a stimulus coming from outside. That’s called bottom-up processing.

• But what if you’re not perceiving an orange anymore? What if you’re just temporarily storing the image of an orange that you saw recently but that was taken out of view? Now the nerve cells in your eyes are not sending signals back into the brain and driving a pattern of neural activity that corresponds to your representation of the orange. What’s going to drive the neural activity and keep it active even when you can no longer see the orange?

• One natural possibility is that’s what the prefrontal cortex does: It drives the neural activity in posterior brain areas and keeps them active, even though there’s nothing coming in from perception. And when neural activity is driven internally rather than being driven by external stimuli, that’s called top-down processing.

• The hypothesis that the prefrontal cortex provides top-down excitation of posterior brain regions during working memory tasks also makes sense of the finding that different regions of the prefrontal cortex are involved in working memory for different kinds of information.

• Different parts of the prefrontal cortex are connected to different parts of the posterior cortex. And if a prefrontal region is going to provide top-down excitation of a posterior region, then it needs to be connected to it.
• This explains why different parts of the prefrontal cortex would be activated when you’re storing different types of information. The information is actually being stored in the posterior cortex, in the same area that tends to represent and process that information during normal perception. And because there is a specific part of the prefrontal cortex that is connected to that part of the posterior cortex, that’s the region that would provide top-down excitation for it.

The Convergence of Psychology and Neuroscience

In Alan Baddeley’s model of working memory, which assumes that working memory can be subdivided into different components, he argues that we should distinguish a phonological loop from a visuospatial buffer and that both of these are controlled by a central executive.

That model actually maps pretty naturally onto the neural results addressed in this lecture. For example, Jonides and Smith found that storing verbal information depends on completely different brain circuits than storing spatial information. And that makes perfect sense, assuming that we use the phonological loop to store verbal information while we use the visuospatial sketchpad to store spatial information.

Furthermore, a natural interpretation of the neural data is that the prefrontal cortex provides top-down excitation of posterior brain areas. That seems similar to the top-down control that you would expect Baddeley’s central executive to exert. And Baddeley assumes that the central executive component of working memory is implemented in the prefrontal cortex.
SUGGESTED READING

Fuster, *The Prefrontal Cortex*.
Osaka, Logie, and D’Esposito, *The Cognitive Neuroscience of Working Memory*.
Roberts, Robbins, and Weiskrantz, *The Prefrontal Cortex*.

QUESTIONS TO CONSIDER

1. Baddeley’s psychological model of working memory maps onto some of the neuroscientific findings in some ways. Can you think of any ways in which it doesn’t?

2. Based on what you’ve learned, how do you think damage to the frontal lobe would affect someone’s behavior?
SOME SCIENTISTS BELIEVE THAT WITH APPROPRIATE TRAINING, INTELLIGENCE CAN be increased somewhat. Specifically, there is some evidence that training someone’s working memory can lead to increases in fluid intelligence, which refers to the ability to reason and solve new problems independent of previously acquired knowledge. There is even evidence that this kind of training can help children with attention deficit hyperactivity disorder (ADHD). But the claim that training can change intelligence is highly controversial, and many scientists don’t believe it.
IMPROVING FLUID INTELLIGENCE

• In 2008, a study was conducted by Susanne Jaeggi, Martin Buschkuehl, John Jonides, and Walter Perrig that was inspired by the work of Graeme Halford and his colleagues, who argued that working memory and intelligence share a common capacity constraint. In other words, one of the key factors influencing how smart you are is how much information you can hold in your working memory.

• Evidence shows that working memory is very important to thought in general. People with greater working memory capacity tend to perform better on a wide range of cognitive tasks, such as reading comprehension, reasoning, and standardized tests. In addition, working memory capacity is one of the best predictors of performance on IQ tests. And because the problems on IQ tests tend to predict performance on a bunch of other cognitive tasks, that suggests that working memory plays a central role in cognition more generally.

• Inspired by these kinds of findings, Jaeggi and her colleagues wanted to see if training people’s working memory could increase working memory capacity and thereby increase fluid intelligence. They developed a working memory task for the training that could be made increasingly difficult as people improved so that it would continue to stretch the working memory capacity of the participants and hopefully cause that capacity to grow.

• The researchers found that the training on the working memory task improved participants’ task performance. But the critical question is whether training leads to improvements in fluid intelligence. To answer that question, the researchers gave participants a 10-minute IQ test both before and after training and tested whether participants would be able to solve significantly
more problems after training compared with before. Of course, the problems that were used were different in the pretest and the posttest.

• Sure enough, participants solved significantly more problems after the working memory training than they did initially. Before training, participants were able to solve between 9 and 10 problems within the 10-minute time limit. But after training, they were solving 12 problems on average.

• Although that finding is consistent with an increase in fluid intelligence, that’s not the only possible explanation. For example, maybe the problems on the second test were a little easier than the problems on the first test. Or maybe taking the first test gave the participants some practice doing IQ tests, and that’s why they performed better on the second test. Neither of those explanations has anything to do with the working memory training.

• To address those kinds of concerns, the researchers also recruited a control group of participants who didn’t do the working memory training. But in every other way, they were treated the same as the training group. They took the same IQ tests, and the amount of time between the 2 tests was the same as the training group. But instead of training on the working memory task, they just went about their lives as normal.

• On the initial IQ test, the control group’s performance was virtually identical to that of the training group. They also solved between 9 and 10 problems in the 10-minute time limit on average. But on the second test, the performance of the 2 groups was very different: Whereas the training group solved about 12 problems on average, the control group only solved about 10.5 on average.
• That difference between the training group and the control group can’t be attributed to a difference in how easy the tests were. After all, the control group took the same tests. It also can’t be attributed to practice on the first test, because the control group also got to take the first test. And they performed just as well as the training group did before the training.

• The researchers therefore concluded that the superior performance of the training group on the second IQ test was caused by the training. Apparently, working memory training can improve performance on IQ tests. And because IQ tests are designed to measure fluid intelligence, the results suggest that working memory training can increase fluid intelligence.

• If working memory training really does increase fluid intelligence, then you might expect that more working memory training would lead to greater increases than less training would. And that’s exactly what the researchers found: The more training people got, the more their performance on the IQ test improved. These results suggest that working memory training causes an increase in performance on the IQ test.

Improving ADHD Symptoms

• Another area in which working memory training has sparked a lot of interest is attention deficit hyperactivity disorder (ADHD), which is characterized by long-term problems in paying attention, excessive activity, and difficulty with impulse control. It’s often treated by some combination of psychotherapy and psychostimulant medication, but there is a lot of interest in trying to find behavioral interventions that might help. And some evidence suggests that working memory training might be such an intervention.
In 2005, Torkel Klingberg and colleagues published a randomized control trial providing some of the strongest evidence that working memory training might help ADHD. They recruited 53 children with ADHD between the ages of 7 and 12.

Half the children were randomly assigned to complete at least 20 days of computerized working memory training for about 40 minutes per day. The children had to do both visuospatial working memory tasks and auditory working memory tasks, and the tasks became more and more difficult as the children got better.

The other half of the children served as a control group. They also performed the same working memory tasks for the same amount of time, but the tasks were all easy and didn’t become more difficult as the children improved. So, the only real difference between the 2 groups was in the intensity of the working memory training and whether it stretched the children or not.

The scientists reported 2 interesting results: The children in the training group improved more than the control group on 2 working memory tasks on which they weren’t trained, suggesting that the training improved working memory ability more generally and not just the tasks on which the children got practice; and the children in the training group also improved more than the control group on 2 tests that are typically impaired in ADHD.

ADHD is the most commonly diagnosed mental disorder in children and adolescents.
• Consistent with these lab results, the parents of the children in the training group reported a significant reduction in ADHD symptoms compared with the parents of children in the control group.

There is evidence that appropriate training can increase working memory capacity and even improve fluid intelligence, and those effects might be related to changes in brain connectivity. However, not all studies that have trained working memory have improved fluid intelligence.

Unfortunately, this is also the case in the ADHD literature. Although some studies find improvements in ADHD symptoms after working memory training, other studies don’t.

Why this is the case is still a topic of considerable debate. But these discrepancies will all get resolved eventually; over time, science gets closer and closer to the truth.

How Does Working Memory Training Affect the Brain?

• What is changing in the brain during and after working memory training? Todd Thompson, Michael Waskom, and John Gabrieli investigated this question using functional MRI, a technique that is similar to positron-emission tomography that can be used to measure brain activity in humans.
• The scientists randomly assigned some participants to train on Jaeggi’s working memory task for 20 days. Other participants were randomly assigned to train on a perceptual object tracking task that is also demanding but that doesn’t emphasize working memory.

• Both before and after training, all the subjects participated in a functional MRI scan that estimated brain activity during Jaeggi’s working memory task. The researchers then examined how that activity changed as a function of the training.

• Thompson and his colleagues found that the working memory training led to 2 major changes. First, brain activity was reduced after working memory training compared with before training. This is now a very common finding in neuroimaging studies, and the standard interpretation is that the more you practice a task, the less hard the brain has to work to perform it. The result is lower activation levels.

• But this result isn’t specific to working memory training; you’ll typically find reduced brain activation after practicing any task, whether it involves working memory or not.

• They also found another neural change that was specific to working memory training: The connections between prefrontal regions and posterior brain regions became stronger. How could strengthening these connections help improve working memory performance?

• As you learned in the previous lecture, a very popular theory about how the prefrontal cortex interacts with posterior brain regions during working memory argues that it provides top-down excitation of those posterior regions. The idea is that when you’re actively perceiving visual or auditory stimuli, the perceptual pathways from the eyes and ears drive activity in posterior brain regions.
• But how do you keep the brain representations of those stimuli active if you want to remember them after the stimuli disappear? You need excitatory input coming from somewhere else. And that’s what the prefrontal cortex provides, according to this theory.

• But for that to work, you need good connections between the prefrontal cortex and the posterior brain regions that it excites. And sure enough, as those connections get stronger, working memory performance improves.

Should you spend time and effort trying to train your working memory?

There are plenty of brain games, computer games, and apps that offer the opportunity to train your brain, and many of those programs include working memory training. But in general, it is not worth it to spend time engaged in such training.

There is some evidence that such training might help you, and it might also be fun. But if your main goal is to improve your cognitive abilities, there are better ways to spend your time.

In particular, evidence shows that eating a good diet and pursuing an active lifestyle with plenty of physical exercise can help your brain at least as much as cognitive training—and probably more.
• But that theory makes another interesting prediction: People whose connections strengthen the most during the training should also exhibit the most improvement in working memory performance. And that’s exactly what Thompson and his colleagues found. The people whose prefrontal-posterior connections changed the most also showed the most change in working memory performance.

• Together, these results suggest that working memory training leads to changes in brain connections. And those connectivity changes contribute to improvements in fluid intelligence.

SUGGESTED READING

Jaušovec and Pahor, *Increasing Intelligence.*
Klingberg, *The Overflowing Brain.*
———, “Training and Plasticity of Working Memory.”

QUESTIONS TO CONSIDER

1 Based on what you learned in this lecture, do you believe Jaeggi’s claim that they managed to increase fluid intelligence in their participants? Why or why not?

2 How would society be affected if we could improve people’s intelligence, perhaps even dramatically? Would all the effects be positive?
The Learning Brain

LECTURE 19

How Motivation Affects Learning

The next 5 lectures are about factors that can have a big impact on learning and memory. This lecture is about a factor that may fly under the radar but can have an enormous effect on learning: motivation. Psychologists have done quite a bit of work exploring the question of what influences motivation and have identified at least 4 factors that play a critical role: self-efficacy, perceived control, intrinsic motivation, and perceived value. As you will learn in this lecture, these factors can influence learning in different ways.
Academic Achievement of American High School Students

Every 3 years, the Programme for International Student Assessment tests 15-year-olds all over the world to assess their achievement in key academic areas, such as reading, math, and science. In 2015, the US was ranked 38th out of 71 countries in math, 24th in science, and 24th in reading. And that’s despite the fact that America spends more per student than all but 3 or 4 countries in the world.

Many people are quick to blame the schools or teachers for the mediocre performance of US students. But one factor that is often overlooked is how teen culture in America views education and how motivated high school students are to work hard in school.

To investigate this issue, Laurence Steinberg led a large survey in which about 20,000 American high school students were asked about their motivation and engagement in school. Here are a few of the more startling findings:

- More than 1/3 of high school students said the primary way they get through the day at school is by “goofing off with their friends.”

- Almost 90% of high school students said they had copied homework from a friend in the last year.

- American high school students spend about 4 hours per week on homework. High school students in other cultures typically spend 4 hours on homework every day.

- Less than 20% of those surveyed said their friends think it’s important to do well in school, and less than 25% regularly discuss schoolwork with their friends.

- Almost 20% of students said they don’t try as hard as they can in school because they’re afraid of what their friends would think.

Based on these kinds of results, Steinberg argued that the real crisis in American education doesn’t lie in the schools themselves; rather, it lies in a culture that undermines student motivation and engagement.
Self-Efficacy

- Self-efficacy refers to your confidence in your ability to achieve some goal. If you’re confident in your ability to solve crossword puzzles, then you would have high self-efficacy in that domain. Conversely, if you have very little confidence in your crossword puzzle ability, then your self-efficacy would be low.

- Your self-efficacy is likely to be different in different domains. You might be very confident in your ability to solve crosswords, but not at all confident in your ability to solve calculus problems—or vice versa. Everyone has a different profile of self-efficacy across domains.

- It’s important to note that your self-efficacy, or confidence, in some domain can be different than your actual ability in that domain. But the opposite can also be true; that is, your ability can be much higher than your self-efficacy.

- Self-efficacy has an enormous impact on learning. And there are a few reasons. First, self-efficacy influences what people try to learn. The basic idea is that if you don’t believe that you’re capable of learning something, then you may not bother even trying. After all, why devote the time and energy if you believe you’re going to fail?

- For example, imagine a high school student who believes that she is bad at math. Maybe she had a bad experience in an earlier math class, or maybe other people have told her that she’s not the type of student who does well at math. But for whatever reason, she has now come to believe that she is just not cut out to learn math. As a result of that low self-efficacy, she decides not to try. Rather than risking failure, she chooses to take other, less challenging courses instead.
• This happens all the time. A much lower percentage of women than men pursue college majors in the STEM (science, technology, engineering, math) fields. And this is not because women are any less capable than men in these areas. But women who are just as capable as men nevertheless often doubt their ability in these domains more than men do; that is, their self-efficacy is lower even though their ability isn’t. And if your self-efficacy is low, you may decide not to pursue a goal that you could actually accomplish if you set your mind to it.

• Another way that self-efficacy influences learning is by affecting persistence. Research shows that people with higher self-efficacy tend to continue working toward their goals even in the face of difficulties.

• Suppose that you’re trying to learn a challenging skill, such as how to play the piano. It’s going to take a serious commitment of time and energy to get good at playing the piano, and you’re going to face some obstacles that you’ll have to overcome with hard work and persistence.

• But if your self-efficacy is low, you may mistakenly conclude that you just can’t do it and that it’s not worth continuing to work at it. As a result, many people with low self-efficacy give up even when they probably could have acquired the skill with a little more work.
Perceived Control

- Another factor that can significantly influence motivation and learning is perceived control, which refers to the extent to which you believe that you are in control of how much you learn, as opposed to your learning being dependent on forces outside your control.

- For example, imagine a student named Peter who does poorly on an exam despite studying really hard for it. Given that he studied hard, Peter might feel like the exam was simply unfair and that his poor performance was outside his control.

> Just as self-efficacy is about your belief in your ability rather than your ability itself, perceived control is about your belief in how much control you have rather than the actual level of control itself.

> A number of studies have found that perceived control can have a substantial impact on motivation and engagement in learning. For example, Raymond Perry, along with a number of his colleagues, found that students who were high on perceived control exerted more effort in their studies than students whose perceived control was low. They also reported less boredom and anxiety during school as well as greater motivation to try to do well. And they also got better grades.
• That would be an example of low perceived control. Peter attributes his poor performance to an external factor over which he has no control—namely, an unfair exam.

• But now imagine another student named Holly who also studied hard for the same exam and also performed poorly. But unlike Peter, Holly assumes that if she had prepared in a different way, then she could have done better. So, maybe she goes to the instructor’s office hours to review her exam, figure out what she missed, and identify more effective ways to study in the future.

• That would be an example of high perceived control. Holly assumes that she has some control over her performance and that if she studies in a more effective way, she’ll do better on the next exam.

• Note that in this situation, Peter and Holly perceive different levels of control in exactly the same learning situation. They both presumably have about the same level of control in this situation, but their perception of their level of control is different.

• High perceived control is closely related to the idea of a growth mindset, an idea that has been studied extensively by Carol Dweck, who has argued that it’s important to distinguish between what she calls a fixed mindset and a growth mindset.

• People with a fixed mindset view their talents and abilities as fixed and unchangeable. The idea of a fixed mindset and the idea of low perceived control are similar. If your poor performance is a result of fixed abilities, then you have very little perceived control. And from that point of view, putting a lot of energy into studying or working hard doesn’t make a lot of sense. In fact, students with a fixed mindset might view the need to work hard as a sign of inferior intelligence.
• In contrast, people with a growth mindset view their abilities as malleable, or changeable. A growth mindset is more consistent with a high level of perceived control. If you think your abilities can change with effort, then that means you have more control over your performance, so poor performance would tend to lead to more effort rather than less.

• People with a growth mindset also tend to have different goals than people with a fixed mindset. Specifically, the goals of people with a growth mindset are typically more about improving and ultimately mastering some challenging domain. That’s sometimes called a mastery orientation. Conversely, the goals of people with a fixed mindset are typically more about performing well and demonstrating their innate ability. They have a performance orientation.

• There’s now quite a bit of evidence that having a growth mindset is associated with significantly more learning and better academic performance. For example, one study found that academic performance in seventh graders with a growth mindset tended to improve over the next few years of school, while the academic performance of those with a fixed mindset stayed relatively constant.

• Even more impressive, teaching students that intelligence is malleable rather than fixed has been shown to improve subsequent learning and academic performance.

• Dweck has even conducted studies suggesting that it might actually be counterproductive to praise children for their intelligence, because doing so tends to emphasize the ability and might promote a more fixed mindset. Instead, she suggests praising children for the process and for their development and growth.
Intrinsic Motivation

- A third factor that has been found to significantly influence learning is intrinsic motivation. When you’re intrinsically motivated to do something, you do it because you want to. It’s inherently interesting or enjoyable to you, so you do it for the fun of it. In contrast, when you’re extrinsically motivated to perform a task, you do it because it satisfies some external goal.

- Intrinsic motivation and personal interest are associated with greater learning across many studies. For example, fourth graders remember more about assigned reading passages that they rate as personally interesting compared with passages that they find less interesting.

- Likewise, college students who develop an interest in a particular topic, such as computers, are more likely to study computer-related information on their own and persevere longer on computer-related assignments compared with students who have less interest in the topic.

- Surprisingly, adding external incentives for good performance can often reduce intrinsic motivation and undermine learning. For example, in one famous study, undergraduate psychology students worked on an inherently interesting puzzle called the Soma cube. The puzzle could be put together in a variety of different configurations, and in each session, the students were timed while they tried to reproduce a configuration that was shown on a piece of paper.

- In one of the sessions, half the students were paid a dollar for each configuration they were able to reproduce. But in the next session, they went back to doing it without any monetary incentive. The other half of the students never got any money and just did it for fun.
• Interestingly, the students who never got paid maintained their interest in the puzzle and kept working on it, while the students who had been paid lost interest after the money dried up.

• The researchers argued that providing an external incentive—money—had undermined the students’ intrinsic motivation. Now rather than doing it for fun and interest, they started doing it for the money. And when there was no more money, they were no longer interested.

• This effect poses a challenge for education: On one hand, teachers need to provide tests and external assignments with grades that serve as an incentive for students to work hard, but doing so could undermine the students’ intrinsic motivation and interest and paradoxically impair their learning. Providing appropriate external incentives while nurturing a student’s intrinsic motivation is one of the real challenges of effective teaching.

Perceived Control

• The fourth factor that has been shown to have a significant impact on learning is the value that students place on what they’re learning. Do students care about what they’re learning? Do they think that what they’re learning is important in some way? If so, that can significantly increase the amount that they learn.

• Jacquelynne Eccles has done some of the best work on the importance of value in learning. For example, she and her colleagues have demonstrated that student beliefs about the value of mathematical knowledge are one of the best predictors of whether those students will enroll in math classes or not. But once the students are enrolled, their self-efficacy, perceived control, and intrinsic interest are the best predictors of their actual performance.
SUGGESTED READING

Bandura, *Self-Efficacy.*
Deci and Flaste, *Why We Do What We Do.*
Duckworth, *Grit.*
Dweck, *Mindset.*

QUESTIONS TO CONSIDER

1. There are 4 factors that can significantly influence motivation: self-efficacy, perceived control, intrinsic motivation, and perceived value. Which of these factors do you think has had the biggest influence on your motivation to learn?

2. How could teachers apply the information in this lecture to help unmotivated students?
How are learning and memory affected by how we feel? Exactly how do our feelings affect our learning and memory? What’s going on in the brain and the body that might explain the effects of stress and emotion on memory? This lecture will address these types of questions.
Emotional Memories

• Psychologists refer to the vivid memories of traumatic or emotional events as flashbulb memories. For many people, their memory of the 9/11 attacks are a good example: They vividly remember where they were, who they were with, what they were doing, and many other contextual details.

• Our memories for emotionally arousing events tend to be more vivid than our memories for more neutral events. For example, Margaret Bradley, Peter Lang, and their colleagues recruited nearly 90 undergraduates and asked them to rate pictures based on how emotionally arousing they were and how pleasant they were.

• Immediately afterward, they asked the participants to describe as many pictures as they could remember. They also called them a year later and asked them to do the same thing again. And on both tests, participants remembered significantly more of the pictures that they rated as emotionally arousing.

• There’s also evidence that the effect of emotion on memory actually gets stronger over time. Stephen Kaplan demonstrated this effect as early as the 1960s. He and a student named Lewis Kleinsmith asked about 50 undergraduate students to try to remember 8 arbitrary word-number pairings. For example, they might have to remember that the word “vomit” was paired with the number 4 while the word “swim” was paired with the number 7.

• Some of the words, such as “vomit” and “rape,” were more emotionally arousing than other, more neutral words, such as “swim” and “dance.” And those differences had a dramatic impact on people’s memory and how that memory changed over time.
• About 20 minutes after studying the pairs, people were able to remember about 20% of the numbers associated with words that were not emotionally arousing. The next day, that percentage dropped to about 12%. And a week later, participants remembered virtually none of the numbers associated with the neutral words.

• But the researchers found the opposite for words that were highly arousing: 20 minutes after studying the pairs, the participants remembered about 20% of the numbers associated with words that were emotionally arousing. That’s about the same as for the neutral words. But the next day, their memory for those numbers actually got better rather than worse. Now they remembered almost 40% of the numbers. And after a week, their performance was even better.

• More recent studies have found similar results. As time passes, the gap between emotional memories and neutral memories grows. And that has led many scientists to hypothesize that emotional arousal strengthens memory consolidation.

• So, emotional memories are typically more vivid than neutral memories. People create flashbulb memories that are extremely detailed and that they remember for a long time. But are those emotional memories accurate? Most people certainly assume that they are, given their vividness and their attention to detail. And if asked to rate their confidence in the accuracy of emotional memories, people inevitably give very high confidence ratings.

• But our memory often reflects a plausible reconstruction of what we experienced, and it can be distorted in a variety of ways. Furthermore, we’re typically unaware of these distortions in our memory and assume that what we think we remember actually happened. And it turns out that’s also true for emotional memories.
• For example, consider the *Challenger* disaster. On January 28, 1986, the space shuttle broke apart 73 seconds into its flight, killing all 7 crew members. Many people vividly remember where they were and what they were doing when they first heard about the tragedy.

• Ulric Neisser and Nicole Harsch interviewed 44 students who were in Neisser’s psychology class when the disaster happened. He asked them to fill out a questionnaire about their memory for the event in class the day after it happened and contacted them again when they were seniors and asked them to fill out a similar questionnaire.

• The researchers compared the 2 reports on 7 key attributes, including where they said that they were when they heard the news, what they were doing, and who told them. Half the subjects gave conflicting answers for at least 5 of the attributes, and a quarter of them were wrong about all 7.

• Nevertheless, when asked to rate their confidence in their memory on a scale of 1 to 5, the average rating was 4.17. In fact, 13 of the 44 participants rated their confidence as 5 out of 5, and 3 of those 13 people had actually misremembered all 7 key attributes.

• Clearly, although emotional memories are vivid and long-lasting, they are subject to the same kinds of distortions as other memories are.

• Most of the time, it’s presumably adaptive to form vivid memories for emotionally arousing information. Remembering a traumatic event such as a car accident or getting robbed might help you avoid similar situations in the future. But in some cases, traumatic memories can become maladaptive and intrusive.
* For example, victims of post-traumatic stress disorder (PTSD) often experience intrusive and recurrent flashbacks to previous traumatic events. And those symptoms can persist for an extended period of time, significantly interfering with their daily life.

When most people think of PTSD, they think of war veterans whose memories of traumatic battles have become consuming and debilitating. But soldiers aren’t the only ones who experience PTSD. Experiences like the sudden, unexpected death of a loved one or being physically or sexually assaulted can also cause PTSD.

It’s normal to feel afraid during and after traumatic events, and almost everyone will experience a variety of unpleasant reactions for a period of time. But most people recover from those symptoms naturally within a month or so. Victims of PTSD don’t. They continue to feel extremely stressed and frightened long after the disturbing event, even when they’re no longer in any danger.
How Feelings Affect Learning and Memory

• In a hypothesis proposed by J. A. Easterbrook called cue utilization theory, he argued that emotional arousal tends to restrict our utilization of environmental cues. Put simply, the more emotionally aroused we get, the more we restrict our focus of attention to only the most relevant environmental features. And focusing attention can often improve learning.

• One of the best pieces of evidence for cue utilization theory is the weapon focus effect, which is the finding that when people encounter someone with a weapon, they tend to focus most of their attention on the weapon itself. As a result, they often remember a lot about the weapon, but not so much about the perpetrator or other features of the event.

• In one study, participants were presented with a sequence of pictures of a customer going through a line at a fast-food restaurant. Half of the participants saw some pictures in which the customer pointed a gun at the cashier, who then handed over some money. The other half saw the customer hand the cashier a check, and then the cashier also handed over some money. The pictures for the 2 groups were identical except for the change from a gun to a check.

• The researchers found that participants in the weapon condition spent more time looking at the gun, while participants in the check condition spent more time looking at other features, such as the customer’s appearance. Sure enough, the people in the check condition remembered the customer better than the people in the gun condition—just as cue utilization theory would predict.

• This result also demonstrates that stress and emotional arousal don’t always improve every aspect of memory. In this case, the stressful gun condition actually produced worse memory for the
customer than the unstressful check condition did. It all depends on what you pay attention to.

• Stress tends to make you narrow your focus of attention to the most central, important information. And memory for that information is often improved. But memory for other information is typically impaired, precisely because you ignored it.

• Short-term, acute emotions and stress tend to make memories stronger and more vivid, although they don’t protect memory from subsequent distortion. Does long-term, chronic stress also strengthen memory? To answer that question, Victoria Luine, along with Bruce McEwen and 2 other colleagues, measured memory performance of rats that had been exposed to chronic stress for 3 weeks and of rats that had not been stressed.

• The animals were placed in a radial arm maze, in which 8 narrow tracks, called arms, extend outward from a central platform. At the end of each arm is a small well containing a peanut. The rat is placed in the middle and has to walk out to the end of each arm to get all 8 peanuts.

• The rat wouldn’t want to walk down the same arm twice because the peanut won’t be there anymore, so that would be considered a mistake, while walking down an arm that the rat hasn’t visited before would be considered a correct answer.

• Luine and her colleagues compared the memory performance of rats who had been stressed out for 3 weeks with the memory performance of rats who hadn’t and found that stress impaired memory performance. The chronically stressed rats made more mistakes and made them earlier than the control rats.

• While short-term stress often strengthens memory, long-term, chronic stress seems to undermine it.
The Biological Basis of Stress and Emotion

• What’s going on in the body and the brain when we experience intense emotions? And how does it affect learning and memory?

• When we’re stressed or experience intense emotions, we activate a biological system called the HPA axis, which includes the hypothalamus, the pituitary gland, and the adrenal glands. When the HPA axis is activated, the end result is the release of stress hormones in the bloodstream, which in turn trigger a fight-or-flight response: You get a jolt of adrenaline, your mouth goes dry, your pupils dilate, your sensations are heightened, and your heart starts to race.

• Given that short-term stress often strengthens memory, it’s natural to ask whether it’s the stress hormones that produce that effect. To investigate that question, Larry Cahill and James McGaugh, along with 2 other colleagues, used a drug called propranolol to block the effect of the stress hormones. Then, they examined the effects on memory.

• Stress hormones work by attaching to special receptor molecules throughout the body and turning them on, triggering the fight-or-flight response. Propranolol attaches to the same receptors that the stress hormones attach to, but it prevents the stress hormones from turning the receptors on. So, if the activity of stress hormones is critical to enhancing emotional memory, then emotional memory should not be enhanced in people who take propranolol.

• Cahill and his colleagues tested this idea by presenting people with 2 stories to remember. One was an emotional story about a boy walking with his mom, getting hit by a car, and being rushed to the hospital to be treated for life-threatening injuries. The other was a neutral story in which the boy and his mom walk to the hospital and observe a simulated emergency response.
• Some people took propranolol before listening to the story while other people took a placebo. A week later, everyone’s memory was tested, and the results in the placebo group were compared to the results in the drug group.

• The placebo group showed the standard emotional enhancement effect. People in this group had a significantly stronger memory for the emotional story compared with the neutral story. But the drug group didn’t. Their memory for the emotional story was no stronger than their memory for the neutral story. These results suggest that the release of stress hormones is what causes emotional memories to be vivid and strong.

• There is also evidence that chronic exposure to stress hormones over time can lead to changes in the brain that undermine learning and memory. For example, certain asthma and anti-inflammatory medications increase stress hormone levels, and patients taking these medications sometimes exhibit learning and memory deficits.

• Recall that classical conditioning is the type of learning that Ivan Pavlov studied in his dogs. After repeatedly presenting a conditioned stimulus—a bell—with an unconditioned stimulus—food—Pavlov’s dogs learned an association between the bell and the food and would therefore salivate as soon as they heard the bell.

Hormones play an important role in how stress and emotion affect memory.

There are specific areas of the brain that play a crucial role in learning and remembering emotional information, and a lot of the evidence has come from studies of classical fear conditioning.
• Fear conditioning is very similar, except that the unconditioned stimulus is something unpleasant, such as a shock, instead of food. For example, you might condition a rat so that it associates the sound of a tone with getting a shock. After learning, the rat will exhibit a stereotypical fear response when it hears the tone. It will freeze in place, and its breathing and heart rate will increase.

• A number of studies have examined the neural basis of fear conditioning and have repeatedly identified a neural structure called the amygdala as being particularly important. The amygdala is an almond-shaped brain region just in front of the hippocampus in the medial temporal lobes. It is known to play an important role in the processing of emotion, although its role in fear and fear conditioning has been studied the most.

• For example, rats and other animals that have lesions to the amygdala don’t exhibit normal fear conditioning. After such lesions, these animals do not learn the standard association between a conditioned stimulus, such as a tone, and a fearful conditioned stimulus, such as a shock.

• Furthermore, administering drugs that block long-term potentiation—the long-term strengthening of synaptic connections that is thought to play a crucial role in many types of learning—in the amygdala also prevent fear conditioning. These studies demonstrate that the amygdala plays a crucial role in emotional learning.

Many of the effects that emotion and stress have on learning and memory seem to depend on your amygdala.
• Other studies have shown that it’s also critical for the consolidation of emotional memories. For example, injecting stress hormones into the amygdala immediately after learning has been shown to produce strong, longer-lasting memories. Conversely, blocking the effect of stress hormones in the amygdala impairs this kind of consolidation.

• Similar results have also been observed in human beings who have damage to the amygdala as a result of stroke or brain injury. For example, these patients don’t show the normal narrowing of attention that emotion tends to produce in people without brain damage. They also don’t exhibit the same memory advantage for emotional information compared with neutral information that most people show, either initially or after a delay.

SUGGESTED READING

McEwen and Lasley, *The End of Stress as We Know It.*

QUESTIONS TO CONSIDER

1. Do you have any flashbulb memories for particularly emotional events from your past? Do you think those memories are more accurate than other memories, or just more vivid?

2. Can you think of any ways to reduce the level of chronic stress in your life (and thereby potentially improve your learning and memory)?
How Sleep Affects Learning

Many people view sleep as an annoyance and a waste of time, but we can’t function as well when we don’t get enough sleep. Our ability to think clearly, to react quickly, and to focus our attention all decline when we’re sleep deprived. In addition to sleep’s role in helping us be alert and focused, there is now a great deal of evidence that sleep plays a crucial role in learning and memory—which is the subject of this lecture.

Sleep deprivation has been implicated in a number of major tragedies, including the space shuttle Challenger explosion, the Exxon Valdez oil spill, and maybe even the Chernobyl nuclear disaster.
The Behavioral Effects of Sleep on Learning

• A number of studies have found a correlation between poor sleep and impaired learning as measured by academic performance. For example, one study found that the average grade point average of high school students who slept less than 6 hours a night was around a B−, whereas the average for students who slept 9 hours or more was around a B+.

• These types of results are compelling, but they’re also correlational. And correlation does not imply causation: Just because poor sleep is correlated with poor academic performance, that doesn’t necessarily mean that poor sleep is causing the poor performance. For example, maybe poor grades cause poor sleep rather than the other way around, or maybe some other factor is causing both poor grades and poor sleep.

We human beings spend roughly a third of our lives sleeping. That means that a 60-year-old has spent about 20 years asleep.
To address these kinds of concerns, a number of studies have randomly assigned some people to a sleep deprivation condition and other people to a non–sleep deprived condition and then assessed learning in the 2 groups. These studies have also found that sleep deprivation impairs learning.

For example, in one study, conducted at the Stanford Center for Sleep Sciences and Medicine, adolescents had their memory tested after a normal night of sleep and after a night without sleep. Specifically, they were presented with 25 four-letter words and later were asked to try to remember as many as they could. After a normal night of sleep, they remembered about 12 words on average. But after sleep deprivation, they only remembered between 8 and 9. So, their performance was about 30% worse.

Studies like this confirm that learning and memory are better after a good night’s rest. After all, many things are better after a good night’s rest; you’re more alert, and you’re better at paying attention.

You also learn and remember information better before a good night’s rest. If you study some information and then sleep on it, the sleep itself often strengthens and consolidates your memory so that you’ll be able to remember it better in the future. This effect applies to both explicit, declarative memory as well as implicit, procedural learning.
Strategies for Improving the Quality of Sleep

By adopting some or all of the following strategies, the quality of your sleep is likely to improve. And as your sleep improves, so will your learning and memory.

- Try to get enough sleep. Most adults should be getting at least 7 hours of sleep at night, and preferably 8 or 9. Different people need different amounts, but ideally you should be going to bed early enough that your body wakes up on its own before the alarm clock goes off.

- Avoid caffeine, nicotine, and alcohol for a few hours before you go to bed. All these drugs have been shown to disrupt the quality of sleep—so has heavy food, so try to avoid eating a big meal close to bedtime.

- Tailor your bedroom for a good night’s sleep. Keep it as peaceful and clean as possible so that it feels like a relaxing oasis. Invest in a comfortable mattress and pillow and get curtains that will block out the light as effectively as possible. If it’s not quiet, consider a fan or white noise machine. And keep it cool. We sleep best when the air temperature is between 60° and 67° Fahrenheit.

- Establish a regular bedtime routine. Try to go to bed at roughly the same time every day, even on weekends. You might also adopt some relaxing bedtime habits, such as reading or taking a bath, that your body will begin to associate with going to bed and falling asleep. And once you go to bed, try to avoid watching TV or using electronics, which can make it more difficult to fall asleep.

- Get some exercise during the day. Take a walk or go for a bike ride. As little as 10 minutes of aerobic exercise can significantly improve the quality of your sleep.
What Happens in the Brain while We Sleep

- A common belief is that the brain turns off, or deactivates, when we go to sleep. In fact, until the 1950s, that was a common assumption among sleep scientists. But in 1953, Eugene Aserinsky and Nathaniel Kleitman made a discovery that changed sleep science forever.

- They used electroencephalography (EEG) to record people’s brain waves while they slept. And they found that, far from being inactive, the brain goes through predictable cycles of unique activity patterns when we sleep. In fact, at one point during these cycles, the brain is just as active as it is when we’re awake.

- Aserinsky also noticed that people move their eyes behind their closed eyelids during these periods of significant brain activity, but not during other periods of sleep. He therefore referred to the highly active periods as rapid eye movement (REM) sleep and to the other periods of sleep as non-REM sleep.

- Scientists now know that there are many fundamental differences between REM sleep and non-REM sleep. For example, if you wake people up during REM sleep, they are much more likely to report that they were dreaming, and quite often those dreams are vivid and bizarre. But if you wake them up from non-REM sleep, they’re much less likely to say they were dreaming.

- REM sleep is also associated with a kind of paralysis that prevents the limbs from moving. Many scientists believe that this is the body’s way to prevent us from acting out our dreams while we’re sleeping.

Sleepwalking is associated with non-REM sleep rather than REM sleep.
• During normal sleep, we will typically cycle between non-REM and REM sleep every 1.5 to 2 hours. We first enter a light non-REM sleep, from which we can easily be awakened. Then, we move into deeper stages of non-REM sleep, during which large populations of neurons fire in unison 1 to 4 times per second. This produces strong, low-frequency brain waves and is referred to as slow-wave sleep.

• During slow-wave sleep, our core temperature drops, and it’s more difficult to wake up. We typically spend 20 to 40 minutes in this kind of deep sleep before transitioning back into lighter non-REM sleep for a few minutes and then finally into REM sleep.

• The first period of REM sleep is usually pretty brief, lasting only 1 to 5 minutes. Then, we transition back into non-REM sleep, and the cycle begins again. Overall, we spend about a quarter of our total sleep time in REM sleep, about half in light non-REM sleep, and another quarter in deep, slow-wave non-REM sleep, but the proportion changes throughout the night.

• With each new cycle, the REM periods tend to get a little bit longer, while the deep, slow-wave periods tend to get shorter and may disappear entirely in the last few cycles. As a result, the first few cycles are dominated by deep, slow-wave sleep, while later cycles are dominated by REM and light non-REM sleep.

• The fact that the first few hours of sleep are qualitatively different from the last few hours has led some scientists to hypothesize that different types of sleep help to consolidate different types of learning. Specifically, they have hypothesized that slow-wave sleep is more important in the consolidation of explicit, declarative memories, while REM sleep is more important in the consolidation of implicit, procedural memories.
• But why should sleep help consolidate any memories, whether they’re explicit or implicit? One idea is that sleep protects new memories. So, if you learn something new and then sleep on it, then somehow the memory becomes less susceptible to interference or forgetting. According to that view, sleep doesn’t change the memory in any way; it just passively stabilizes it.

• An alternative idea is that sleep actively changes memories and generalizes them so that they can be used and remembered in a wider variety of settings. Recent evidence is favoring this more active view of sleep’s role in consolidation.

Reactivating Memories while We Sleep

• There’s quite a bit of evidence that we reactivate our memories while we sleep. And although it’s tempting to think that memory reactivation would always correspond to a kind of dreaming and might therefore occur during REM sleep, that’s not actually true. Reactivation of declarative memories is most associated with non-REM, slow-wave sleep.

• But does this reactivation actually cause the memory to be strengthened or consolidated? Remember, correlation does not imply causation. To infer causality, we need to experimentally manipulate reactivation and observe an effect on memory strength. But how could we influence whether someone reactivates a memory while they’re sleeping?

• Björn Rasch, Jan Born, and a few colleagues did just that in one of the most creative sleep experiments, in which human volunteers learned an object location task before going to sleep for the evening. Specifically, they were presented with an array of cards
with pictures on them and had to remember where matching cards were located in the array. After learning, they went to sleep, and then their memory was tested the next morning.

• But while they were learning the locations of the cards, they were also presented with a smell—specifically, the smell of roses. Smells can be very strong memory cues, and in this case, the scientists used the smell of roses to try to reactivate memory of the card location task during sleep. So, they monitored the participants’ brain waves while they were sleeping and then presented the smell of roses during different periods of sleep.

• Amazingly, presenting the smell of roses during non-REM, slow-wave sleep improved their memory performance the next day. And the effect was quite specific: Presenting the smell when the subjects were still awake didn’t help their retention. Likewise, presenting the smell during REM sleep didn’t improve their performance. Finally, presenting the smell during slow-wave sleep only helped people who had smelled the roses when they were learning the task; it didn’t make any difference in people who hadn’t smelled anything during learning.

• This was not just a correlation. This experiment demonstrated that smelling roses during slow-wave sleep caused improved memory the next day. And a natural explanation is that the smell evoked the memory of the cards during sleep and that reactivating that memory strengthened it.

• In a separate experiment, the scientists used functional neuroimaging to examine brain activity when people were exposed to smells that had been presented during previous learning. They measured neural activity during both slow-wave sleep and when
people were awake, and they found that presenting the smell of roses during slow-wave sleep led to activation in the hippocampus. In fact, hippocampus activity was stronger during sleep than it was when participants were awake.

• The hippocampus is strongly associated with explicit, declarative learning and memory. So, the results suggest that the smell was indeed triggering reactivation of the previously learned memories during slow-wave sleep. It also strengthened those memories the next day.

Theories of Sleep’s Role in Memory Consolidation

• Two of the most popular theories about how the role of sleep in memory consolidation works at a neural level are the system consolidation theory and the synaptic homeostasis theory.

• Explicit memories might depend on the hippocampus initially but gradually get consolidated into the cerebral cortex over time. We want to be able to learn new things quickly, but we don’t want the new learning to interfere with our previous memories. We want our memories to be plastic so that we can learn new things, but we also want them to be stable.

• The brain’s solution is to have 2 separate memory systems: one for fast, immediate learning and another for slower learning that integrates new information with old. The hippocampus is assumed to be the fast learning system that can quickly learn new relationships and associations. And that allows us to be plastic and flexible.
• But consolidation of those memories into the cortex is slower and more gradual, interleaving the new memories with older existing memories. That allows us to add new information without overwriting older information, but it requires the hippocampus to reactivate new memories so that they can be incorporated into the existing memory networks without overwriting what’s already there.

• And that’s where sleep comes in, according to the system consolidation theory. During periods of slow-wave sleep, new memories are repeatedly reactivated, and those reactivations allow those memories to be gradually incorporated into the cerebral cortex without overwriting previous memories.

• According to the other major theory, synaptic homeostasis, learning new information when you’re awake tends to increase the strength of synapses between neurons, and sleep serves to downscale synaptic strength back to a more standard level.

• But wouldn’t downscaling synaptic strengths simply undermine the previous learning and cause you to forget it? The answer is no, and here’s why: Learning tends to strengthen a relatively small proportion of synapses and leaves most others unchanged. But downscaling during sleep is assumed to apply to all the synapses in a neural circuit. As a result, the strong synapses aren’t affected very much, while the weak synapses get significantly reduced. Because the strong synapses are presumably the most reliable, while the weak synapses are noisier, the overall effect is to improve the quality of the memory representation.

• The synaptic homeostasis theory and the system consolidation theory are not mutually exclusive. In fact, many sleep scientists believe both mechanisms play a role in the consolidation of memories during sleep.
• First, reactivation of memories during slow-wave sleep leads to the strengthening of synapses in the cerebral cortex and the integration of the new memory with preexisting memories. That’s the system consolidation part. But then those synapses are downscaled to maintain a homeostatic equilibrium and to improve the signal-to-noise ratio in the memory. That’s the synaptic homeostasis part.

• It’s even possible that different periods of sleep are associated with the 2 functions, with slow-wave, non-REM sleep being more important for system consolidation and REM sleep being more important for synaptic homeostasis. Perhaps that’s even the reason we have different types of sleep, although at present that’s speculation.

SUGGESTED READING

Hobson, *Dreaming.*
Stickgold and Walker, *The Neuroscience of Sleep.*
Walker, *Why We Sleep.*

QUESTIONS TO CONSIDER

1. How significantly is your learning affected by your sleeping habits? Do you think that you learn better after a good night’s sleep?

2. Are there any specific steps you can take to improve the quality of your sleep?
THE COMMON BELIEF THAT AGING IS INEVITABLY ASSOCIATED WITH A significant deterioration in mental abilities, including learning and memory, is wrong. In the absence of disease, such as Alzheimer’s, the mental impairments associated with aging are typically restricted to a few specific cognitive processes, and most other aspects of mental life don’t decline much. This lecture will explore what scientists are discovering about the effects of aging on learning and memory—as well as what we can do about it. As you will discover, there are scientifically proven steps we can take to help us keep our mental abilities sharp as we get older.
How Learning and Memory Change as We Age

- Aging has dramatically different effects on fluid intelligence compared to crystallized intelligence.

  - Recall that fluid intelligence refers to cognitive abilities that are relatively independent of what you know. Can you think logically, identify patterns, and solve novel problems quickly and effectively? Brain teasers and puzzles that depend more on your ability to think in creative ways than on how much you know emphasize fluid processing ability.

  - Recall that crystallized intelligence refers to cognitive abilities that depend critically on your knowledge, experience, and acquired skills. For example, crossword puzzles place significant demands on crystallized intelligence because they depend a lot on how much you know about the world.

- Around the year 2000, Denise Park and her team gave people tests that tap into fluid processing ability—such as asking people to try to remember random words or line drawings or testing how fast they could perform tasks that didn’t depend on knowledge—and generated plots of people’s performance as a function of their age.

- These same declines were seen in episodic memory and working memory.

  - Recall that episodic memory refers to long-term, explicit memory for personal episodes that you have experienced. Episodic memories are remembered from a first-person perspective, as if you’re reliving them through your own eyes. They’re also tied to a specific time and place. Unfortunately, Park found that our ability to store and retrieve episodic memories tends to get a little bit worse with each passing decade.
Recall that working memory is our ability to store information for up to a minute or so and then retrieve that information when we need it later. For example, if you have to add some multidigit numbers in your head, you have to constantly store the results of each column and then retrieve that information later to finish the solution. Park found that working memory also tends to decline with age.

It’s important to keep in mind that subtle age-related declines in episodic and working memory are normal. Many older people are worried about Alzheimer’s disease, so when they notice that their ability to learn and remember isn’t quite as good as it used to be, they naturally worry that it means they’re going to develop dementia. But occasional lapses in memory are normal as we age and are caused by completely different mechanisms than the much more severe symptoms of Alzheimer’s disease.

Furthermore, quite a few studies demonstrate that given enough time, older people can perform fluid processing tasks just as well as younger people. In fact, Timothy Salthouse analyzed age-related declines in fluid intelligence as a function of processing speed and
found that once he controlled for how fast people were, the age differences vanished. So, it’s probably more about speed than it is about ability.

• It’s also important to note that there are substantial differences between different people. Some people experience a lot of learning and memory problems as they get older, but other people experience very few. Most scientific studies of aging average across people of a similar age, and when this is done, the average amount of decline is found. But keep in mind that roughly half the people in the sample are doing better than the average.

• So, storing information in, and retrieving information from, both episodic memory and working memory often (but not always) decline a little as we get older. But it turns out that there are other types of learning and memory that don’t typically decline with age—and may even improve. For example, consider crystallized intelligence, which depends critically on your knowledge, experience, and acquired skills.

• Park’s group also tested this kind of processing ability, using tasks that tested things like world knowledge and vocabulary. The results on these tasks looked very different than the results for fluid intelligence. Here, the older groups tended to perform better than the younger groups.

• Semantic memory, or your knowledge base of everything you know about the world, is a type of long-term, explicit memory, just like episodic memory; that is, you can consciously bring to mind things you know from your semantic memory, and you can verbalize those memories and talk about them.

• But unlike episodic memory, semantic memories are not remembered from a first-person perspective and are not tied to a specific time and place. And in the absence of disease, our semantic
memory seems to improve with age. Our vocabulary gets bigger; our knowledge of the world expands. As a result, our crystallized intelligence remains stable or even improves.

- In addition to crystallized intelligence being preserved with age, your memory for skills and habits is also pretty stable as you get older. Knowing how to read, how to speak a language, and how to play an instrument are examples of procedural memory. And studies have repeatedly found that procedural memory doesn’t normally decline as we get older.

**How the Brain Changes as We Age**

- One important line of work in the area of how our brain changes as we age has been conducted by Naftali Raz and his colleagues, who examined MRI scans from the brains of a large number of healthy adults, ranging from 20 to 80 years old. Using the MRI scans, they painstakingly traced specific brain structures in each individual participant and measured the volume. Then, they plotted the volume of different structures as a function of the age of the participant. Doing so allowed them to determine whether a given brain region shrinks with age or whether its volume remains relatively constant or even grows.

- Raz’s team found 2 main brain regions that tend to shrink as we age: the hippocampus and the prefrontal cortex.

  - Recall that the hippocampus is the region that is most associated with amnesia (remember Henry Molaison, or patient HM). When Raz and his colleagues plotted the size of the hippocampus as a function of age, they found that the hippocampus tends to shrink a little bit with each passing decade. And that was true
both when comparing old people to young people and when comparing volume estimates in the same individual 5 years later. This study suggests that one reason why episodic memory tends to decline with age may be that the hippocampus is shrinking.

Recall that the prefrontal cortex is kind of like the CEO of the brain, controlling what we pay attention to, managing goals, and delegating responsibilities to other brain processes. In particular, the prefrontal cortex is hypothesized to play a central role in working memory. When Raz and his colleagues plotted prefrontal cortex volume versus age, they found that the prefrontal cortex tends to get a little bit smaller as we get older. If the prefrontal cortex is shrinking as we get older and working memory depends on the prefrontal cortex, then we can understand why working memory might tend to get worse as we age.
There are steps that we can take to help our brains age a little more gracefully and perhaps preserve our learning and memory abilities as long as possible. Four strategies that have fairly strong scientific support are eating right, staying active, maintaining relationships, and reducing stress. You can remember these 4 strategies with the acronym EARS, where E stands for eating right, A stands for activity, R stands for relationships, and S stands for stress reduction.

1 Eating right. There is quite a bit of evidence that eating a healthy diet with fewer calories can extend lifespan. For example, scientists have investigated the effects of eating a Mediterranean diet, consisting of a lot of fruits and vegetables, olive oil, fish, nuts, and legumes; whole grains; and moderate amounts of alcohol. One study found that the incidence of heart attack, stroke, and death were significantly lower in people in the Mediterranean diet groups than people in the control group and that eating a Mediterranean diet improved cognitive functions.

Studies have found that eating a Mediterranean diet reduces your risk of developing Alzheimer’s disease, maybe by as much as 50%.
A number of studies have found that learning a second language is associated with better cognition in later life, and others have found that learning a complex new hobby, such as digital photography or quilting, also has cognitive benefits.

2 Activity. In a study of the effects of physical activity on the mind and brain, Kirk Erickson and Arthur Kramer recruited more than 120 older people and randomly assigned half of them to a year of aerobic exercise, while the other half did stretching and toning but didn’t participate in aerobic exercise. As expected with normal aging, brain scans of the hippocampus looked a little smaller in the control group after a year than it did before the experiment. But in the other group, both the left and the right hippocampus actually got a little larger after a year of aerobic exercise. Furthermore, changes in the size of the hippocampus were associated with changes in memory performance. Vigorous mental activity can also help us age more gracefully.

3 Relationships. There is a growing body of evidence that good social relationships can help us stay sharp as we age. In a famous study, one group of older participants worked with 5 to 7 other participants on a long-term project that involved team-based problem-solving, while another group of older participants continued life as usual without that regular social interaction. Scientists found that the people who had been assigned to the social interaction group performed better on all tests of cognitive performance, including processing speed, working memory, reasoning, and spatial processing.
Stress reduction. Recall that when we experience stress, a biological system called the HPA axis is activated, triggering a fight-or-flight response: You get a jolt of adrenaline, your mouth goes dry, your pupils dilate, your sensations are heightened, and your heart starts to race. This response is very helpful if you’re dealing with a life-threatening situation, but many people chronically activate the HPA axis and the associated fight-or-flight response from daily stress, and this can lead to disease and actually increase the speed of aging.

It’s not always easy to reduce stress, especially if you’re constantly faced with deadlines or other obligations. But one method that has been scientifically demonstrated to reduce stress is meditation. In particular, meditation has been found to lower heart rate, reduce blood pressure, and lower levels of bad cholesterol.

It also turns out that 3 of the most effective approaches to reducing stress are the same methods that help us age more gracefully: eating right, staying active, and maintaining social relationships.
SUGGESTED READING

Buettner, *The Blue Zone*.
Park and Schwarz, *Cognitive Aging*.

QUESTIONS TO CONSIDER

1. Have you noticed any changes in your cognitive abilities as you age? If so, what changes have the biggest impact on your daily life?

2. Considering the acronym EARS, are there any changes you’d like to make in your life that might help you age more gracefully?
This lecture will address a topic that is critically important but that is surrounded by many misconceptions—learning disabilities. Most definitions of the term “learning disability” arouse controversy, but the education field tends to use the term “specific learning disorder” (SLD). The word “specific” makes clear that the learning problem is typically limited to a specific domain, such as learning to read or write, and would not extend to learning other things, such as how to ride a bike or tie a shoelace. This lecture will focus on dyslexia, including the cognitive and neural mechanisms that underlie it and how it’s treated.
Specific Learning Disorders

• The key feature of a specific learning disorder (SLD) is an unusual difficulty in learning some academic domain that cannot be explained by the child’s intellect, educational opportunities, sensory abilities, motivation, or emotional state.

• There is a mistaken belief that SLDs reflect low intellect or a lack of motivation. In fact, the learning problem is present despite normal intelligence. It’s a specific problem in learning a particular academic topic and doesn’t imply that the child will have intellectual difficulties anywhere else.

• And perhaps because of that discrepancy between their intellect and academic achievement, many people assume that children with an SLD must be lazy. After all, if it’s not a problem with their intellect, or their vision, or their home life, or some other obvious factor, then it’s natural to attribute the problem to a lack of effort.

• And although repeated failure in an academic subject can eventually lead to a kind of learned helplessness and to giving up, that’s not usually the cause of the problem initially. In fact, many children with an SLD struggle in their learning despite working very hard, maybe even harder than most other children.

• The implication is that SLDs are caused by something biological in the student’s brain rather than something in their external environment.

• Another common misconception is that there’s a clear dividing line between children with SLDs and children without SLDs. The truth is that SLDs exist on a continuum, and the threshold for what constitutes an SLD is actually somewhat arbitrary.
In some cases, the diagnosis will be easy. If a child has a very severe problem learning to read that is completely out of line with his or her intellectual ability, then it might be a very obvious diagnosis. Conversely, you’ll also find many children whose learning seems totally normal and who obviously don’t have an SLD.

But the problem is you’ll find children at every point between those extremes. You’ll find children who struggle a little more than average but for whom the problem is actually pretty negligible. You’ll also find children with a problem that could be considered minor. You’ll find others for whom the problem is moderate and still others for whom it’s significant.

So, where do you draw the line when the line you draw will be somewhat arbitrary? Many scientists actually choose not to draw a line. Instead, they study reading ability or math ability—or whatever it is—as a continuous variable. Then, they try to explain why some children have a more or less severe disability, rather than just treating it as a binary, black-or-white outcome.

As a child, Steven Spielberg had a very difficult time with reading, and to this day, reading still requires a lot of time and effort and is much more difficult than it is for most other adults.

But his job requires him to do quite a bit of reading, especially of scripts. Spielberg is now one of the most successful movie directors in history, so he has obviously learned to cope with his disability extremely well.

SLDs can come in a number of different forms. Some children have difficulty learning to write, which is often referred to as dysgraphia. Children with dysgraphia have problems producing legible handwriting and often make an unusual number of spelling errors.
• One final misconception is the idea that learning disabilities are a phase that children go through and that they’ll grow out of. In fact, the scientific evidence shows that SLDs tend to persist into adulthood, which makes sense given their biological origin. But that doesn’t mean that people with SLDs can’t adapt and learn to cope with them. They can.

• Another common form of SLD is dyscalculia, which refers to a difficulty learning math. Students with dyscalculia have much more difficulty learning and using basic arithmetic operations than other children their age.

• Another common form of learning disability is called specific language impairment (SLI). Children with SLI exhibit delayed language development in the absence of hearing loss or other developmental delays. SLI is also called developmental language disorder, language delay, or developmental dysphasia.

Dyslexia

• Perhaps the most common SLD, and also the best known, is dyslexia. In fact, some reports estimate that as many as 80% of children with a learning disability suffer from dyslexia. Dyslexia has also received more attention from scientists than any other learning disability, and a great deal has been learned about what’s going on.

• Dyslexia is characterized by a difficulty with recognizing or decoding written words that cannot be attributed to poor vision, low intelligence, or lack of education. These problems make it very difficult for children with dyslexia to read.
But reading involves more than just decoding written words; it also requires the ability to comprehend what sequences of decoded words mean. And although some classification systems include impairments in either process, most scientists define dyslexia as a problem with written word decoding—not language comprehension. For example, most dyslexics can understand spoken language just fine; their problem is in figuring out what words the letters on the page represent.

While the key symptom of dyslexia is an unusual difficulty in recognizing individual written words, both in terms of speed and accuracy, there are many other associated symptoms. Children with dyslexia typically have trouble sounding out words. They will often mispronounce words and confuse one word for another that has a similar spelling. They may even complain of feeling sick or dizzy when they read.

Scientists and educators refer to the difficulty of learning to read as developmental dyslexia. This is distinguished from acquired dyslexias, which can arise from brain damage in adulthood. The shorter term, “dyslexia,” will be used to refer to developmental dyslexia in this lecture.
• Because reading comprehension depends on fast and accurate word recognition, comprehension also naturally suffers. Although most dyslexic children can and do eventually learn to read, they typically continue to read more slowly than other people, even as adults.

• Dyslexia is usually first noticed in school, but unfortunately it is often overlooked and attributed to laziness or stupidity instead. In fact, dyslexic children often mistakenly conclude that their reading problems mean that they must be dumb, and problems with self-esteem are extremely common.

• Like most other learning disabilities, dyslexia represents the end of a continuum, so categorizing someone as dyslexic is not always clear-cut. Perhaps as a result, estimates of how common dyslexia is vary. But most scientists believe that somewhere between 5% and 10% of school-aged children could be considered dyslexic.

Dyslexia’s Cognitive Mechanisms

• In the 1920s, those who studied dyslexia assumed that it was a visual problem, and children who suffered from dyslexia were often prescribed some sort of visual training as a treatment. The belief that dyslexia is a visual deficit persists to this day among some people in the general population, but it’s wrong, at least in most cases.

Some dyslexics report feeling as if letters within words jump around when they’re trying to read. If you want to experience what this is like, visit Victor Widell’s web-based simulation:

http://geon.github.io/programming/2016/03/03/dsxyliea.
• The evidence suggests that the underlying problem in dyslexia is usually in the processing of phonology, which refers to the basic, atomic sounds from which all words are composed. Those sounds are called phonemes, and they differ from language to language. For example, there are a total of 44 different phonemes in English, and every word in the language is made up of a subset of those sounds in a specific order.

• Being able to break down a spoken word into its component phonemes becomes less important as you get skilled at recognizing hundreds of thousands of words at a glance, but it’s a crucial skill when you’re learning to read.

• When you’re first starting to read, written words are just unfamiliar strings of letters, and you have to go through a sequence of steps to figure out what word those letters correspond to. And a critical step in that process is breaking down the sound of the word into its component phonemes.

• Most children with dyslexia exhibit a deficit in phonological awareness; that is, they’re unaware of the phonological structure of the words they hear. They can’t figure out that “buh” is the first sound in “bat” and that “aa” is the first sound in “after.” And that lack of phonological awareness makes it very difficult to sound out written words and figure out what they are.

Dyslexia’s Neural Mechanisms

• Neuroimaging techniques, such as positron-emission tomography and functional MRI, have made it possible to estimate neural activity in human beings while they’re performing different
cognitive tasks. These methods have revolutionized the study of many cognitive functions, including the study of reading and dyslexia.

• Reading involves a variety of cognitive processes. It involves phonological mechanisms to process sounds as well as other linguistic mechanisms to process the grammar and the meaning of what is being read. And the mechanisms involved in processing phonology, grammar, and meaning are also needed for spoken language, so they’re not unique to reading.

• But reading also requires visual mechanisms to recognize the letters and words, and those mechanisms aren’t required for spoken language. They are unique to reading.

• Neuroimaging studies of reading find neural activity in brain networks involved in spoken language and in networks involved in visual recognition. Specifically, when people are speaking or listening to spoken language, they tend to activate 2 major areas in the left hemisphere that are named after the famous neurologists who first identified them.

  • Broca’s area is on the left side of your brain, toward the front and the bottom, a few inches behind your left eye. Broca’s area is named after the French neurologist Paul Broca, and it’s critically involved in speech production and in processing grammar and phonology.
• Wernicke’s area, named after the German neurologist Carl Wernicke, is also on the left side of the brain a few inches above your left ear. Evidence suggests that Wernicke’s area and nearby brain regions are crucially involved in processing the meaning of speech as well as phonology.

• Both of these brain regions are activated during reading, too, even though you’re not normally hearing or speaking when you read. But in addition to these regions, reading also activates regions in the visual cortex, such as the visual word form area, which is on the bottom surface of the left hemisphere of brain, toward the back. It’s critically important in the visual recognition of letters and written words.

• Numerous neuroimaging studies of dyslexics have repeatedly found that dyslexics exhibit less neural activity in Wernicke’s area and in the visual cortex than normal readers do. Some studies have also reported the same thing in Broca’s area, although those results are not as consistent. Furthermore, structural neuroimaging studies have found that these same brain regions are physically smaller in dyslexics compared with normal readers.

• Perhaps most interesting, a number of studies have found evidence that the connections between these brain areas don’t work as efficiently as they should in dyslexia. In particular, the visual areas that recognize words and the language areas that process phonology and meaning don’t seem to be able to communicate with each other as effectively as they need to.

• Obviously, that kind of communication is critical to reading. After all, those are presumably the same connections that the brain uses to associate the sight of a word with both its sound and its meaning. So, if those connections aren’t working as well as they should, then it makes sense that reading would be disrupted. And it is.
What can be done to help a dyslexic child learn to read?

Schools in the US are legally obligated to implement an Individualized Education Program for any child diagnosed with dyslexia. The child will first be tested to identify specific areas where remediation is needed, and then a tailored education plan is developed to address those needs and maximize the child’s chance of academic success.

In the case of dyslexia, that plan might include intense training in recognizing the phonemes that make up words and in mapping those phonemes onto letters. Then, the child might get substantial practice at sounding out words to build up reading speed and accuracy. Another common approach is to try to build up a vocabulary of frequent words that the child learns to recognize relatively quickly and accurately. Finally, the plan might include training on comprehending the meaning of sentences and paragraphs that have been read.

Although this kind of intense, individualized training can help, it’s not a cure, and reading problems tend to persist into adulthood.

Nevertheless, most dyslexics can significantly improve their reading, especially if the problem is detected early. In particular, children who get help with their reading starting in kindergarten or first grade can often improve enough to succeed in elementary school and high school, while children who start getting help later have a more difficult time and may not be able to catch up.
SUGGESTED READING

Fletcher, *Learning Disabilities.*
Pennington, *Diagnosing Learning Disorders.*
Shaywitz, *Overcoming Dyslexia.*

QUESTIONS TO CONSIDER

1. What do you think is the most common misconception about dyslexia in the general population?

2. Many elementary school teachers aren’t experts on learning disabilities and can’t devote substantial amounts of time to individual students. How do you think the US educational system should handle this problem?
Optimizing Your Learning

His final lecture will draw on what you’ve learned in this course and offer 5 suggestions about what you can do to learn more effectively. By implementing some or all of these suggestions, you will hopefully be able to get even more out of your efforts to learn and grow in the future.

Learning has a lot more to do with what the student does than with what the teacher does. As the great psychologist Herbert Simon put it, “Learning results from what the student does and thinks, and only from what the student does and thinks. The teacher can advance learning only by influencing what the student does to learn.”
1. Adopt a positive mindset.

- Suppose that you want to learn something complex and challenging, such as a foreign language or a musical instrument. Learning something so complex would be very rewarding, yet few people actually try. There are undoubtedly several reasons why this is the case, but one thing that stops many people is simply the belief that they can’t do it—that it’s just too difficult and beyond their ability.

- The truth is that the human brain is the most amazing, sophisticated, and powerful mechanism in the universe—and you have one! Your brain is always learning, whether you’re trying to learn or not. It has already learned a bewildering array of complex motor skills, including how to stand up, walk, and run. It has already learned to read, write, and do math. And perhaps most amazingly, it has already mastered a natural language, which is arguably more complicated than anything else you would ever want to learn.

- Believing that you can learn something challenging is the first—and, in some ways, the most important—step. Without that belief, you might not even try. You’d also be likely to give up at the first sign of difficulty.

- In addition, it’s important to recognize that your learning is your responsibility. Your learning is up to you.

- What do you do when you encounter an obstacle to your learning? The easy way out would be to say there’s nothing you can do. For example, you could blame the teacher of a course and attribute the problem to poor instruction. But if you do that, then you’re not going to learn the material.
• The alternative approach is to ask yourself what you can do to overcome the obstacle. You could try to find another resource, such as a book or website, that might help you learn the information. Or you could discuss the material with a friend who’s an expert on the topic. These are examples of taking control of your learning.

• And this is how the most effective learners keep learning. They don’t let obstacles get in the way; instead, they find ways to overcome difficulties and continue their learning.

• You need to adopt a positive mindset whenever you’re trying to learn something new. You need to see challenges and obstacles as opportunities to grow. After all, it’s when we stretch ourselves and get outside of our comfort zone that we grow the most. And that kind of positive attitude—referred to as a growth mindset—is something we can get better and better at.

2. Be strategic and deliberate about your learning.

• Not all approaches to learning are equal. When you’re trying to learn a new skill, deliberate, challenging practice is more effective than mindlessly practicing the skill. If we want to maximize our learning, then we should be thoughtful about how we spend our time and try to do things that will maximize our learning.

• To do that in practice, we can set specific goals for learning. Limit yourself to 2 or 3 goals at a time; any more than that could quickly become overwhelming and ultimately discouraging. You want your goals to be challenging so that they will stretch you and force you to learn. But they should also be specific and achievable with concerted effort.
• Setting challenging, but manageable, learning goals for yourself can be very effective. You might want to write your goals down and establish a target date by which you’d like to try to accomplish your goals. You could even identify a reward that you’ll give yourself if you accomplish your goal by the deadline. That kind of simple positive feedback can make you even more eager to accomplish the next goal on your list.

• Another important way to make your learning more strategic is to identify holes in what you want to learn and then systematically fill them in. Although this makes a lot of sense, it’s not always our natural tendency. After all, it’s tempting to work on what we’re already good at. Doing so provides positive reinforcement and gives us a sense of accomplishment and satisfaction. But it also limits how much we learn and grow.

• Furthermore, difficulties during practice are often desirable when it comes to long-term learning, even though they may hurt short-term performance. Strategies such as spacing out your learning over time, deliberately challenging yourself with tasks that are just outside your current ability, and interleaving learning about different topics will all tend to make learning more difficult. But they also tend to produce the best results in the long run.

Cramming leads to less long-term learning than spacing the same amount of studying over time.

Randomizing and interleaving what you work on is better than learning about one topic and then switching to another topic in blocks.

Relating new information to information you already know can also help you learn it more effectively.
3. Learn actively rather than passively.

- We learn better when we are actively engaged in processing information rather than passively encoding it. For example, rereading and highlighting—which are more passive study strategies—aren’t nearly as effective as generating explanations and especially testing yourself, which are more active strategies.

- You may have experienced the difference between active learning and passive learning in the work environment. As many employers will tell you, there’s a huge difference between so-called book learning and real-world, on-the-job training.

- But it’s not just the work world where you can see the advantages of active learning. Imagine trying to learn algebra without doing any practice problems. It just wouldn’t work. You can read the textbook over and over, but until you’ve solved a bunch of actual problems, you’ll never master algebra.

- How can we be more active in our learning so that we can get the most out of it? One idea is to intentionally ask questions while we’re learning. Suppose that you want to learn about gardening, so you’re reading a book on the topic. One excellent way to get the most out of your reading is to try to come up with a set of key questions that the book answers.

- For example, imagine that you have to make up a test on the material in that book. What questions would you include? This exercise can be extremely helpful. For one thing, it forces you to pay careful attention to what you’re reading and to actively engage with it. It also requires you to identify the key ideas so that you can ask questions that tap into the important concepts rather than the trivial details.
• Another way to make your learning more active and less passive is to test yourself. Evidence shows that taking tests on material you’ve studied is one of the best ways to learn that material. In particular, testing yourself is much better than rereading or highlighting. One reason may be because testing yourself gives you practice retrieving information from memory, and that’s ultimately what you want to be able to do in the future.

• But where are you going to get the test? You’ll occasionally run across a book that includes some questions, but that’s the exception, not the rule. But if you’ve adopted the previous suggestion and made up a quiz on the material you’re trying to learn, then you’re all set! Just wait until the next day or week and then try taking the quiz you made up. The exercise of taking that test will help consolidate what you’ve learned. And if there are questions you can’t answer, then that tells you exactly what you might want to review.

• A final practical way to make your learning more active and less passive is to try to teach others what you’re learning. There’s no better way to expose holes in your understanding than to try to explain something to other people.

• Trying to teach also forces you to engage deeply with the information. You have to figure out what information you need to convey, and you need to come up with a coherent story line in which each idea naturally follows from the previous ideas.

• Preparing to teach information also has a very strong motivational component. Basically, you don’t want to look stupid. And that desire can motivate you to go over the material carefully and double-check the accuracy of what you’re planning to say.
4. Identify good sources of information that will challenge you.

- Computer scientists have a saying: Garbage in, garbage out. It means that a computer program is only as good as the data that you give it as input. If the program is correct and you give it reliable data as input, then you should get reliable answers as output. But if you give it unreliable, garbage data as input, then the answers you get out will also be garbage—even if the program itself is correct.

- The same goes for the neural network inside your skull. If you train your brain on information that is unreliable or biased, it will learn generalizations that may be unreliable or flat-out wrong.

- So, if you want to optimize your learning, then it’s crucial to give your neural network information that is as reliable and unbiased as possible. But how can we do that?

  - Consider the source. Who is providing the information, and what are his or her qualifications? Is he or she actually trained in the field that you’re trying to learn about, or is he or she just a blogger with an opinion?

  - Consider the evidence. Does the source provide actual evidence in support of their claims, or is it really just opinion? If there is evidence, can you confirm its authenticity, and does it come from credible sources? A quick Google search of an empirical claim can often identify its source and authenticity (or lack thereof).

  - Be skeptical. There’s a lot of misinformation out there, particularly on the internet. So, it pays to be skeptical and to try to verify information using other sources before trusting a source.
• Seek out different points of view—particularly ones that are different from your own and that will challenge you. Deeply engaging with alternative points of view will stretch you and help you learn significantly more than you could from a source you already agree with.

Human beings have a natural tendency to seek out information that is consistent with their current beliefs and to disregard information that isn’t. But if you really want to learn and grow, you’re better off learning about ideas that are different than your own.

5. Stay active, eat right, and get enough sleep.

• If you want to be the best learner you can be, then you need your brain to be functioning as well as it possibly can. And the same things that keep your body healthy also tend to keep your brain healthy. Your body provides your brain with the nutrients and oxygen that it needs to thrive, so if your body—particularly your heart—is healthy, then your brain usually will be, too.

• There are many things we can do to keep our brains healthy, but let’s focus on 3 that scientific studies have identified as particularly important: staying active, eating right, and getting enough sleep.

• One way to stay active is by exercising your brain with challenging, engaging intellectual stimulation. Think of your brain like a muscle that needs exercise to stay strong and healthy; the more you challenge yourself mentally, the healthier your
brain will be. Research shows that activities such as mastering a challenging hobby can improve brain function. There’s even stronger evidence that staying active physically can also improve brain function; it is perhaps the best way to keep your mind sharp as you age.

- Study after study has found that your diet not only influences your health and longevity, but it also can have a dramatic impact on your mental functions. For example, eating a relatively low-calorie Mediterranean diet has not only been found to improve heart health, but also to improve cognitive function and even significantly reduce the risk of Alzheimer’s disease.

- Sleep plays an important role in learning and memory, and good sleep hygiene can help keep us mentally sharp. Try to get 7 to 8 hours of sleep a night. Try to go to bed and get up at about the same time every day so that your body gets into a standard cycle. Avoid alcohol or coffee for a few hours before bedtime. Try to make your bedroom a peaceful haven that is as dark and quiet as possible. Implementing just a few of these ideas could help improve your sleep, which in turn could improve your brain functions.

SUGGESTED READING

Duckworth, *Grit.*
Dweck, *Mindset.*
Ericsson and Pool, *Peak.*
Ratey and Hagerman, *Spark.*
Waldrop, “The Science of Teaching Science.”
QUESTIONS TO CONSIDER

1. Which of the 5 suggestions discussed in this lecture resonated the most for you? Are there specific steps you could take to put the suggestions into practice?

2. Are there any strategies that weren’t in this lecture but that you’ve found helpful in optimizing your learning and memory?


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